

UTILIZATION OF HDPE PLASCTIC WASTE AS AN ADDITIONAL MATERIAL IN PERVIOUS CONCRETE MIXTURE

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ABSTRAK

Perkembangan infrastruktur perkotaan semakin banyak menggunakan material kedap air seperti beton konvensional dan aspal yang dapat mengurangi infiltrasi air secara alami serta meningkatkan limpasan permukaan dan risiko banjir. Beton berpori (pervious concrete) menjadi salah satu alternatif karena memiliki struktur rongga yang saling terhubung sehingga memungkinkan air meresap melalui permukaan perkerasan. Namun, tingginya kadar rongga yang memberikan sifat permeabilitas sering kali menyebabkan penurunan kekuatan mekanis beton. Penelitian ini bertujuan untuk menganalisis pengaruh penambahan limbah plastik high-density polyethylene (HDPE) daur ulang pada campuran beton berpori terhadap kuat tekan dan permeabilitas. Penelitian ini menggunakan metode eksperimen laboratorium dengan empat variasi campuran, yaitu campuran kontrol tanpa HDPE serta campuran dengan penambahan HDPE sebesar 1%, 1,5%, dan 2% dari berat agregat. Benda uji berbentuk silinder dibuat dan dirawat dalam kondisi terkontrol. Pengujian kuat tekan dilakukan pada umur 7 dan 14 hari menggunakan mesin uji tekan, sedangkan pengujian permeabilitas dilakukan untuk mengukur kemampuan infiltrasi air pada beton. Hasil penelitian menunjukkan bahwa penambahan HDPE mempengaruhi sifat mekanis dan hidrolik beton berpori. Kuat tekan tertinggi diperoleh pada campuran dengan penambahan HDPE sebesar 1,5%, yaitu sebesar 18,14 MPa pada umur 14 hari. Peningkatan kadar HDPE di atas nilai tersebut menyebabkan penurunan kuat tekan yang diduga akibat lemahnya ikatan antara partikel plastik dan pasta semen. Hasil pengujian permeabilitas menunjukkan bahwa campuran tanpa HDPE memiliki nilai permeabilitas tertinggi sebesar 0,058 cm/s, sedangkan nilai permeabilitas menurun seiring meningkatnya kadar HDPE. Meskipun demikian, seluruh variasi campuran masih memenuhi kebutuhan permeabilitas untuk aplikasi perkerasan berpori. Secara keseluruhan, limbah plastik HDPE berpotensi dimanfaatkan sebagai bahan tambahan pada beton berpori untuk meningkatkan kuat tekan dengan tetap mempertahankan kemampuan permeabilitas yang memadai. Campuran optimum diperoleh pada penambahan HDPE sebesar 1,5% karena memberikan keseimbangan terbaik antara kuat tekan dan kemampuan infiltrasi air.

Kata kunci : beton berpori, plastik HDPE, kuat tekan, permeabilitas, material daur ulang

ABSTRACT

Urban infrastructure development increasingly relies on impervious materials such as conventional concrete and asphalt, which reduce natural water infiltration and increase surface runoff and flood risk. Pervious concrete offers an alternative solution because its interconnected pore structure allows water to infiltrate through the pavement surface. However, the high void content that provides permeability often reduces its mechanical strength. This study aims to evaluate the effect of incorporating recycled high-density polyethylene (HDPE) plastic waste into pervious concrete mixtures on compressive strength and permeability performance. An experimental laboratory method was applied using four mixture variations: a control mixture without HDPE and mixtures containing 1%, 1.5%, and 2% shredded HDPE by weight of aggregate. Cylindrical specimens were prepared and cured under controlled conditions. Compressive strength tests were conducted at 7 and 14 days using a compression testing machine, while permeability tests were performed to measure the water infiltration capacity of the concrete. The results show that HDPE addition affects both mechanical and hydraulic properties of pervious concrete. The highest compressive strength was obtained in the mixture containing 1.5% HDPE, reaching 18.14 MPa at 14 days. Increasing HDPE content beyond this level resulted in reduced compressive strength, likely due to weaker bonding between plastic particles and the cement matrix. Permeability results indicate that the control mixture without HDPE achieved the highest permeability value of 0.058 cm/s, while permeability gradually decreased as HDPE content increased. Nevertheless, all mixtures maintained sufficient permeability for pervious pavement applications. Overall, the findings indicate that recycled HDPE plastic can be

used as an additive in pervious concrete to improve compressive strength while maintaining acceptable permeability performance. The optimum mixture identified in this study is 1.5% HDPE, which provides a balanced performance between mechanical strength and water infiltration.

