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Cement Dosage and Granular Class as Key Factors in the Properties of Pervious Concrete: A Comprehensive Study

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ABSTRACT

This study explores the impact of varied cement doses (250, 275, 300, 325, and 350 kg/m³) and granular classes (D_{max} of 8, 10, 12.5, and 20 mm) on pervious concrete characteristics. The concrete's fresh and hardened states are examined to identify the ideal cement dosage and granular class for optimal properties. Workability in the fresh state is measured using the slump test and air content analysis. In the hardened state, performance is assessed through water permeability, porosity, density, compressive strength, and electrical resistivity tests. The research reveals that granular class D_{max} significantly affects pervious concrete properties. A smaller D_{max} and lower cement dosage enhance workability, while in the hardened state, a smaller D_{max} combined with higher cement dosage reduces porosity and water permeability and increases mechanical strength and density. The ideal combination of cement dose and granular class varies depending on the specific property under consideration. This study emphasizes the importance of carefully selecting granular class and cement dosage to achieve desired pervious concrete qualities. These findings provide valuable insights for practitioners aiming to enhance the sustainability and resilience of urban infrastructure using pervious concrete.

1. INTRODUCTION

In the context of rapid urbanization and population growth, soil impermeabilization presents significant environmental, developmental, and safety challenges [1-3]. It obstructs the natural infiltration of rainwater into aquifers, increasing surface runoff and flood risks during heavy rainfall [4, 5], while also disrupting local climate stability by limiting the exchange of heat and moisture. In response, urban stormwater management has shifted towards integrated strategies that restore natural hydrological processes like evaporation and infiltration [5]. Among these solutions, pervious concrete has emerged as a leading material [6]. Its porous structure allows water to pass through, reducing surface water accumulation during storms and directing it into the soil [6, 7]. Composed of aggregates, cement, and water, pervious concrete balances mechanical strength with high permeability, making it a sustainable choice for various outdoor applications. The American Concrete Institute (ACI) [6] provides guidelines on the composition of pervious concrete, specifying cement content between 270 and 415 kg/m³ and water-to-cement (W/C) ratios from 0.27 to 0.40. Pervious concrete primarily consists of coarse, uniformly graded gravel (1190–1880 kg/m³) and around 7% fine aggregates, typically sand, which improve compressive strength and durability [8-10]. Compressive strengths typically range from 2.8 to 28 MPa, as reported by several authors [7, 11-18], with water permeability rates between 81 and 730 l/min/m². These parameters are crucial in balancing water permeability and mechanical strength. Dynamic adjustments in component proportions and the careful selection of aggregate combinations enable designers to create pervious concrete tailored to specific project requirements. Our primary objective is to develop a pervious concrete mix that balances mechanical strength and water permeability while minimizing cement use to reduce costs and environmental impact [19]. Our study is guided by the following research questions: (1) How does varying cement dosage influence the trade-off between compressive strength and water permeability? (2) What impact does maximum aggregate size have on pervious concrete performance? (3) Can a high-performing mix be achieved using only natural aggregates and moderate cement dosages, without the need for additives?

By adhering to industry norms and carefully selecting gravel percentages, our study provides practical insights for improving pervious concrete formulations for large-scale applications. In previous research efforts, scholars have focused on enhancing pervious concrete formulations, emphasizing mechanical strength and water permeability. Huang et al. [20] compared granite and dolerite in pervious concrete compositions, finding that dolerite outperformed granite in imparting greater strength and permeability. Xu et al. [21] explored the influence of aggregate size and notch depth on fracture performance, demonstrating that larger particles improved resistance and fracture energy. Yu et al. [22] investigated the interaction among aggregate size, cement paste thickness, and compressive strength, observing an increase in strength with larger aggregate dimensions. Ćosić et al. [13] examined the effect of aggregate type and size, revealing that smaller aggregate fractions enhanced strength attributes and increased density. Mulyono and Anisah [23] explored the effects of water-cement ratios (0.27-0.34) and aggregate sizes, finding that smaller aggregates led to higher porosity but lower density, affecting both compressive strength and permeability. Yu et al. [24] investigated the optimization of pore structure in pervious concrete and found that reducing the porosity of smaller pores while maintaining larger ones enhanced both compressive strength and water permeability. Singh and Sidhu [25] examined the fracture and fatigue properties of pervious concrete with a 15-20% void ratio, concluding that high-strength pervious concrete (32-45 MPa) can be achieved while maintaining a high void ratio, suitable for heavy-load road applications. Singh et al. [26] developed a multi-criteria decision-making framework to optimize pervious concrete mixtures based on performance characteristics, providing guidelines for material selection. Boakye and Khorami [27] investigated the influence of calcined clay pozzolan and aggregate size on the mechanical and durability properties of pervious concrete, offering insights into optimizing strength and sustainability. Kaplan et al. [28] explored the use of recycled aggregates in lightweight pervious concrete, assessing the impact on mechanical properties and permeability.

