

Experimental Investigation of Mechanical and Hydraulic Performance of Sustainable Permeable Concrete Blocks Using Recycled and Bio-Based Materials

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Abstract: Rapid urbanization and the increasing use of impervious pavements have intensified problems related to stormwater runoff, urban flooding, and groundwater depletion. Permeable concrete pavement has emerged as a sustainable solution due to its ability to allow water infiltration through interconnected voids. In this study, sustainable permeable concrete blocks were developed using recycled plastic, bio-based materials, and fly ash to evaluate their mechanical and permeability performance under controlled laboratory conditions. The specimens were tested for compressive strength, permeability, and aggregate impact resistance in accordance with IS 2386 (Part 4), IS 516:1959, and ACI 522R-10 guidelines. Experimental results showed that the fly ash-based permeable concrete exhibited the highest compressive strength of 25.29 N/mm² due to improved pozzolanic bonding and matrix densification. The recycled plastic permeable concrete demonstrated the highest permeability rate of 0.1 cm/sec because of increased interconnected voids, while the bio-based concrete exhibited comparatively lower compressive strength but enhanced environmental sustainability. The aggregate impact values of all specimens were within acceptable ranges, indicating satisfactory toughness characteristics. The study concludes that the incorporation of recycled plastic, bio-based materials, and fly ash in permeable concrete is an effective approach for developing sustainable, eco-friendly, and low-cost pavement systems suitable for stormwater management and low-traffic infrastructure applications.

Keywords - Permeable concrete, Sustainable pavement, Recycled plastic, Fly ash concrete, Bio-based materials, Water permeability, Green infrastructure

1. Introduction

Rapid urbanization and infrastructure development have significantly increased the use of impervious surfaces such as roads, pavements, and parking areas, which restrict the natural infiltration of rainwater into the ground. As a result, urban regions frequently experience problems including stormwater runoff, urban flooding, drainage congestion, and depletion of groundwater resources [1]. Conventional concrete pavements, although structurally strong, do not permit water infiltration and therefore contribute to surface water accumulation and environmental degradation. In recent years, permeable concrete pavement has emerged as an innovative and sustainable solution for addressing these challenges due to its porous structure containing interconnected voids that allow water to pass through the pavement surface and infiltrate into the underlying soil [2]. This permeability characteristic not only reduces surface runoff and water logging but also supports groundwater recharge and sustainable urban drainage systems.

The performance of permeable concrete mainly depends on factors such as aggregate size, void ratio, compaction, water-cement ratio, and the type of constituent materials used in the concrete matrix. However, despite its superior permeability characteristics, permeable concrete generally exhibits lower compressive strength compared to conventional dense concrete because of the presence of interconnected voids. Therefore, achieving an optimum balance between permeability and mechanical strength remains one of the major challenges in the development of durable permeable pavement systems. Furthermore, increasing environmental concerns regarding plastic waste accumulation, industrial by-products, and depletion of natural construction materials have encouraged researchers to explore sustainable alternative materials in concrete production.

The experimental investigation was conducted using relevant Indian Standards and international guidelines. Since no dedicated Indian Standard is currently available for permeable concrete, IS 12727:1989 for no-fines concrete and IS 456:2000 guidelines were considered for concrete preparation and general properties [3], [4]. The Aggregate Impact Test was performed according to IS 2386 (Part 4), the Compressive Strength Test followed IS 516:1959, and the Permeability Test was conducted based on ACI 522R-10 recommendations [1], [2].



Fig 1. A: Permeable Concrete Block

Figure 1.A demonstrates the water infiltration behavior of permeable concrete, where water passes through interconnected voids present within the concrete structure. The porous arrangement of aggregates allows efficient drainage and reduces surface water accumulation, making permeable concrete suitable for sustainable pavement and stormwater management applications.

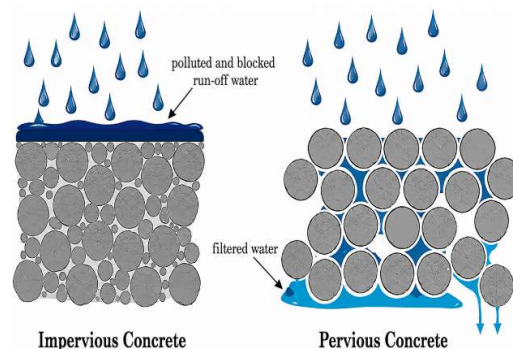


Fig1. B: Schematic diagram of Permeable concrete structure

Figure 1.B presents a comparative illustration between impervious concrete and pervious (permeable) concrete under rainfall conditions. In impervious concrete, water is unable to penetrate through the surface due to the dense concrete structure, resulting in surface runoff, water accumulation, and potential urban flooding problems.

Several previous studies have investigated the use of recycled plastic, fly ash, and bio-based materials individually in concrete applications. However, limited research has been reported on the comparative evaluation of these sustainable materials under similar permeable concrete pavement conditions. In particular, the combined assessment of compressive strength, permeability characteristics, and aggregate impact resistance for recycled plastic, bio-based, and fly ash permeable concrete blocks remains insufficiently explored. Therefore, there exists a need for a systematic comparative investigation to identify the most suitable sustainable material for permeable pavement applications based on both structural and hydraulic performance.

To address these challenges, the present study focuses on the development and comparative experimental evaluation of permeable concrete blocks incorporating recycled plastic, bio-based materials, and fly ash as sustainable replacement materials. The prepared concrete blocks were tested for compressive strength, permeability, and aggregate impact resistance under controlled laboratory conditions. The incorporation of recycled plastic contributes to effective waste management and reduction of environmental pollution, while fly ash utilization minimizes cement consumption and promotes sustainable reuse of industrial by-products. Similarly, bio-based materials enhance environmental sustainability through the utilization of renewable natural resources in construction applications. The major contributions of this research are summarized as follows:

- Development of sustainable permeable concrete blocks using recycled plastic, bio-based materials, and fly ash.
- Comparative experimental evaluation of mechanical and permeability characteristics of different permeable concrete specimens.
- Investigation of the relationship between permeability and compressive strength in sustainable permeable concrete systems.
- Assessment of the suitability of alternative waste materials for low-traffic permeable pavement applications.

- Promotion of eco-friendly and sustainable construction practices for urban stormwater management.

2. Literature Review

Permeable concrete pavement has gained significant attention as a sustainable solution for mitigating urban stormwater runoff, improving groundwater recharge, and reducing surface water accumulation. Several studies have investigated the influence of material composition, aggregate properties, and structural configurations on the mechanical and hydraulic performance of permeable concrete systems.