Keywords : *pervious concrete, hdpe plastic, compressive strength, permeability, recycled materials*

1. INTRODUCTION

Urban infrastructure development has significantly increased the use of impervious materials such as concrete and asphalt for highways, urban roads, and residential pavements. While these materials provide durability and structural capacity for transportation systems, they also cover naturally porous soil surfaces and prevent water infiltration. As a result, rainwater is rapidly converted into surface runoff, increasing the risks of urban flooding, erosion, and water pollution. The expansion of sealed land surfaces has therefore become a major environmental concern in rapidly developing regions. Although conventional concrete pavements remain essential for infrastructure development, their environmental impacts require innovative engineering solutions that support sustainable stormwater management.

One promising solution is the development of pervious concrete. Pervious concrete, also known as porous concrete, is designed with little or no fine aggregate, creating an interconnected void structure that allows water to infiltrate through the material. According to the American Concrete Institute, pervious concrete typically consists of cement, coarse aggregate, water, and sometimes admixtures, with minimal or no fine aggregate, resulting in a mixture with a slump value close to zero (ACI 522R-10, 2020). This structure allows rainwater to pass through the concrete matrix at relatively high infiltration rates, generally ranging from 0.20 to 0.54 cm/s, facilitating groundwater recharge and reducing surface runoff (ACI 522, 2010; IRC 44, 2017; Singh, Biligiri, and Sampath, 2022). However, due to its high void ratio and reduced paste content, pervious concrete typically exhibits lower mechanical strength than conventional concrete.

To improve the mechanical performance of concrete while addressing environmental concerns, researchers have explored the use of recycled plastic materials in cement-based composites. Several studies have investigated the incorporation of plastic waste into concrete mixtures using different polymers, including raw plastic granules as partial replacements for fine aggregates (Yang et al., 2015), polyethylene terephthalate (PET) bottle waste (Saikia and de Brito, 2014), polyvinyl chloride (PVC) pipe waste (Binici et al., 2016), and high-density polyethylene (HDPE) waste (Shanmugapriya, 2017). Previous studies also indicate that HDPE fibers can improve concrete performance by

enhancing ductility and mechanical interlocking within the cement matrix (Kobayashi, 1981). Soroushian et al. (1992) reported that HDPE fiber-reinforced concrete can achieve flexural toughness comparable to concrete reinforced with polypropylene and high-modulus polyethylene fibers, while Bhavi et al. (2012) found that incorporating 0.2–1.0% recycled HDPE fibers increased compressive strength, tensile strength, flexural strength, and impact resistance by approximately 15%, 23%, 22%, and 200%, respectively.

Despite these promising results, the application of HDPE in pervious concrete remains limited, and further investigation is required to understand how recycled HDPE influences both the mechanical properties and permeability performance of pervious concrete. A comprehensive review by Yin et al. (2015) emphasized the need for additional research on the structural behavior of HDPE fiber-reinforced concrete, particularly regarding the balance between mechanical strength and hydraulic performance in pervious concrete systems.

Therefore, this study investigates the use of shredded HDPE plastic waste as an additive in pervious concrete mixtures. The research evaluates the compressive strength and permeability characteristics of pervious concrete containing HDPE and compares its performance with conventional pervious concrete without HDPE addition. By examining the potential of recycled HDPE as a reinforcing material, this study aims to contribute to the development of sustainable pavement materials that combine improved mechanical performance with effective stormwater management.

2. LITERATURE REVIEW

Pervious concrete is widely used as a sustainable construction material due to its ability to improve water infiltration and reduce surface runoff. Compared with conventional concrete, pervious concrete provides better drainage performance and supports groundwater recharge, making it suitable for low-traffic pavements, roofs, and similar applications. Therefore, studying pervious concrete is important to understand its role in improving soil water recharge (Ramesh and Gomasa, 2021). According to ACI 522R-10, the typical mix design for pervious concrete consists of cement (270–415 kg), aggregate (1190–1480 kg), a water–cement ratio of 0.27–0.34, and a sand-to-gravel ratio ranging from 0 to 1:1 (Jurnal Sipil Statik Vol. 7 No. 3 March

2019 (351–358) ISSN: 2337-6732). The addition of sand can reduce pore content while increasing compressive strength.