However, while these studies significantly advanced our understanding of the impact of aggregate size and cement dosage on pervious concrete, they often relied on complex formulations, including the use of recycled materials, chemical admixtures, or mineral additives. For example, Raimon et al. [29] utilized marble waste and fly ash to improve compressive strength, but this approach increased material complexity and cost. Shen et al. [30] proposed an ultra-high-performance paste to achieve high compressive strength (up to 60.93 MPa) while maintaining permeability, but the use of advanced materials further elevated production costs. Similarly, Mulyono and Anisah [23] found that adjusting the water-cement ratio and aggregate size improved permeability, but their use of additional components like superplasticizers increased formulation complexity. These approaches, while effective, often present practical challenges when applied in large-scale projects where cost and simplicity are critical. Our investigation focuses on the relationship between cement dosage and maximum aggregate size (Dmax) and their combined impact on the properties of pervious concrete. By examining twenty formulations with varying cement dosages (250 to 350 kg/m³) and Dmax values (8, 10, 12.5, and 20 mm), we aimed to find an optimal balance between mechanical strength, as indicated by compressive strength, and hydrological efficiency, represented by water permeability. Achieving this balance is challenging due to the typically inverse relationship between compressive strength and permeability. Unlike previous studies that incorporated recycled materials, chemical admixtures, or mineral additives to enhance performance, our study takes a distinct approach by eliminating these additional components. Instead, we focus on optimizing natural aggregate sizes and moderate cement dosages to maintain both performance and cost-efficiency. This not only minimizes production costs and CO_2 emissions associated with cement use but also provides a scalable and sustainable solution for high-performance pervious concrete. Our work is particularly well-suited for large-scale, low-cost applications where economic and environmental constraints are crucial, offering a simpler, more accessible alternative without sacrificing essential performance metrics like strength and permeability.

2. MATERIALS AND EXPERIMENTAL METHOD

The materials used in this study include water, cement, and aggregates:

Water: Laboratory tap water was used for the concrete mixes. The water quality adhered to standard specifications for concrete mixing in civil engineering applications.

Cement: The cement used in this investigation was CEM I/52.5, with a specific gravity of 3.1. This type of cement was selected for its high strength properties and consistency. The chemical composition of the cement is provided in Table 1. Importantly, this cement contains no additives, aligning with the goal of reducing material complexity and environmental impact. To assess the influence of cement dosage on the properties of pervious concrete, five distinct dosages were employed: 250 kg/m³, 275 kg/m³, 300 kg/m³, 325 kg/m³, and 350 kg/m³.

Aggregates: The study utilized four types of gravel (G1, G2, G3, and G4) and one type of natural sand (S1), as outlined in Table 2. The aggregates were delivered in 1200-kilogram "Big Bags" to the Laboratory of Mechanics and Civil Engineering Materials (L2MGC). The gravels and sand were sourced from natural materials in France, ensuring consistency in particle size and mechanical properties. The particle size distribution curves for these aggregates are presented in Figure 1 [31]. The absorption coefficients (WA24h), porosity (n), and density of both the sand and gravel are provided in Table 3. Furthermore, the microstructural properties of the aggregates were analyzed using Energy Dispersive X-ray Spectroscopy (EDX), and the results are displayed in Table 4.

These natural aggregates were selected to ensure uniformity in the mix and consistency in particle size distribution. No recycled materials or chemical additives were used in this study, aligning with the research's focus on developing a sustainable, simplified pervious concrete formulation.

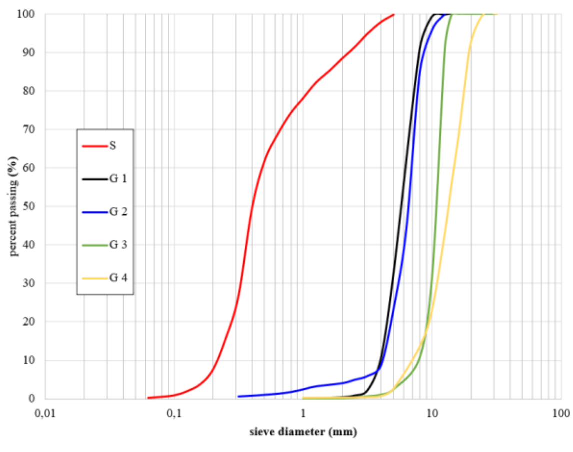

Figure 1. Particle size distributions of aggregates

Table 1. The chemical composition of cement

SiO_2	Al_2O_3	Fe_2O_3	CaOt	MgO	SO_3	K_2O	CaO
19.9	5.1	3.3	64.3	0.9	3.2	0.86	1.9
Phase	-	-	C3S		C3A		C4AF
Proportion (%)	-	-	61.7		8.6		10.8