Previous studies have primarily focused on comparing permeable pavements with conventional impermeable materials. Bhusal G. et al. (2024) reported that permeable concrete blocks exhibited significantly higher porosity compared to impermeable blocks and burnt clay bricks, resulting in improved groundwater infiltration performance. Similarly, Ono B. W. et al. (2017) demonstrated that articulated permeable concrete blocks achieved permeability values of approximately 10^{-3} m/s, outperforming traditional interlocking concrete blocks and porous asphalt due to their enhanced drainage characteristics.

Several researchers investigated the influence of aggregate composition and gradation on the performance of pervious concrete. Rathore H. (2024) evaluated different pervious concrete mixtures and observed that the inclusion of sand and fly ash reduced permeability due to changes in pore structure. Gao S. et al. (2023) reported that lightweight ceramsite aggregates provided higher permeability coefficients than conventional crushed aggregates, highlighting the importance of aggregate type in hydraulic behavior. Likewise, Barreto Sandoval G. B. (2023) demonstrated that discontinuous aggregate gradation improved particle packing and compressive strength, whereas aggregate size and sediment characteristics influenced clogging behavior. Braga N. T. de S. et al. (2022) further emphasized that binary combinations of coarse aggregates affected both mechanical strength and hydraulic properties in permeable concrete systems.

The relationship between aggregate size, porosity, permeability, and compressive strength has also been widely investigated. Tayyiba S.K.M. (2024) compared Fine Pervious Concrete (FPC), Coarse Pervious Concrete (CPC), and Nominal Pervious Concrete (NPC), reporting that increased water-cement ratios reduced porosity and permeability. Abd. Halim N. H. et al. (2018) analyzed porous concrete paving blocks with varying aggregate sizes and observed significant variations in strength and permeability characteristics. Similarly, Lyu Q. et al. (2024) demonstrated that aggregate size had a stronger influence on pore structure than physical properties, while lower aggregate-to-cement ratios improved compressive strength. Ah Lian C. N. et al. (2024) concluded that 8 mm aggregate size provided optimum performance in terms of strength, porosity, and hydraulic efficiency for permeable concrete curb applications.

Recent studies have also explored alternative materials and sustainable modifications to improve permeable concrete performance. Liu H. et al. (2021) investigated crumb rubber-modified permeable concrete bricks and reported enhanced permeability and freeze-thaw resistance. Saboo N. et al. (2023) introduced the Film Thickness Index (FTI) concept for pervious paver block mix design and observed that film thickness and water-cement ratio significantly influenced infiltration rate and compressive strength. Barua G. et al. (2024) proposed fiber-reinforced permeable pavements with low tortuosity, achieving infiltration rates exceeding 1 cm/s and compressive strengths above 27 MPa while improving clogging resistance. Furthermore, Shubbar A. A. et al. (2023) evaluated different paving patterns and reported superior hydraulic and structural performance for 45° herringbone configurations compared to 90° layouts.

The influence of block geometry and mix proportions on mechanical performance has also been examined. Desharyanto D. et al. (2025) evaluated non-sand concrete blocks with different mix ratios and observed varying compressive strengths and water absorption capacities. Similarly, Karkar A. et al. (2021) compared rectangular, hexagonal, and zigzag pervious concrete paver blocks and found that hexagonal blocks exhibited higher compressive strength, whereas rectangular blocks showed better flexural behavior.

The previous investigations have extensively evaluated aggregate gradation, block geometry, aggregate size variation, and isolated sustainable materials such as crumb rubber and fly ash, limited studies have performed a comparative investigation of recycled plastic, bio-based materials, and fly ash under identical permeable concrete pavement conditions. Furthermore, the combined evaluation of compressive strength, permeability characteristics, and aggregate impact resistance for these sustainable materials remains insufficiently explored. Most existing studies emphasize either hydraulic performance or mechanical properties independently, while integrated assessment of structural and permeability behavior for sustainable permeable concrete systems is still lacking.

Therefore, the present study addresses this research gap by developing and experimentally evaluating permeable concrete blocks incorporating recycled plastic, bio-based materials, and fly ash, followed by comparative analysis of their compressive strength, permeability performance, and aggregate impact resistance for sustainable pavement applications.

3. Material & Methods

The performance of permeable concrete blocks is primarily governed by the properties of constituent materials, mix composition, and void structure. In the present study, sustainable materials such as recycled plastic, bio-based materials, and fly ash were incorporated in the preparation of permeable concrete blocks to evaluate their influence on compressive strength, permeability, and aggregate impact resistance. Ordinary Portland Cement (OPC), coarse aggregates, chemical admixtures, and potable water were used as the primary binding and supporting materials. The materials utilized in this investigation are listed below:

- RecyclePlastic
- Biobased material
- FlyAsh
- Cement
- Admixture
- Coarse Aggregate
- Water

The mix design of permeable concrete plays a crucial role in determining its mechanical strength, permeability characteristics, and overall durability. In the present study, different sustainable materials such as recycled plastic, bio-based material, and fly ash were incorporated into the concrete mix to evaluate their influence on the performance of permeable concrete blocks. The mix proportions were selected based on preliminary trial mixes to achieve an optimum balance between compressive strength and water infiltration capacity while maintaining adequate interconnected voids. Uniform aggregate sizes ranging from 10–12 mm were used throughout the experimental program to ensure consistency in pore structure and permeability behavior. The detailed mix proportions adopted for different permeable concrete specimens are presented in Table 1.

Table 1: Mix Design Proportions of Recycled Plastic, Bio-Based, and Fly Ash Permeable Concrete Blocks

Material Type	Cement (kg/m ³)	Aggregate (kg/m ³)	Replacement Material (%)	Water-Cement Ratio	Admixture (%)
Recycled Plastic	350	1450	10% Plastic Replacement	0.35	1.5
Bio-Based Material	360	1420	12% Bio-Based Material	0.38	1.2
Fly Ash	320	1480	20% Fly Ash Replacement	0.32	1.0

Table 1. presents the mix design proportions adopted for the preparation of recycled plastic, bio-based, and fly ash permeable concrete blocks. The table highlights the variation in cement content, aggregate proportion, replacement material percentage, water-cement ratio, and admixture dosage used to achieve an optimum balance between compressive strength and permeability characteristics.

Recycle Plastic: Recycled plastic is obtained from waste materials such as plastic bottles, bags, packaging materials, and containers, which are collected, sorted, cleaned, and processed into usable forms like flakes, pellets, or fibers. The most commonly used types of plastics in construction applications include polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polypropylene (PP). These materials are non-biodegradable in nature, and their reuse in concrete helps reduce environmental pollution while promoting sustainable construction practices. In the preparation of recycled plastic permeable concrete blocks, plastic materials are generally used as a partial replacement for natural aggregates or as reinforcing fibers. When used as aggregate replacement, shredded plastic particles substitute a portion of fine or coarse aggregates, resulting in a reduction in density and an increase in void content. This is particularly beneficial in permeable concrete, where interconnected voids are essential for allowing water to pass through the material. From a functional perspective, recycled plastic enhances the permeability of concrete by increasing the void ratio, which allows efficient water infiltration and reduces surface runoff. This makes it highly suitable for applications in urban drainage systems, where managing stormwater is a critical concern. Additionally, the use of plastic contributes to sustainability by reducing landfill waste, conserving natural aggregates, and lowering the overall environmental footprint of construction activities.