Advantages of Pervious Concrete

Pervious concrete, also known as porous concrete, is a cement-based material with high void content that allows water to infiltrate through the pavement surface. This characteristic makes pervious concrete suitable for sustainable stormwater management systems (American Concrete Institute Committee 522, 2010). The main advantage of pervious concrete is its ability to reduce surface runoff and enhance groundwater recharge. Paul D. Tennis, Michael L. Leming, and David J. Akers (2004) reported that permeable pavement systems can significantly improve drainage performance and reduce the load on conventional stormwater infrastructure. It is commonly applied in parking areas, pedestrian pathways, and low-traffic roads due to its effective drainage capacity (Ramesh and Gomasa, 2021). However, its structural strength is generally lower than that of conventional concrete due to its high porosity, prompting ongoing research to optimize mix design and improve mechanical performance while maintaining permeability.

Compressive Strength

Compressive strength is a key parameter used to evaluate the mechanical performance of concrete, representing the maximum load a specimen can withstand before failure (Setiawan et al., 2010). The compressive strength of pervious concrete is generally lower than that of conventional concrete due to its porous structure. American Concrete Institute Committee 522 (2010) reported that the compressive strength of pervious concrete typically ranges from approximately 2.8 MPa to 28 MPa, depending on mixture composition, aggregate characteristics, and water–cement ratio.

Previous studies indicate a clear relationship between porosity and compressive strength in pervious concrete. Ryan Zhong and Kay Wille (2015) explained that increasing void content improves permeability but reduces compressive strength due to the reduction of load-bearing solid phases within the concrete matrix. Similarly, Paul D. Tennis, Michael L. Leming, and David J. Akers (2004) emphasized that optimizing aggregate gradation and water–cement ratio is necessary to maintain adequate structural capacity.

Permeability

Permeability is a key property of pervious concrete that determines its ability to transmit water through interconnected voids within the material structure. According to Adam M. Neville (1995), the permeability of cement-based materials is influenced by the size, distribution, and connectivity of pores formed during the hydration process. However, the pore structure of pervious concrete may be susceptible to clogging. Evan Z. Bean, William F. Hunt, and

Dale A. Bidelspach (2007) reported that infiltration capacity can decrease over time due to the accumulation of fine sediments and debris within the pore network. Lance Haselbach, Robert Freeman, and Simon Beecham (2011) also observed that long-term clogging can significantly reduce permeability if proper maintenance is not implemented. High-density polyethylene (HDPE), with its hydrophobic surface and low water absorption, has potential to maintain open pore channels within pervious concrete while supporting sustainable plastic waste management.

3. RESEARCH METHODS

This study employed an experimental laboratory method to evaluate the performance of pervious concrete incorporating recycled high-density polyethylene (HDPE) plastic waste. The experiment compared conventional pervious concrete with pervious concrete containing shredded HDPE plastic. Testing procedures referred to relevant Indonesian National Standards (SNI). The independent variable was the percentage of HDPE plastic added to the mixture, while the dependent variables were compressive strength and water absorption/permeability. Control variables included the mix composition, specimen dimensions, curing conditions, and testing procedures.

The pervious concrete mix was determined based on the solid volume calculation for 1 m³ of concrete. The base mixture consisted of 1411.76 kg/m³ of coarse aggregate, 324.78 kg/m³ of cement, and 87.69 kg/m³ of water. HDPE plastic waste was incorporated as a percentage of aggregate weight at three levels: 1%, 1.5%, and 2%, equivalent to 14.11 kg/m³, 21.17 kg/m³, and 28.23 kg/m³, respectively. A control mixture without HDPE was also prepared. The mixture proportions are presented in Table 1.

Table 1. Mix Design of Pervious Concrete (per 1 m³)

Parameter	Konsentrasi (%)
CaO	22.25
MgO	5.1
Fe ₂ O ₃	5.85
Al ₂ O ₂	16.8
SiO ₂	26.31
H ₂ O	22.16

Source: Data processing by researchers

Concrete specimens were prepared using cylindrical molds. Coarse aggregate and cement were first dry-mixed, followed by the addition of shredded HDPE according to the specified variation. Water was then added gradually until a homogeneous mixture was obtained. The concrete was

placed into molds and compacted manually to maintain the interconnected void structure of pervious concrete.