Table 2. Physical properties of aggregates

Aggregate	Nomenclature	Density (Kg/m^3)	WA 24h (%)	n (%)	Dmax
Sand	S: 0/5	2596	1.07	0.33	5
Gravel 1	G1: 4/8	2375	3.01	2.52	8
Gravel 2	G2: 4/10	2517	0.69	0.52	10
Gravel 3	G3: 4/12.5	2631	1.01	0.44	12.5
Gravel 4	G4: 4/20	2701	0.68	0.51	20

Table 3. The aggregate distribution

Aggregate	Nomenclature	Particle Size (mm)	Image
Sand	S	0/5	Figure 2
Gravel	G1	4/8	Figure 3 (a)
Gravel	G2	4/10	Figure 3 (b)
Gravel	G3	4/12.5	Figure 3 (c)
Gravel	G4	4/20	Figure 3 (d)

Figure 2. Sand used in our study

(a) (b) (c) (d)

Figure 3. Gravels used in our study

Table 4. The Edx analysis for gravels

Aggregate	D_{max}	Fe_2O_3	CaO	K_2O	SO_3	SiO_2	Al_2O_3	MgO
Sand	5	1.89	39.79	0.15	1.51	16.23	2.32	0.81
Gravel 1	8	0.32	0.25	0.09		92.04	1.01	
Gravel 2	10	2.79	14.92	0.48	4.94	68.14	2.4	0.89
Gravel 3	12.5	3.67	19.65	0.35	0.47	78.31	7.21	0.19
Gravel 4	20	2.31	1.1			78.64		0.15

3. EXPERIMENTAL METHOD

The different constituents of the pervious concrete are chosen according to the recommendations of the ACI [6] and the volume dosages of the different constituents are then calculated concerning the Eq. (1):

$$1m^3 = \frac{M_c}{\rho_c} + \frac{M_g}{\rho_g} + \frac{M_s}{\rho_s} + V_w + V_v \quad (1)$$

where, M_c, M_g, and M_s (kg) are the masses of cement, gravel, and sand, respectively ρ_c, ρ_g, and ρ_s (kg/m^3) are their densities. V_w (m^3) is the volume of water, and V_v (m^3/m^3) is the volume of voids. Several formulations are tested (Table 5). The water/cement and sand/gravel ratios were maintained across all formulations. This ensured uniformity in the mixing process while allowing the analysis of cement dosage impact. (*W/C*=0.36, *S/G*=0.07).

The mixing sequence: followed the same procedure for all pervious concrete compositions, ensuring consistency across samples. The concrete was prepared using an electric mixer with a nominal capacity of 65 litres. The following steps outline the precise mixing sequence and durations:

- Initial Mixing: The dry cement and aggregates were added to the mixer and blended for 60 seconds. The water-to-cement (W/C) ratio was kept constant at 0.36 across all formulations, ensuring consistent hydration across the different cement dosages. The sand-to-gravel (S/G) ratio was also kept constant at 0.07, which helped to maintain a stable proportion of fine to coarse aggregates throughout the mix.
- First Water Addition: After the dry materials were mixed, 70% of the total water was added to the mixer, and the mixture was blended for 30 seconds.
- Final Water Addition: The remaining 30% of the water was then added, and the entire mix was blended for another 60 seconds to achieve full hydration and uniform consistency.

Compaction and Vibration: The fresh pervious concrete was poured into cylindrical molds with dimensions of (11×22 cm) Nine samples were prepared for each concrete composition. The concrete was placed into the molds in three layers, and after each layer, the mold was subjected to 5 seconds of vibration using an electric vibrating table to compact the concrete and minimize air voids. After the final layer, the top of the mold was leveled to ensure a consistent initial height of 220 mm. The weight of each sample was measured to ensure consistency in initial porosity. This step ensured uniformity in samples with similar aggregate particle sizes and compositions.

Curing Process: The molds were sealed in plastic bags for 24 hours to prevent moisture loss during the initial curing phase. After demolding, the samples were immersed in water at 25℃ for a period of 28 days to achieve full curing. This curing process was critical for the development of the mechanical and permeability properties of the concrete.

Slump Test: The workability of the pervious concrete was evaluated using an Abrams cone, following EN 12350-6 [32]. The concrete was placed into a truncated cone mold (base diameter: 20 cm, top diameter: 10 cm, height: 30 cm) in three layers, with each layer compacted 25 times using a 16 mm diameter metal rod. The slump was measured by comparing the height of the demolded concrete to the original height of the mold. This method was chosen for its simplicity and effectiveness in providing quick feedback on the workability of the concrete mix, ensuring consistent results across all formulations.

Air Content Test: The air content of the fresh concrete was measured using an 8-liter aerometer, following NF EN 12350-7 [33]. This instrument gave a direct reading of the occluded air content as a percentage. Measuring air content is critical for understanding the workability and permeability of the concrete, as it directly affects the performance of the pervious concrete in its final application.