Permeability Test

Material: Recycle PlasticMaterial

Formula for Permeability Test:

$$\text{Permeability} = \text{Volume of Block} / \text{Area} \times \text{Time}$$

$$\text{Volume of Block} = \text{Length} \times \text{Width} \times \text{Height}$$

$$= 150 \times 150 \times 150$$

$$= 1125$$

$$\text{cm}^3 \text{ Area} = \text{Length} \times$$

width

$$= 150 \times 150$$

$$= 225 \text{ cm}^2$$

Time = 50 sec

$$\text{Permeability} = 1125 / 225 \times 50$$

$$= 0.1 \text{ cm/sec}$$

But as per the reference of ACI 522R-10, the value should be 0.4 - 0.8 cm/sec.

CompressiveStrengthTest

Material: Recycle Plastic Material

Formula for Compressive Strength Test:

$$\text{CompressiveStrength Test} = \text{Maximum Load Applied} / \text{Cross Sectional Area}$$

$$= 300000 / 22500 \text{ mm}^2$$

$$= 13.33 \text{ N/mm}^2$$

But, as per the reference of IS 516: 1959 [2], the value should be 7.4 N/mm²

Table 2: Aggregate Impact Test of Recycle Plastic

Sr.No.	Description	Symbol	Value	Unit
1	Initial weight of sample	W1	380	g
2	Weight of fines (passing 2.36 mm)	W2	23.5	g
3	Aggregate Impact Value	(W2/W1)×100	6.18	%

Aggregate Impact Value = 6.18%

But as per the reference of IS 2386: Part 4 [1], the aggregate impact value should be 6.5-7.2 %



Fig 2. Recycle Plastic Material

The figure 2. shows shredded recycled plastic particles used as a sustainable replacement material in the preparation of permeable concrete blocks. These plastic flakes are obtained from processed plastic waste and incorporated into the concrete mix to reduce environmental pollution and promote waste recycling.

Biobased Material: Bio-based materials are increasingly being used in the construction industry as sustainable alternatives to conventional materials, particularly in the production of permeable concrete blocks. These materials are derived from natural, renewable, and organic sources such as agricultural residues, plant fibers, and biomass ash. Common examples include rice husk ash, sugarcane bagasse ash, coconut shells, and natural fibers like coir, jute, and bamboo. The use of such materials not only helps in reducing environmental pollution but also promotes the efficient utilization of locally available waste resources. In the preparation of bio-based permeable concrete blocks, these materials are typically incorporated either as partial replacements for cement or aggregates, or as reinforcing elements. For instance, rice husk ash and bagasse ash are rich in silica and can act as pozzolanic materials, partially replacing cement and contributing to the binding properties of concrete. On the other hand, coconut shells can be used as a substitute for coarse aggregates, resulting in a lighter concrete with increased porosity. Natural fibers such as coir and jute are often added to improve tensile strength, reduce cracking, and enhance the overall durability of the concrete. From a mechanical perspective, bio-based permeable concrete generally exhibits moderate compressive strength compared to conventional concrete. While the strength may be slightly lower, the addition of natural fibers enhances flexibility and reduces brittleness, thereby improving resistance to cracking. However, the performance of such concrete depends largely on the type and proportion of bio-based material used. Excessive replacement levels may lead to a significant reduction in strength and durability, so it is essential to determine an optimum mix proportion through experimentation.

Permeability Test

Material: Bio based Material

Formula for Permeability Test:

$$\text{Permeability} = \frac{\text{Volume of Block}}{\text{Area} \times \text{Time}}$$

$$\begin{aligned} \text{Volume of Block} &= \text{Length} \times \text{Width} \times \text{Height} \\ &= 150 \times 150 \times 150 \\ &= 1125 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} \text{Area} &= \text{Length} \times \text{Width} \\ &= 150 \times 150 \\ &= 225 \end{aligned}$$

$$\begin{aligned} &\text{cm}^2 \\ &\text{Time} \\ &= 140 \text{ sec} \end{aligned}$$

$$\begin{aligned} \text{Permeability} &= \frac{1125}{225 \times 140} \\ &= 0.035 \text{ cm/ sec} \end{aligned}$$

But, as per the reference of ACI 522R-10, the value should be 0.5 - 0.9 cm/sec.

Compressive Strength Test

Material: Bio based Material

Formula for Compressive Strength Test:

$$\begin{aligned} \text{Compressive Strength Test} &= \frac{\text{Maximum Load Applied}}{\text{Cross Sectional Area}} \\ &= \frac{124000}{22500} \\ &= 5.51 \text{ N/mm}^2 \end{aligned}$$

But, as per the reference of IS 516: 1959 [2], the value should be 6.8 N/mm²

Table 3: Aggregate Impact Test of Biobased Material

Sr.No.	Description	Symbol	Value	Unit
1	Initial weight of sample	W1	380	g
2	Weight of fines (passing 2.36 mm)	W2	23.5	g
3	Aggregate Impact Value	$(W2/W1) \times 100$	6.18	%

Aggregate Impact Value = 6.18%

But, as per the reference of IS 2386 (Part 4) [1], the aggregate impact value should be 7.5-8.5 %



Fig. 3: Bio Based Material

The figure 3. illustrates the bio-based material used in the preparation of sustainable permeable concrete blocks. The fibrous organic material enhances the eco-friendly characteristics of the concrete while contributing to lightweight and porous structural behavior.

FlyAsh Material: Fly ash is one of the most widely used industrial by-products in modern construction and plays a significant role in the development of sustainable permeable concrete blocks. It is a fine, powdery material obtained as a residue from the combustion of pulverized coal in thermal power plants. Instead of being disposed of as waste, fly ash is effectively utilized in concrete as a supplementary cementitious material, helping to reduce environmental pollution and improve certain properties of concrete. It possesses pozzolanic properties, meaning it reacts with calcium hydroxide in the presence of water to form additional cementitious compounds, which contribute to strength and durability. Typically, fly ash is used to replace about 10% to 30% of cement, depending on the desired performance and mix design. In permeable concrete, where a balance between strength and porosity is required, fly ash helps improve the paste quality while maintaining the necessary void structure for water permeability. From a strength perspective, fly ash-based concrete may show slightly lower early strength compared to conventional concrete, but it gains strength over time due to ongoing pozzolanic reactions. This results in improved long-term strength and durability. Additionally, fly ash contributes to reduced heat of hydration, minimizing the risk of thermal cracking, and enhances resistance to chemical attacks such as sulfate and alkali-silica reactions.