After casting, specimens remained in the molds for 24 hours before demolding and were subsequently cured by water immersion. Compressive strength tests were conducted at 3 and 7 days using cylindrical specimens with dimensions of 20 cm in diameter and 30 cm in height. The tests were performed using a compression testing machine with gradually applied load until failure.

Permeability (water absorption) tests were conducted using cylindrical specimens with dimensions of 10 cm in diameter and 20 cm in height. Water was allowed to flow through the specimen, and the infiltration rate was measured to evaluate the permeability characteristics of the pervious concrete. The test results were used to analyze the effect of HDPE plastic addition on the mechanical strength and permeability performance of pervious concrete.

4. RESULT AND DISCUSSION

This section presents and interprets the experimental results obtained from the material characterization tests, compressive strength tests, and permeability tests of pervious concrete mixtures incorporating shredded HDPE plastic waste. The analysis focuses on understanding how the addition of HDPE influences the mechanical and hydraulic performance of pervious concrete. The findings indicate that the incorporation of HDPE affects both compressive strength and permeability characteristics. The results show that the optimum mechanical performance was achieved with a 1.5% HDPE replacement, while permeability tended to decrease as HDPE content increased.

These findings contribute to the growing body of research on sustainable concrete materials, particularly the utilization of plastic waste in porous concrete systems. The discussion also compares the experimental results with previous studies and established standards such as those from the American Concrete Institute (ACI) and the National Ready Mixed Concrete Association (NRMCA), while highlighting engineering implications and research limitations.

Material Characterization and Mix Design

Prior to concrete production, characterization of aggregate materials was carried out to ensure compliance with applicable standards. Aggregate properties significantly influence the performance of pervious concrete because the material relies on interconnected voids formed between coarse aggregate particles. The test results for the aggregates used in this study are summarized in Table 2.

Table 2. Aggregate Material Properties Used in Pervious Concrete Mixtures

Property	Value
Specific Gravity (Oven Dry)	2.76
Specific Gravity (SSD)	2.77
Water Absorption	0.34 %
Moisture Content	0.47 %
Mud Content	0.234 %
Abrasion Value	35.56 %
Impact Value	12.49 %

Source: Data processing by researchers

The fineness modulus of the coarse aggregate (5–10 mm) was determined to be 2.75, which falls within the acceptable range for coarse aggregate gradation. According to Indonesian National Standard SNI PB-0203-76, aggregates used in concrete mixtures must meet specific criteria regarding water absorption, specific gravity, and cleanliness to ensure durability and proper bonding with the cement paste.

The relatively low water absorption value (0.34%) indicates that the aggregate possesses limited porosity, which helps maintain the water–cement ratio during mixing. Additionally, the specific gravity value of 2.773 meets the minimum requirement for aggregates used in structural concrete. The mix proportions were designed following the guidelines presented in ACI 522R-10, which provides recommendations for pervious concrete mix design.



Figure 1. Enumeration Bottle HDPE Plastic Measuring 0.5cm



Figure 2. Aggregate 0.5cm

Table 3. Pervious Concrete Mix Design per 1 m³

Material	Quantity (kg/m ³)
Aggregate	.76
Cement	324.78
Water	87.69
HDPE (1%)	14.11
HDPE (1.5%)	21.17
HDPE (2%)	28.23

Source: Data processing by researchers

The HDPE plastic particles were introduced as a partial replacement for aggregate volume, with the objective of evaluating their effect on both mechanical strength and permeability.

Compressive Strength Test Results

Compressive strength is a fundamental mechanical property that reflects the load-bearing capacity of concrete. In pervious concrete, compressive strength is generally lower than that of conventional concrete due to the presence of a high void ratio required for water permeability. The compressive strength tests were conducted using cylindrical specimens measuring 150 mm in diameter and 300 mm in height, following standard compression testing procedures. Due to time constraints, testing was performed at 7 days and 14 days of curing.