Compressive Strength Test (fcm): Was tested on cylindrical specimens (11×22 cm) according to EN 12390-3 [34]. A ZWICK press was used, applying a constant loading rate of 0.5 MPa/s. Each specimen was coated with ISO-9001 certified surfacing mortar to ensure accurate test results. Compressive strength is a key indicator of the mechanical performance of concrete, and this method provides a reliable and standardized way to measure it.

Splitting Tensile Strength Test (fct): Was evaluated using the splitting tensile strength test on cylindrical specimens (11×22 cm) in accordance with NF EN 12390-6 [35]. The loading rate was 0.05 MPa/s. This test was chosen because it offers a practical and efficient method for determining tensile strength, avoiding the complexities associated with direct tensile tests, while still providing accurate data on the material's tensile behavior.

Water Permeability Test: Was measured using a custom-designed constant load permeability apparatus [36-38]. Water was introduced at a constant height of 220 mm above the specimen, and the flow rate was measured after 60 seconds. The permeability (K) was calculated using Darcy's law (Eq. (2)). This method was selected because it closely simulates real-world drainage conditions, providing an accurate measure of the concrete's hydrological efficiency. The constant head test was specifically chosen for its ease of execution and reliability in laboratory settings.

$$K = \frac{(V \times L)}{(h \times S \times t)} \quad (2)$$

where, V (mm^3) is the volume of water moving vertically through the cylindrical specimen (11×22 cm); t is the time 60 seconds (t=60); L is the height of the test tube (220 mm); S is the cross-section of the specimen and h (mm) is the constant height of the water (h=220 mm).

Porosity and Density: Porosity and 28-day density were determined according to ASTM C1754/C1754M-12 [39]. Samples were air-dried for 72 hours, then fully saturated in water for 48 hours. The dry weight Asec (kg) and floating weight Bhydro (kg) were measured. Porosity P (%) and density ρ (kg/m³) were calculated using Eqs. (3) and (4) with ρw the density of water at 25℃ being used as a constant. The conversion factor K used was 1,273,240 mm^3/kg according to ASTM C1754/C1754M-12 [39].

$$P = \left(1 - \left(\frac{K(A_{sec} - B_{hydro})}{\rho_w\, d^2\, L}\right)\right)100 \quad (3)$$

$$\rho = \frac{K\, A_{sec}}{d^2\, L} \quad (4)$$

Electrical Resistivity: The electrical resistivity of water-saturated specimens was measured (two-point method) using a resistivity meter. After being soaked for 24 hours, two moistened sponges were placed between the specimens and the meter's plates, and readings were taken after a 5-minute stabilization period. This method was chosen as it provides an indirect measure of pore connectivity.

Table 5. Mixture proportions

Mix	D_{max} (mm)	Cement (Kg/m^3)	Water (Kg/m^3)	Gravel (Kg/m^3)	Sand (Kg/m^3)
PC250D8		250	90	1694.92	118.65
PC275D8		275	99	1668.00	116.76
PC300D8	8	300	108	1641.07	114.88
PC325D8		325	117	1614.14	113.00
PC350D8		350	126	1587.21	111.11
PC250D10		250	90	1719.11	120.34
PC275D10		275	99	1690.67	118.35
PC300D10	10	300	108	1662.24	116.36
PC325D10		325	117	1633.80	114.37
PC350D10		350	126	1605.36	112.38
PC250D12,5		250	90	1668.98	116.83
PC275D12,5		275	99	1627.06	113.89
PC300D12,5	12.5	300	108	1585.13	110.96
PC325D12,5		325	117	1543.21	108.02
PC350D12,5		350	126	1501.29	105.09
PC250D20		250	90	1710.37	119.73
PC275D20		275	99	1667.41	116.72
PC300D20	20	300	108	1624.44	113.71
PC325D20		325	117	1581.48	110.70
PC350D20		350	126	1538.52	107.70

4. RESULTS AND DISCUSSIONS

4.1 Properties at the fresh state

The slump test results in Figure 4 show that workability decreases as both cement dosage and aggregate size (D_{max}) increase. For example, at 250 kg/m³, the slump drops from 18 cm for D8 to 14 cm for D20, while at 350 kg/m³, it falls from 12 cm to 8 cm. This is due to the reduced surface area of larger aggregates, which require less cement paste, and the thicker paste at higher cement dosages, reducing fluidity. These findings align with El-Hassan et al. [40], Mohammed and Al-Mashhadi [41], and Li et al. [42], who also observed reduced workability with larger aggregates and higher cement content. The results highlight the trade-off between workability, compressive strength, and permeability, supporting the study's objectives of optimizing natural aggregate mixes with moderate cement dosages.

Figure 5 shows that occluded air content increases with larger aggregate sizes (D_{max}) and decreases with higher cement dosages. At 250 kg/m³, occluded air rises from 7% for D8 to 14% for D20, while at 350 kg/m³, it ranges from 3% to 14%. Larger aggregates create more voids, trapping air, whereas higher cement content fills these voids, reducing air content. These results align with Li et al. [42] and Mohammed and Al-Mashhadi [41], who also observed increased air content with larger aggregates and lower cement dosages. The balance between air content and other properties, such as strength and workability, is critical for optimizing pervious concrete.