Permeability Test

Material: Fly Ash Material

Formula for Permeability Test: $\text{Permeability} = \frac{\text{Volume of Block}}{\text{Area} \times \text{Time}} \times \text{Volume of block}$

$$\begin{aligned} \text{block} &= \text{Length} \times \text{Width} \times \text{Height} \\ &= 150 \times 150 \times 150 \\ &= 1125 \end{aligned}$$

$$\text{cm}^3 \text{ Area} = \text{Length} \times \text{Width}$$

$$\begin{aligned} &= 150 \times 150 \\ &= 225 \text{ cm}^2 \end{aligned}$$

Time = 130 sec

$$\begin{aligned} \text{Permeability} &= \frac{1125}{225 \times 130} \\ &= 0.038 \text{ cm/sec} \end{aligned}$$

Compressive Strength Test

Material: Fly Ash Material

Formula for Compressive Strength Test:

$$\begin{aligned} \text{Compressive Strength Test} &= \frac{\text{Maximum Load Applied}}{\text{Cross Sectional Area}} \\ &= \frac{569000}{22500} \\ &= 25.29 \text{ N/mm}^2 \end{aligned}$$

But, as per the reference of IS 516: 1959 [2], the value should be 10.2 N/mm²

Table 4: Aggregate Impact Test of Fly Ash Material

Sr.No.	Description	Symbol	Value	Unit
1	Initial weight of sample	W1	380	g
2	Weight of fines (passing 2.36 mm)	W2	23.5	g

3	Aggregate Impact Value	$(W2/W1) \times 100$	6.18	%
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Formula for Aggregate Impact Test:

$$\text{Aggregate Impact Test} = (W2 / W1) \times 100$$

$$\text{Aggregate Impact Value} = 6.18 \%$$

But, as per the reference of IS 2386[1] (Part 4, the value should be 5.5-6.5 %



Fig. 4: Fly Ash Material

Fig. 4 shows fly ash material collected as a fine powder residue from thermal power plants after coal combustion. Fly ash is widely used in construction and concrete production due to its cement-like properties and ability to improve strength and durability.

Cement: Cement is the primary binding material used in the preparation of permeable concrete blocks, playing a crucial role in holding the aggregates together while maintaining sufficient strength and durability. In permeable (pervious) concrete, cement forms a thin paste that coats the coarse aggregates and binds them at their contact points, creating a rigid structure with interconnected voids. Unlike conventional concrete, where cement paste fills most of the voids, in permeable concrete the amount of paste is carefully controlled to ensure that the void spaces remain open for water infiltration. In our Project work, we have used Ordinary Portland Cement (OPC). In terms of function, cement in permeable concrete must achieve a balance between strength and permeability. If too much cement paste is used, it can fill the voids and reduce permeability, defeating the purpose of permeable concrete. On the other hand, insufficient cement content may lead to weak bonding and reduced structural integrity. Therefore, an optimum cement content is selected to ensure that the aggregates are adequately coated and bonded without clogging the void structure. The properties of cement significantly influence the overall performance of permeable concrete. It contributes to compressive strength, durability, and resistance to environmental effects. Properly hydrated cement paste enhances the load-bearing capacity of the blocks, making them suitable for applications such as pavements, parking areas, and pedestrian pathways.



Fig. 5: Cement

Fig. 5 shows cement material used as a binding agent in construction and concrete preparation. Cement provides strength and durability by binding different materials together to form a solid structure.

Admixture: Admixtures are specially formulated chemical or mineral substances added to concrete in small quantities to modify its properties in the fresh or hardened state. In the preparation of permeable concrete blocks, admixtures play a very important role because this type of concrete requires a careful balance between strength, workability, and permeability. Since permeable concrete contains little or no fine aggregates and has a high void content, achieving proper consistency and bonding becomes challenging. Admixtures help overcome these challenges and improve overall performance. In our study work, we have use admixtures such as Retarder, Water reducing admixture. In permeable concrete, admixtures are mainly used to enhance the workability of the mix without increasing the water content. One of the most commonly used admixtures is a superplasticizer (water-reducing agent), which improves the flow and coating ability of cement paste around aggregates. This is important because in permeable concrete, the paste should be sufficient to bind aggregates but not so fluid that it fills the voids and reduces permeability. By reducing water demand, superplasticizers help maintain strength while preserving the porous structure. Admixtures also contribute to improving the durability of permeable concrete blocks. They can enhance resistance to chemical attacks, reduce shrinkage and cracking, and improve long-term performance. In some cases, mineral admixtures such as fly ash, silica fume, or slag are used along with chemical admixtures to further refine the concrete properties.



Fig. 6: Various Types of Admixtures

Fig. 6 shows various types of chemical admixtures used in concrete preparation to improve its properties and performance. These admixtures help enhance workability, strength, durability, porosity control, and air entrainment in concrete mixtures.

Coarse Aggregate: Coarse aggregate is one of the most important constituents in the preparation of permeable concrete blocks, as it forms the primary structural framework and is mainly responsible for creating the interconnected void system that allows water to pass through the concrete. Unlike conventional concrete, where both fine and coarse aggregates are used to achieve a dense structure, permeable concrete relies almost entirely on coarse aggregates with little or no fine aggregates. This unique composition is what gives permeable concrete its characteristic porosity and drainage capability. The properties of coarse aggregates significantly affect the performance of permeable concrete. Strong and durable aggregates contribute to higher compressive strength and resistance to wear and abrasion, which is important for applications like pavements and parking areas. At the same time, the size and distribution of aggregates determine the void ratio and permeability rate. Larger aggregate sizes generally create higher permeability but may reduce strength, while smaller sizes improve strength but may slightly reduce permeability. Hence, an optimum balance between size, strength, and void content is necessary. In our project work, we have use 10-12 mm size aggregates for all the three type of permeable concrete blocks.



Fig.7: Aggregate 20 mm size

Fig. 7 shows 20 mm size coarse aggregates commonly used in concrete and construction works. These aggregates provide strength, stability, and durability to the concrete structure by forming the main bulk of the mix.



Fig.8: Aggregate 10 mm size

Figure 8 illustrates the 10 mm size coarse aggregates used in the preparation of permeable concrete blocks. These aggregates provide an optimum balance between compressive strength and porosity by forming interconnected voids required for effective water infiltration and drainage performance.



Fig.9: Aggregate 6 mm size

Figure 9 shows the 6 mm size aggregates, which possess smaller particle dimensions and provide denser packing within the concrete matrix. The use of finer aggregates can improve bonding and compressive strength; however, it may reduce permeability due to decreased void content.