Figure 3. After Testing Press

Table 4. Average Compressive Strength Results

HDPE Variation	7 Days (MPa)	14 Days (MPa)
0 %	11.79	16.13
1 %	10.82	12.58
1.5 %	14.22	18.14
2 %	10.29	12.25

Source: Data processing by researchers

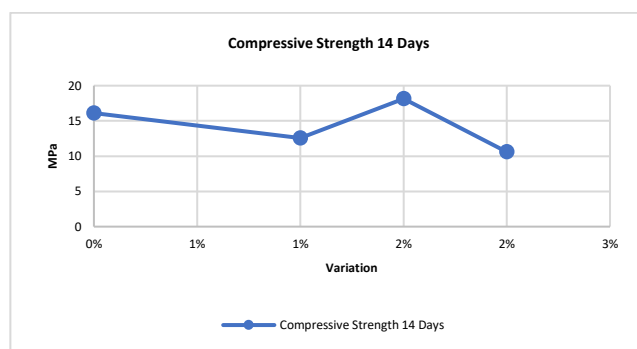


Figure 4. Composition Variation Relationship Graph HDPE with Compressive Strength Results 14 Pervious Concrete Day

The results indicate that compressive strength increased with curing age for most mixture variations. The highest compressive strength was obtained in the mixture containing 1.5% HDPE, which reached 18.14 MPa at 14 days. This result suggests that a moderate amount of HDPE may improve particle interlocking within the aggregate skeleton, thereby enhancing load transfer between aggregate particles. However, when the HDPE content increased to 2%, the compressive strength decreased. This reduction may be attributed to weaker bonding between the plastic particles and cement paste, as plastic materials typically exhibit lower adhesion compared to mineral aggregates.

The compressive strength values obtained in this study fall within the typical range reported for pervious concrete. According to National Ready Mixed Concrete Association (2011) and American Concrete Institute (2010), the compressive strength of pervious concrete generally ranges between 2.8 MPa and 28 MPa.

Table 5. Typical Compressive Strength Range of Pervious Concrete

Source	Minimum (MPa)	Maximum (MPa)
National Ready Mixed Concrete Association, 2011	3.5	28

American Concrete Institute, 2010

Source: Data processing by researchers

Although the compressive strength achieved in this research does not reach the approximately 30 MPa requirement for heavy-duty road pavements, the values obtained are sufficient for low-load infrastructure applications, such as pedestrian walkways, park pathways, and parking areas. From an engineering perspective, these findings demonstrate that incorporating small percentages of HDPE plastic waste in pervious concrete can produce a structurally acceptable material for non-structural or light-traffic pavement systems.

Permeability Test Results

Permeability is a critical property of pervious concrete because it determines the material’s ability to allow water infiltration and reduce surface runoff. High permeability enables effective stormwater management and contributes to groundwater recharge. Permeability tests were conducted on cylindrical specimens measuring 100 mm in diameter and 200 mm in height using a constant-head method.



Figure 5. Permeability Test Equipment



Figure 6. Permeability Time for All Variants



Figure 7. Permeability Tool Hole Hose is Nighbened

Table 6. Average Permeability Results

HDPE Variation	Flow Time (s)	Permeability (cm/s)
0 %	24.63	0.058
1 %	40.61	0.034
1.5 %	43.11	0.032
2 %	46.55	0.030

Source: Data processing by researchers

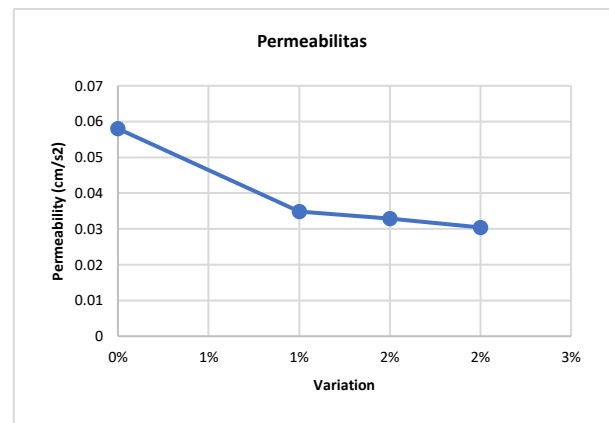


Figure 8. Graph of the Relationship between HDPE Composition Variations and Concrete Permeability Results

The permeability results indicate that the highest permeability value occurred in the mixture without HDPE, while permeability decreased as the HDPE content increased. This trend suggests that the addition of plastic particles partially reduced the interconnected pore structure responsible for water infiltration.

Despite this decrease, the permeability values obtained in this study remain within the range typically reported for pervious concrete. According to Charles H. Crouch, Greg S. Pittenger, and Robert K. Brown (2006), the permeability coefficient of pervious Portland cement concrete generally ranges from 0.001 cm/s to 10 cm/s, depending on the mixture composition and void ratio.