Figure 6 shows a clear relationship between slump and occluded air content, with larger D_{max} values correlating with higher air content and reduced slump. This trend is consistent across all cement dosages, with polynomial trendlines showing high R^2 values above 0.9, indicating strong correlations. For larger aggregates ($D_{max} \geq 10$ mm), occluded air increases with slump, but higher cement dosages reduce both air content and slump by filling voids. Interestingly, the relationship for D8 is more linear, with the effect of cement dosage becoming significant at 250 kg/m³. These results suggest that balancing slump and occluded air is critical for optimizing workability, mechanical strength, and hydraulic efficiency in pervious concrete. This complex interaction aligns with previous studies [41, 43] and underscores the importance of fine-tuning mix design for specific applications.

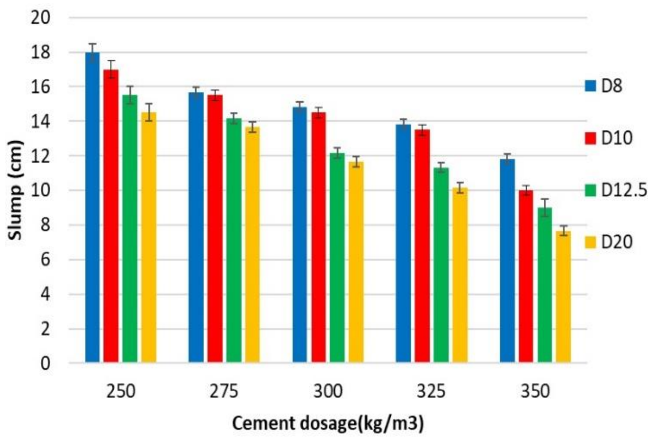

Figure 4. Slump test results for previous concretes

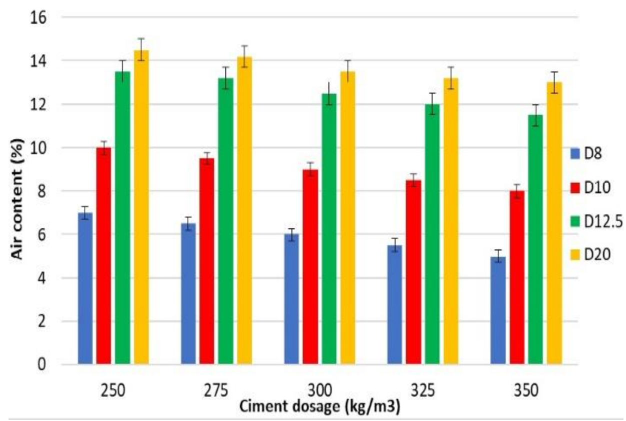

Figure 5. Air contents results for previous concretes

Higher cement dosages reduce both air content and slump, while larger aggregates increase air content but decrease slump. Balancing these factors is key to achieving optimal workability and mechanical performance.

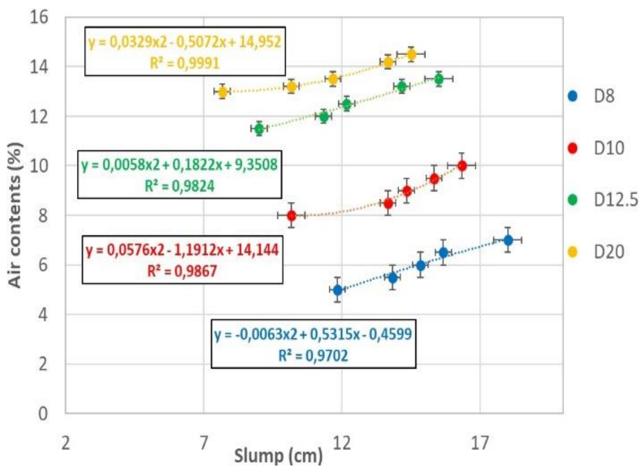

Figure 6. Relation between air contents and slump

4.2 Properties at the hardened state

Figures 7 and 8 show that increasing aggregate size (D_{max}) leads to higher porosity and permeability, while higher cement dosages reduce both properties. For example, at 250 kg/m³, porosity ranges from 25% (D8) to 35% (D20) and permeability from 10 mm/s to 35 mm/s. This trend is due to larger aggregates creating more void spaces, allowing better water flow, while higher cement content fills these voids, restricting flow. These results align with Barreto Sandoval et al. [44], who found that larger aggregates enhance permeability, and Akkaya and Çağatay [45], who observed that increased cement dosage reduces void content. This indicates that optimizing pervious concrete properties requires carefully balancing cement dosage and aggregate size. Larger aggregates improve permeability, making them ideal for drainage applications, but high cement dosages can compromise permeability by filling voids. Future research should explore the use of additives to maintain high permeability without sacrificing strength.