Water: Water is a fundamental component in the preparation of permeable concrete blocks, as it is essential for initiating the chemical reactions that lead to the hardening and strength development of concrete. In permeable concrete, water plays a more controlled and critical role compared to conventional concrete because the objective is not only to achieve strength but also to maintain a porous structure that allows water infiltration. When water is added to cement, it triggers a process known as hydration, in which cement particles react chemically with water to form binding compounds. These compounds, primarily calcium silicate hydrates (C-S-H), are responsible for holding the aggregates together and giving strength to the concrete. In permeable concrete blocks, this hydration process must be carefully controlled so that enough cement paste is formed to bind the aggregates without filling the voids that are necessary for permeability. Water also plays an important role in determining the workability of the concrete mix. In permeable concrete, workability is typically low, and the mix appears dry or harsh compared to normal concrete. However, it should still be workable enough to allow proper mixing, placing, and compaction. The use of admixtures such as superplasticizers can help improve workability without increasing water content, thereby preserving the porous structure.



Fig. 10: Effect of Water Content on the Workability of Permeable Concrete

Figure 10 illustrates the influence of water content on the workability and consistency of permeable concrete mixtures. Insufficient water results in poor bonding and inadequate coating of aggregates, while excessive water fills the voids and reduces permeability; therefore, an optimum water content is required to achieve proper workability while maintaining interconnected pores.

Recycled Plastic Permeable Concrete Paver: The preparation of recycled plastic permeable concrete paver involves the use of plastic waste as a partial replacement material. Initially, the collected plastic waste is cleaned and shredded into small pieces to ensure uniform mixing. The required quantities of cement, coarse aggregate and shredded plastic are measured accurately as per the mix design. The dry materials, including cement, aggregates and plastic pieces, are mixed thoroughly to achieve a uniform distribution. Water is then added gradually while mixing to obtain the desired consistency. Care is taken to ensure that the plastic particles are evenly distributed throughout the mix. The prepared mix is then placed into moulds of required dimensions and compacted using light tamping methods. Excessive compaction is avoided to maintain the void structure necessary for permeability. The surface is levelled properly, and the specimens are kept undisturbed for initial setting. After 24 hours, the blocks are demoulded and subjected to curing for a period of 14 days. Proper curing ensures strength development and durability of the blocks.

Bio-Based Permeable Concrete: The bio-based permeable concrete is prepared using natural or organic materials as a partial replacement in the mix. Initially, the required materials such as cement, coarse aggregates and bio-based materials (such as natural fibers or organic additives) are collected and measured accurately. The dry mixing of cement, aggregates and bio-based materials is carried out to achieve uniform distribution. Water is then added gradually to the mix to achieve proper workability. The mix is prepared in such a way that the bio-based materials are evenly dispersed without affecting the void structure. The prepared mix is poured into moulds and compacted carefully using light compaction techniques. Proper care is taken to avoid over-compaction, which may reduce permeability. The surface is finished and levelled. After casting, the specimens are allowed to set for 24 hours and then demoulded for 14 days. The blocks are then cured properly for the required duration to achieve strength and durability.

Fly Ash Based Permeable Concrete: In this method, fly ash is used as a partial replacement for cement in the concrete mix. Initially, the required quantities of cement, fly ash and coarse aggregates are measured according to the mix design. The use of fly ash helps in improving workability and sustainability. The dry materials, including cement, fly ash and aggregates, are mixed thoroughly to achieve a uniform mix. Water is then added gradually and mixed properly to form a workable concrete mix. Care is taken to maintain the correct water-

cement ratio to preserve permeability. The prepared mix is then placed into moulds and compacted using light tamping or rolling methods. Proper compaction ensures bonding while maintaining void spaces for water infiltration. After casting, the specimens are left undisturbed for 24 hours and then removed from the moulds. The blocks are cured for a period of 14 days to achieve desired strength and durability.



Fig. 11 Measurement of Weight of Permeable Concrete Specimen using Digital Weighing

Figure 11 shows the measurement of the permeable concrete specimen weight using a digital weighing balance during laboratory testing. The weight measurement helps determine specimen density and material distribution, which are important parameters influencing the porosity, strength, and permeability characteristics of permeable concrete.



Fig. 12: Preparation of Concrete Block in Laboratory

Figure 12 shows the laboratory preparation process of permeable concrete blocks, including material mixing, mould filling, and specimen casting activities. The controlled preparation process ensures proper distribution of aggregates and sustainable materials to achieve the required strength and permeability characteristics.

Table 1: Dimensions of Block

Sr. No	Parameter	Value	Unit
1	Length	150	mm
2	Width	150	mm
3	Height	150	mm
4	Volume	3375	Cm ³
5	Area	225	Cm ²

Specimen Geometry Calculations

The geometrical properties of the permeable concrete specimens were calculated to determine the specimen volume and cross-sectional area required for compressive strength and permeability analysis.

Volume Calculation

$$V = L \times B \times H = 15 \times 15 \times 15 = 3375 \text{ cm}^3$$

Cross-Sectional Area Calculation

$$A = L \times B = 15 \times 15 = 225 \text{ cm}^2$$

Where: L = Length of Specimen, B = Width of Specimen, H = Height of Specimen



Fig. 13: Coarse Aggregate Placement for Sieve Analysis Test

Figure 13 shows the placement of coarse aggregates on the sieve apparatus during sieve analysis testing. The test is performed to determine aggregate size distribution and gradation, which significantly influence the porosity, permeability, and strength characteristics of permeable concrete.



Fig. 14: Compaction of Aggregate Specimen using Compression Machine

Figure 14 shows the compaction process of the aggregate specimen using a compression machine during laboratory preparation. Proper compaction ensures adequate bonding between aggregates while maintaining interconnected voids necessary for effective water infiltration in permeable concrete blocks.

Maintenance:

Maintenance of permeable concrete pavement is an important aspect to ensure its long-term performance, durability and effectiveness in water infiltration. Unlike conventional pavements, permeable concrete has a porous structure that allows water to pass through it. However, over time, these pores may get clogged due to the accumulation of dust, dirt, debris and other fine particles, which can reduce the permeability of the pavement. Regular maintenance is required to keep the pavement functional and to maintain its infiltration capacity. One of the most common methods of maintenance is cleaning the surface using vacuum sweeping or pressure washing. These methods help in removing accumulated particles from the pores and restoring the permeability of the pavement. Periodic inspection of the pavement is also necessary to identify any signs of damage such as cracks, raveling or surface

wear. Early detection of such issues helps in taking corrective measures and preventing further deterioration. Minor repairs can be carried out using suitable materials to maintain the structural integrity of the pavement. Proper drainage management is also an important part of maintenance. The drainage layer and surrounding areas should be kept clean to ensure smooth flow of water. Any blockage in the drainage system may lead to water accumulation, which can affect the performance of the pavement. In addition to cleaning and repairs, it is important to control the surrounding environment to minimize clogging. Measures such as proper landscaping, controlling soil erosion and preventing the entry of excessive debris can help in maintaining the effectiveness of the pavement.