Therefore, even with HDPE incorporation, the pervious concrete produced in this study still satisfies the functional requirement of allowing water infiltration.

Relationship Between Compressive Strength and Permeability

The relationship between compressive strength and permeability in pervious concrete is typically characterized by an inverse correlation. Increasing the density of the concrete matrix tends to improve compressive strength but simultaneously reduces permeability due to the reduction in interconnected voids. The experimental results of this study confirm this typical behavior.

The mixture containing 1.5% HDPE, which produced the highest compressive strength, exhibited lower permeability than the control mixture without HDPE. Conversely, the control mixture demonstrated the highest permeability due to its more open pore structure. This trade-off highlights the importance of optimizing mixture composition to achieve a balance between mechanical and hydraulic performance. For practical engineering applications, the optimal mixture depends on the intended function of the pavement system.

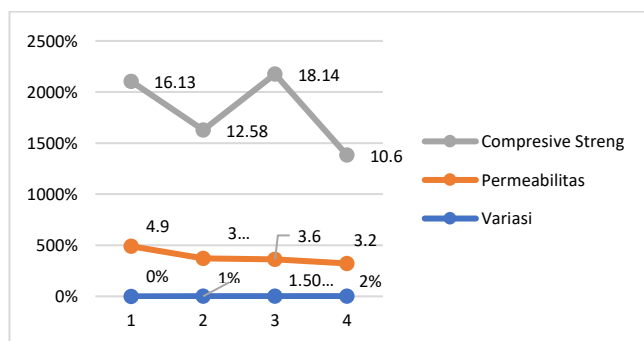


Figure 9. Graph of the Relationship between Compressive Strength and Permeability of Porous Concrete

Engineering Implications

The findings of this study suggest that incorporating HDPE plastic waste into pervious concrete can contribute to sustainable construction practices by reducing plastic waste while maintaining acceptable performance characteristics. The optimum mixture identified in this research was 1.5% HDPE, which provided the best balance between compressive strength and permeability. This material may be particularly suitable for environmentally friendly infrastructure such as:

1. pedestrian pavements
2. parking areas
3. park pathways
4. low-traffic road surfaces

In addition to environmental benefits, the use of recycled plastic materials may reduce landfill waste and promote circular economy principles in the construction industry.

Limitations and Future Research

Despite the promising results, this study has several limitations. First, compressive strength testing was conducted only at 7 and 14 days, whereas standard concrete strength evaluation typically includes 28-day testing. Second, the study evaluated only three HDPE variations (1%, 1.5%, and 2%), which may not represent the full range of possible compositions.

Future research should therefore consider:

1. evaluating long-term compressive strength (28 and 56 days)
2. investigating additional HDPE proportions
3. analyzing durability properties such as freeze-thaw resistance and abrasion resistance
4. studying the microstructure of HDPE-cement bonding using microscopic analysis

Such investigations will provide deeper insight into the long-term performance and structural feasibility of HDPE-modified pervious concrete.

5. CONCLUSION

This study evaluated the compressive strength and permeability performance of pervious concrete incorporating shredded High-Density Polyethylene (HDPE) plastic waste. The results indicate that HDPE addition influences both mechanical and hydraulic properties of the concrete mixture. The optimum compressive strength was obtained at 1.5% HDPE content, reaching an average value of 18.14 MPa at 14 days, which falls within the typical compressive strength range for pervious concrete reported by American Concrete Institute Committee 522 (2010) and the National Ready Mixed Concrete Association (2011). Although this strength level is lower than that required for heavy-duty pavements, it is adequate for low-load applications such as pedestrian pathways, parking areas, and permeable pavement systems. Permeability testing showed that the mixture without HDPE exhibited the highest permeability value, with an average coefficient of 0.058 cm/s. The addition of HDPE slightly reduced permeability due to changes in the pore structure, but the values remained within the typical permeability range of pervious concrete reported by Brian K. Crouch, John Pitt, and Michael Hewitt (2006). The results confirm an inverse relationship between compressive strength and permeability, where increased strength corresponds to reduced permeability due to a denser internal structure.

Overall, the findings suggest that recycled HDPE can be utilized as a supplementary material in pervious concrete while maintaining acceptable structural and drainage performance. However, this study was limited by the testing age (7 and 14 days) and the relatively small number of specimens. Future research should include 28-day strength testing, larger sample sizes, and variations in aggregate sources and HDPE content to further optimize the performance of HDPE-modified pervious concrete.

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