Figure 9 shows a strong linear relationship between porosity and permeability (R^2=0.9791), indicating that higher porosity leads to increased water permeability. This is because larger void spaces between aggregates act as channels for water flow. Larger D_{max} values result in higher porosity and permeability, while increased cement dosage reduces both by filling these voids with additional paste. The correlation confirms that measuring porosity can serve as a reliable predictor for permeability, aiding in the design of effective drainage solutions.

These findings are consistent with previous studies [44, 45], who found similar trends. The results support the study's objective of balancing cement dosage and aggregate size to optimize both hydraulic and mechanical properties. However, the study did not consider chemical admixtures, which could further enhance the mix design. Future research should explore these additives to improve performance under varying environmental conditions.

Higher D_{max} values increase porosity and permeability, while more cement decreases them. The strong correlation between porosity and permeability can be leveraged to design pervious concrete for specific drainage applications.

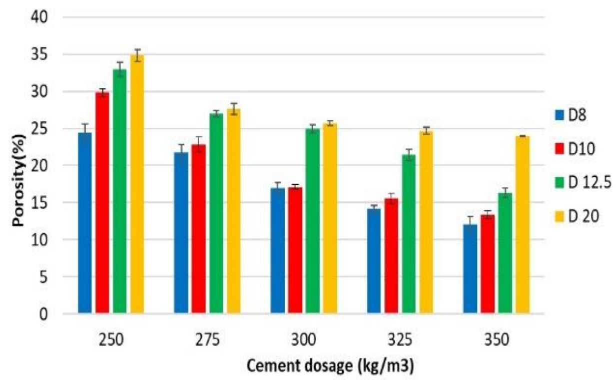

Figure 7. Porosity of pervious concretes

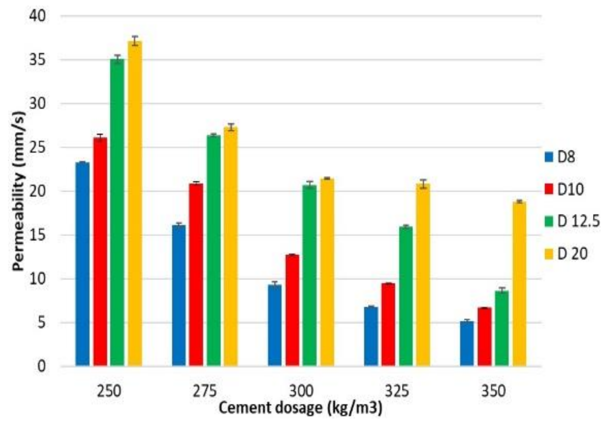

Figure 8. Permeability of pervious concretes

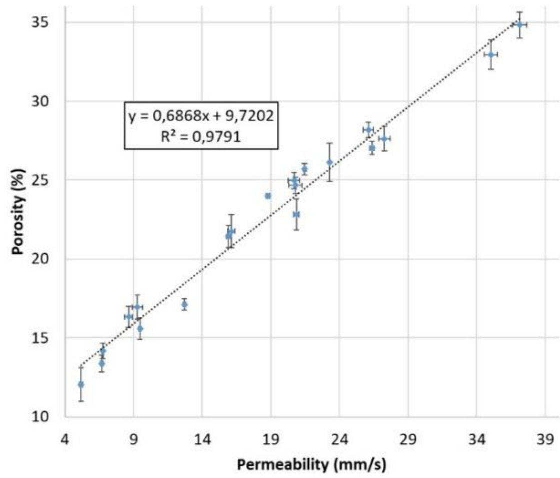

Figure 9. Relation between permeability and porosity of pervious concrete

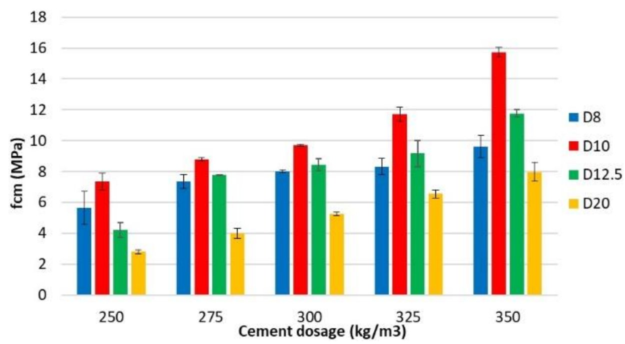

Figure 10. Compressive strengths of pervious concretes

The compressive strength of pervious concrete (as shown in Figure 10) is significantly influenced by both cement dosage and maximum aggregate size (D_{max}). Higher cement dosages enhance strength by increasing matrix density and cohesion, while larger D_{max} values decrease strength due to the increased voids between aggregates. The D10 aggregates provided the highest strength due to better compactness, whereas D8 aggregates showed unexpectedly lower strength, likely due to their higher porosity affecting particle adhesion. The results demonstrate that while increased cement dosage improves strength, it must be balanced against permeability. Larger D_{max} values, although beneficial for permeability, tend to reduce strength. The findings indicate that an optimal mix can be achieved using natural aggregates and moderate cement dosages without additives. These results align with previous studies [42, 46, 47].