Fig. 15: Weighing of Coarse Aggregate using Electronic Weighing Balance

Figure 15 shows the water-cement ratio is carefully controlled to proper bonding without filling the voids. The mix should be workable enough for casting but should not be too wet, as it may reduce permeability. Mix design is an important step in the preparation of permeable concrete. It involves selecting appropriate proportions of cement, aggregate, water and asphalt to achieve the desired properties.

In this study, the mix design is prepared in such a way that it provides sufficient strength while maintaining adequate void content for water infiltration. The proportion of coarse aggregate is kept higher, and fine aggregate is avoided to maintain porosity.

Precautions Taken During Preparation of Permeable Concrete Blocks

During the preparation of permeable concrete blocks, certain precautions are taken:

The preparation of permeable concrete blocks requires careful handling and proper control of materials and processes to achieve the desired strength and permeability. Since permeable concrete has a porous structure, special precautions must be taken to maintain the interconnected voids while ensuring adequate bonding between aggregates. Firstly, proper proportioning of materials is essential. The quantities of cement, aggregates, water and other materials such as recycled plastic, bio-based materials and fly ash should be measured accurately according to the mix design. Any variation in proportions may affect the strength and permeability of the concrete. Secondly, mixing of materials should be carried out uniformly to ensure even distribution of all components. In the case of recycled plastic and bio-based materials, special care should be taken to avoid segregation and ensure proper blending with aggregates. The water content should be carefully controlled during mixing. Excess water may lead to filling of voids and reduction in permeability, while insufficient water may result in poor bonding and reduced strength. Therefore, an optimum water-cement ratio should be maintained. Compaction is a critical step and should be done carefully using light tamping methods. Overcompaction should be avoided as it can reduce the void content and affect permeability. At the same time, insufficient compaction may lead to weak bonding and lower strength. During casting, the moulds should be clean and properly aligned to obtain uniform shape and size of blocks. The surface should be levelled properly without excessive finishing, as it may close the pores. Curing should be started immediately after moulding to prevent loss of moisture. The blocks should be kept in a moist condition for a sufficient period to ensure proper hydration of cement. Proper curing improves strength and durability of the blocks. Additionally, the prepared blocks should be handled carefully during moulding and testing to avoid damage. Environmental factors such as temperature, wind and direct sunlight should also be controlled to prevent rapid drying and cracking.

4. Result Analysis

The experimental study is an essential part of this study, as it helps in evaluating the performance and behaviour of various types of permeable concrete blocks used in permeable pavement systems. The main purpose of conducting experimental work is to analyze the strength and permeability characteristics of the prepared specimens under controlled laboratory conditions. This study provides practical insights into how the material performs when subjected to different types of loading and water flow conditions. In this study, various laboratory tests are carried out on the prepared specimens to determine their mechanical and hydraulic properties. The specimens are first prepared using selected materials and proper mix proportions,

followed by curing for specific duration of 14 days. After curing, the specimens are tested using standard procedures to obtain accurate and reliable results. The experimental program mainly includes tests such as aggregate impact test, compressive strength test and permeability test. These tests are conducted to evaluate the load carrying capacity and water infiltration ability of the permeable concrete blocks. The results obtained from these tests help in understanding the efficiency of the pavement system in reducing surface runoff and improving groundwater recharge. The data collected from the experimental study is analyzed and presented in the form of tables and graphs for better understanding. This analysis helps in identifying the relationship between different parameters such as strength, permeability and curing time. The findings of this experimental study play a crucial role in determining the suitability of permeable concrete pavement for practical applications.

TESTING

Aggregate Impact Analysis

The Aggregate Impact Test was conducted to evaluate the toughness and impact resistance of aggregates used in the preparation of permeable concrete blocks. The aggregate impact value indicates the ability of aggregates to resist sudden shock or impact loading, which is an important parameter for pavement materials subjected to repetitive traffic loads. Lower aggregate impact values represent higher aggregate toughness and improved resistance to crushing under impact conditions. The experimental results revealed that all three permeable concrete specimens exhibited aggregate impact values within the acceptable range specified by IS 2386 (Part IV), indicating satisfactory mechanical stability for low-traffic pavement applications. The recycled plastic permeable concrete block exhibited an aggregate impact value of 6.18%, demonstrating good resistance to impact loading. The improved impact resistance may be attributed to the flexible and energy-absorbing characteristics of plastic particles, which helped dissipate applied stresses within the concrete matrix. Similarly, the fly ash-based permeable concrete specimen also demonstrated favorable impact resistance characteristics. The enhanced performance of fly ash concrete may be associated with improved particle packing and stronger interfacial bonding resulting from pozzolanic reactions between fly ash and cement paste.



Fig. 16 Aggregate Impact Test

Figure 16 shows the reactions contribute to the formation of additional calcium silicate hydrate (C-S-H) gel, thereby improving the toughness and integrity of the concrete structure. In contrast, the bio-based permeable concrete specimen exhibited comparatively lower impact resistance due to the presence of natural organic constituents, which possess lower stiffness and weaker bonding characteristics than conventional mineral aggregates. The incorporation of bio-based materials increased the internal porosity and reduced the ability of the concrete matrix to resist sudden impact loads effectively. The comparative analysis indicates that recycled plastic and fly ash permeable concrete blocks provide better aggregate impact resistance than bio-based concrete specimens. The obtained results suggest that the incorporation of recycled plastic and fly ash can enhance the durability and load-bearing performance of permeable pavement systems while simultaneously promoting sustainable utilization of waste materials in construction applications.

Table 5: Aggregate Impact Test Table

Sr.No.	Description	Symbol	Value	Unit
1	Initial weight of sample	W1	380	g

2	Weight of fines (passing 2.36 mm)	W2	23.5	g
3	Aggregate Impact Value	$(W2/W1) \times 100$	6.18	%

Aggregate Impact Test: $W2 / W1 \times 100$ Calculation for Aggregate Impact Test:

Initial weight of Sample (W1) = 380 g

Weight of fines passing 2.36 mm sieve (W2) = 23.5 g Average

Impact Value = $W2 / W1 \times 100$

= $23.5 / 380 \times 100$

= 6.18 %

Aggregate Impact Value of Different Types of Permeable Concrete Blocks

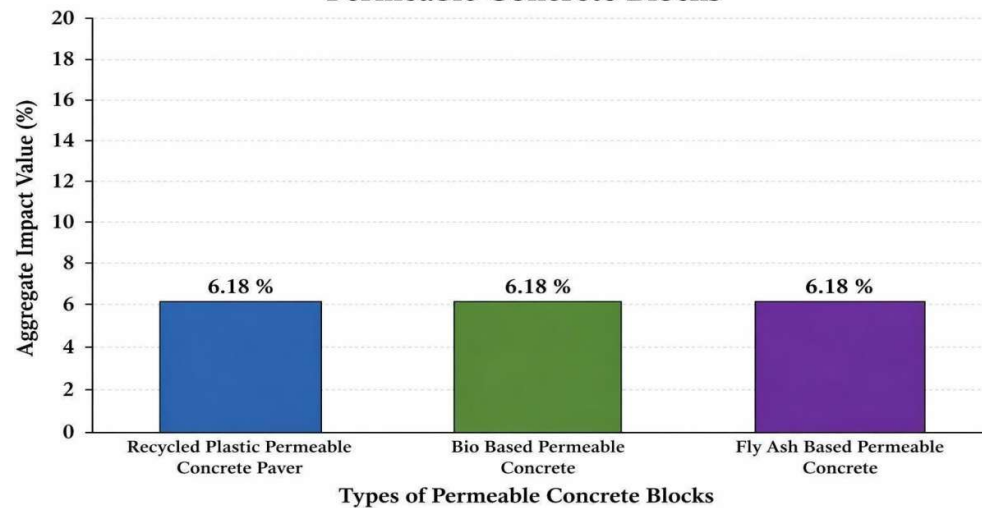


Fig. 17: Comparison of Aggregate Impact Value for Plastic block, Bio material block and Fly

5. Compressive Strength Analysis

Compressive strength is one of the most important mechanical properties of permeable concrete, as it represents the ability of the material to withstand compressive loading without structural failure. In permeable concrete systems, compressive strength is primarily influenced by factors such as aggregate size, interconnected void content, water-cement ratio, degree of compaction, and the type of sustainable replacement material used in the concrete matrix. Due to the presence of intentionally created voids for water infiltration, permeable concrete generally exhibits lower compressive strength than conventional dense concrete. However, adequate strength must be achieved to ensure structural stability for applications such as pedestrian pathways, parking areas, and low-volume traffic pavements. In the present study, compressive strength tests were conducted in accordance with IS 516:1959 to evaluate the load-bearing performance of recycled plastic, bio-based, and fly ash permeable concrete blocks [2]. Cube specimens of dimensions 150 mm × 150 mm × 150 mm were prepared and cured under controlled laboratory conditions for a curing period of 14 days prior to testing. After curing, the dimensions of each specimen were measured accurately using a vernier caliper to determine the effective cross-sectional area. The compressive strength test was performed using a compression testing machine (CTM), where the specimen was positioned centrally on the loading platform to ensure uniform load distribution over the entire surface area. The load was applied gradually and continuously at a constant loading rate without shock until specimen failure occurred. The maximum failure load was recorded, and the compressive strength was calculated as the ratio of applied load to the cross-sectional area of the specimen.

The compressive strength relationship is given by:

$$f_c = \frac{P}{A}$$

Where, f_c : compressive strength (N/mm^2), P: maximum applied load (N), A: cross-sectional area of specimen (mm^2)



Fig. 18: Compressive Strength Test

The experimental results indicated significant variation in compressive strength among the three permeable concrete specimens. The fly ash-based permeable concrete exhibited the highest compressive strength of 25.29 N/mm², which may be attributed to the pozzolanic reaction of fly ash that enhanced particle bonding and matrix densification within the concrete structure. The formation of additional calcium silicate hydrate (C-S-H) gel improved the overall strength and integrity of the concrete matrix. The recycled plastic permeable concrete block achieved a moderate compressive strength of 13.33 N/mm². The inclusion of plastic particles contributed to energy absorption and flexibility; however, the comparatively lower stiffness of plastic materials reduced the overall load-bearing capacity compared to fly ash concrete. Nevertheless, the obtained strength was found to be suitable for low-traffic pavement applications. In contrast, the bio-based permeable concrete specimen exhibited the lowest compressive strength of 5.51 N/mm². The reduced strength may be associated with the increased porosity and weaker interfacial bonding characteristics of natural organic materials within the cementitious matrix. The incorporation of bio-based constituents increased the void ratio, which adversely affected the compressive load resistance of the concrete.

Table 6: Compressive Strength Test Result

Sr.No.	Type of Block	PeakLoad (kN)	Load (N)	CompressiveStrength(N/mm ²)
1	Recycle Plastic	300	300000	13.33
2	Bio Material	124	124000	5.51
3	Fly Ash	569	569000	25.29

Table 6 presents the compressive strength test results of recycled plastic, bio-based, and fly ash permeable concrete blocks. Among all specimens, the fly ash-based permeable concrete exhibited the highest compressive strength of 25.29 N/mm² due to improved pozzolanic bonding and matrix densification within the concrete structure.

Compressive Strength Test:

Compressive Strength = Load / Area

Calculation of Compressive Strength:

Given: Size of specimen = 150 mm × 150 mm × 50 mm

Area = 150 × 150 = 22500 mm²

Formula: Compressive Strength = Load / Area

1) Recycle Plastic Block

Load = 300 kN = 300 × 1000 = 300000 N

Compressive Strength = 300000 /
22500 =

13.33
N/mm²

2) BioMaterial Block

Load = 124 kN = 124 × 1000 = 124000 N
Compressive Strength = 124000 / 22500
= 5.51 N/mm²

3) Fly Ash Material

Load = 569 kN = 569 × 1000 = 569000 N
Compressive Strength = 569000 /
22500 =
25.29
N/mm²

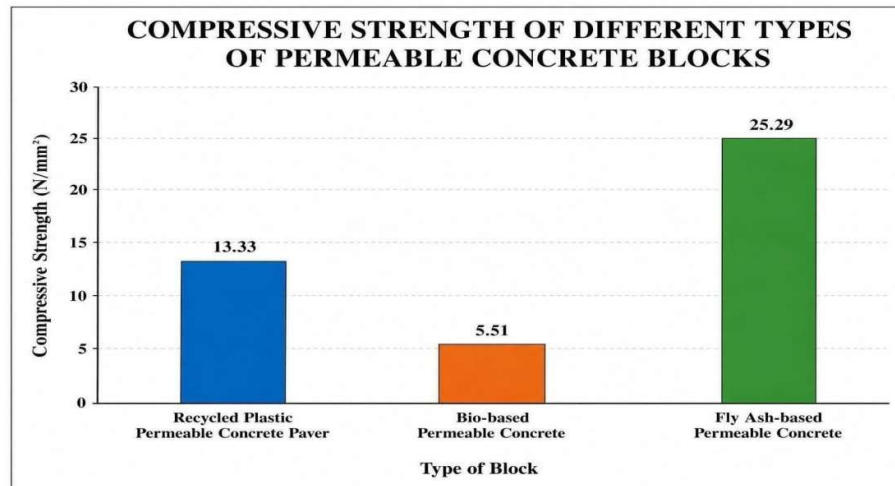


Fig. 19: Graph Showing Compressive Strength of Plastic block, Biomaterial block and Fly-Ash

Permeability (Percolation) Analysis

Permeability is the property of a material that allows fluids to pass through it. In permeable concrete, permeability is one of the most important characteristics, as it determines the efficiency of water infiltration through the pavement. The interconnected voids present in permeable concrete allow water to flow through the material, thereby reducing surface runoff and improving groundwater recharge. The permeability of concrete depends on factors such as void ratio, aggregate size, compaction and mix design. Higher void content results in higher permeability, while excessive compaction may reduce the permeability by closing the pores.