The split tensile strength of pervious concrete, shown in Figure 11, follows a pattern similar to compressive strength, with higher cement dosages significantly enhancing strength due to improved matrix cohesion. Larger D_{max} values (10-20 mm) reduce tensile strength due to increased particle size variation, which weakens cohesiveness. Interestingly, pervious concrete with D8 aggregates exhibited lower tensile strength than D10, likely due to higher porosity, which hinders adhesion within the cement matrix. Our split tensile strength values range from 0.33 to 1.47 MPa, consistent with prior studies that reported values between 1 and 3 MPa [44, 45, 12, 17, 48-50]. These results suggest that optimizing tensile strength requires balancing cement dosage and aggregate size. Smaller aggregates (e.g., D10) with higher cement dosages offer better performance, eliminating the need for additives while maintaining mechanical integrity. This supports our aim of achieving high-performing pervious concrete using only natural aggregates and moderate cement content.

The trend curves in Figure 12 demonstrate a significant positive correlation between density and compressive strength for all D_{max} values, with high coefficients of determination ($R^2 > 0.86$), indicating strong predictive power. Higher density promotes better particle compaction and cohesion, leading to increased compressive strength, as seen in pervious concrete with smaller D_{max} values like D8 and D10. This observation is consistent with findings from Huang et al. [20] and Othman et al. [51], who noted that higher density reduces voids and enhances compressive strength in concrete. For smaller aggregates (D8 and D10), the correlation between density and strength is strongest ($R^2 > 0.9$), suggesting that these sizes are optimal for achieving both high strength and good compactness. Larger aggregates (D12.5 and D20), although showing a positive relationship, have slightly lower coefficients of determination, indicating that other factors may also influence compressive strength for these sizes. These results align with Yu et al. [22], who reported that aggregate size affects strength through pore characteristics and paste thickness. Practically, targeting a higher density in the mix design can enhance mechanical performance, especially for applications where high compressive strength is critical.

The analysis in Figure 13 reveals a moderate inverse relationship ($R^2 = 0.64$) between compressive strength and permeability in pervious concrete. While higher compressive strength typically results in lower permeability due to reduced porosity, this relationship is not absolute, as other factors such as aggregate size, mix quality, and compaction also play crucial roles. Larger aggregates and higher porosity increase permeability but reduce compressive strength, as observed in studies by Huang et al. [20] and Yu et al. [22]. These findings suggest that an optimal balance between compressive strength and permeability can be achieved by carefully controlling aggregate size and cement content.

Our study indicates that using D10 aggregates with moderate cement dosage provides the best balance, offering sufficient strength while maintaining adequate permeability. However, further optimization may involve adjusting aggregate grading or incorporating additives to fine-tune the properties. Future work should explore the use of supplementary cementitious materials to further optimize this balance and address any limitations associated with natural aggregates.

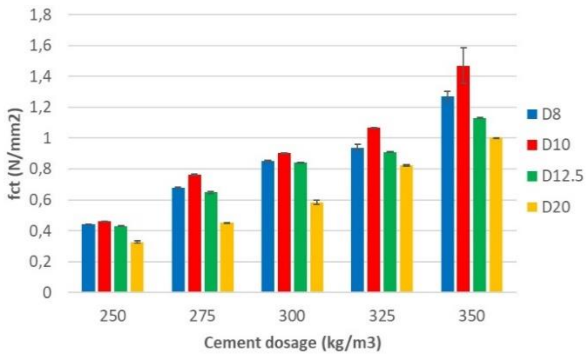

Figure 11. Tensile strength of pervious concretes

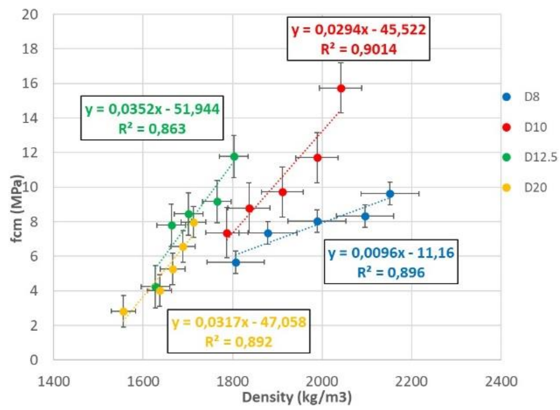

Figure 12. Relation between compressive and density of pervious concretes

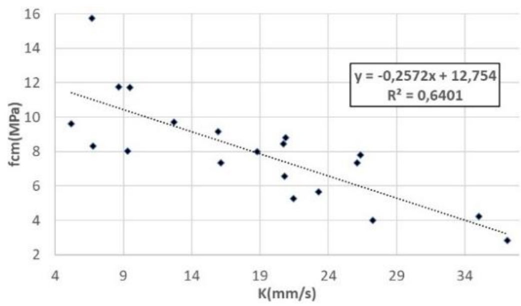

Figure 13. Relations between compressive strengths and permeability of pervious concretes