Fig.20: Water Percolation through Permeable Concrete

Figure 20 shows the water percolation behavior of permeable concrete blocks, where water is allowed to infiltrate through interconnected voids present within the concrete structure. The porous arrangement of aggregates enables efficient drainage and reduces surface water accumulation.

Procedure

The permeability test is conducted by placing the prepared concrete specimen in a suitable permeability test setup or cylindrical mould in such a way that water can pass only through the specimen. Before starting the test, the specimen is properly saturated to ensure uniform flow conditions. A known quantity of water is then poured over the top surface of the specimen, and the flow of water through the specimen is allowed under gravity. The time taken for a specific volume of water to pass through the specimen is recorded using a stopwatch. The water collected at the bottom is measured using a measuring cylinder. The test is repeated for different samples to obtain consistent results. The permeability rate is then calculated based on the volume of water and the time taken for flow. In addition to the basic procedure, it is important to ensure that there is no leakage from the sides of the specimen, as this may lead to incorrect results. The specimen should be properly placed and sealed in the setup to allow vertical flow of water only. The test should be conducted carefully to maintain uniform flow conditions and accurate measurement of time and volume.

Table 7: Percolation (Permeability) Test Results

Sr.No.	Material Type	Volume in cm ³	Area in cm ²	Time in sec	PercolationRateincm/sec
1	PlasticBlock	1125	225	50	0.1
2	Fly Ash	1125	225	130	0.038
3	Bio Material	1125	225	140	0.035

Table 7 presents the percolation test results of recycled plastic, fly ash, and bio-based permeable concrete blocks. Among all specimens, the recycled plastic block exhibited the highest percolation rate of 0.1 cm/sec with the shortest infiltration time, indicating superior permeability performance due to higher interconnected void content.

Percolation Rate Test:

Percolation Rate Test = Volume of Block / Area × Time

Calculation of Percolation Rate Test:

$$\begin{aligned} \text{Volume} &= \text{Length} \times \text{Width} \times \text{Height} \\ &= 150 \times 150 \times 150 \\ &= 1125000 \end{aligned}$$

$$\text{cm}^3 \text{ Area} = \text{Length} \times \text{Width}$$

$$\begin{aligned} &= 150 \times 150 \\ &= 225 \text{ cm}^2 \end{aligned}$$

Time required for 1000 ml water, Time = 50 sec

$$\begin{aligned} \text{Rate (for plastic)} &= 1125 / 225 \times 50 \\ &= 0.1 \text{ cm/sec} \end{aligned}$$

$$\begin{aligned} \text{Rate (for fly ash)} &= 1125 / 225 \times 130 \\ &= 0.038 \text{ cm/sec} \end{aligned}$$

$$\begin{aligned} \text{Rate (for bio material)} &= 1125 / 225 \times 140 = \\ &0.035 \\ &\text{cm/sec} \end{aligned}$$

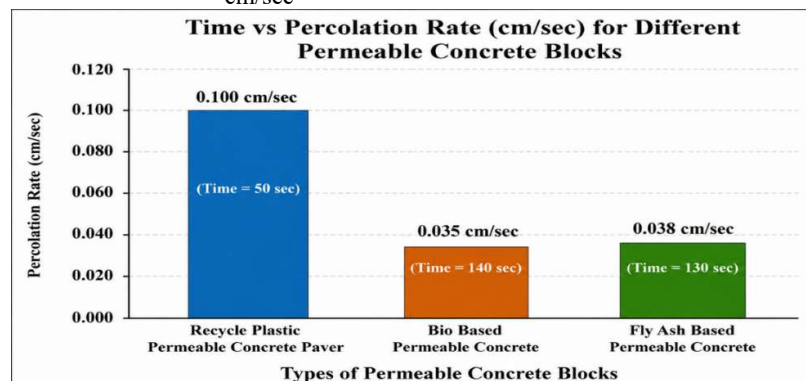


Fig.21: Comparative Analysis of Permeability of Plastic block, Bio material block and Fly Ash block

Figure 21 shows the comparative percolation rates of recycled plastic, bio-based, and fly ash permeable concrete blocks. Among all specimens, the recycled plastic permeable concrete exhibited the highest percolation rate of 0.100 cm/sec with the shortest infiltration time, indicating superior permeability performance.

6. Conclusion & Future Scope

The present study demonstrates that permeable concrete blocks incorporating recycled plastic, bio-based materials, and fly ash exhibit significant potential for sustainable pavement applications due to their permeability characteristics and environmental benefits. The interconnected void structure of all specimens enabled effective water infiltration, thereby reducing surface runoff, minimizing water logging, and promoting groundwater recharge in urban areas. Among the investigated materials, fly ash-based permeable concrete exhibited the highest compressive strength due to enhanced pozzolanic bonding and matrix densification, whereas recycled plastic permeable concrete demonstrated comparatively higher permeability and improved durability against environmental exposure. Bio-based permeable concrete provided enhanced sustainability through the utilization of renewable natural materials, although it exhibited comparatively lower compressive strength. The aggregate impact values of all specimens were found to be within acceptable limits, indicating satisfactory toughness and suitability for low-traffic applications such as footpaths, parking areas, residential roads, and pedestrian pavements. The comparative analysis highlights that the selection of permeable concrete material depends on the required balance between strength, permeability, durability, cost, and environmental sustainability. Overall, the incorporation of recycled plastic, bio-based materials, and fly ash in permeable concrete represents an effective and eco-friendly approach toward sustainable infrastructure development and stormwater management. Future research should focus on optimizing mix design proportions to achieve an improved balance between permeability and compressive strength, particularly for bio-based concrete systems. Long-term durability studies under varying environmental and traffic conditions, clogging behavior analysis, life-cycle assessment, and large-scale field implementation are recommended to further evaluate practical feasibility. Additionally, the integration of industrial by-products, advanced monitoring technologies, and smart pavement systems may enhance the structural performance, sustainability, and functionality of permeable concrete for future green infrastructure and smart city applications.

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