We conducted electrical resistivity tests across frequencies from 1 to 30 kHz. Notably, we observed that resistivity stabilised beyond 20 kHz, making frequencies above this threshold suitable for accurate analysis. Consequently, we assessed resistivity at 30 kHz for reliable data. Our investigation on the electrical resistivity of pervious concrete revealed significant relationships between cement dosage, aggregate size, and the electrical properties of the material (Figure 14). Electrical resistivity decreased with higher cement dosages, reflecting improved particle cohesion and connectivity within the matrix, which facilitates charge movement. These findings align with Hou et al. [52], who observed a similar trend where increased cement content lowered resistivity due to enhanced inter-particle connectivity and reduced void spaces. The higher resistivity observed with 8 mm aggregates, compared to 10 mm and 12.5 mm, suggests that increased porosity in smaller aggregates creates more barriers for electrical conduction. This highlights the complexity of aggregate effects, as noted by Cleven et al. [53], who also reported increased resistivity with higher aggregate porosity. Our results suggest that the electrical resistivity of pervious concrete can be optimized by balancing cement dosage and aggregate size. Specifically, using D10 aggregates with moderate cement dosage provided the most favorable balance, minimizing resistivity while maintaining mechanical performance.

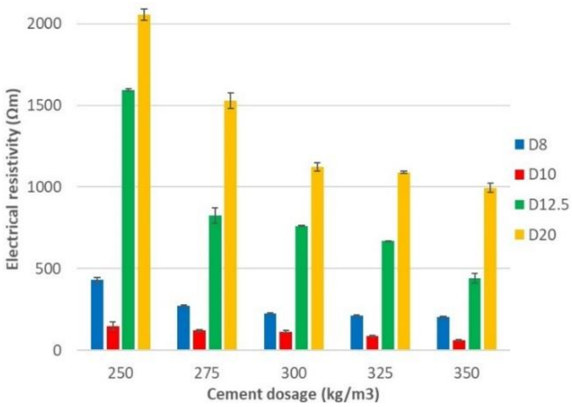

Figure 14. Electrical resistivity of pervious concretes at a frequency of 30khz

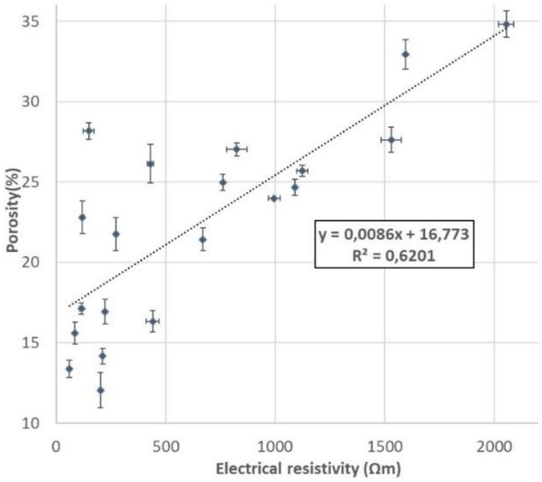

Figure 15. The relation between electrical resistivity and porosity of pervious concretes

The results show a positive linear correlation between electrical resistivity and porosity (Figure 15), meaning that as porosity increases, resistivity also rises. This relationship is influenced by increased air voids, which impede electrical flow. However, factors like aggregate size and pore network tortuosity further complicate this relationship.

While porosity significantly impacts resistivity, achieving a balance between both properties is crucial. Our findings align with those of Huang et al. [20] and Yu et al. [22], confirming that increased porosity generally leads to higher resistivity. To optimize electrical and mechanical performance, a moderate cement dosage combined with smaller aggregates (e.g., D10) appears most effective.

This combination helps maintain adequate compaction and connectivity, providing a balanced formula for pervious concrete applications.

5. CONCLUSIONS

This study explored the impact of aggregate size and cement dosage on the properties of pervious concrete, focusing on the balance between compressive strength, permeability, and electrical resistivity. The findings highlight the following key points:

(1) The ideal formulation involves a cement dosage of 300 kg/m³ and D_{max} of 10 mm. This combination provides high compressive strength (fcm>12 MPa) and satisfactory permeability, while maintaining adequate durability indicated by moderate electrical resistivity. This configuration achieves a balance between mechanical performance and drainage efficiency.

(2) Smaller aggregate sizes (D8 and D10) improve compressive strength due to better compaction and particle cohesion. Larger aggregates (D20) increase permeability but reduce strength, making them less suitable for structural applications.

(3) Higher cement dosages improve cohesion and strength but reduce permeability. Moderate dosages (300 kg/m³) are sufficient to achieve a balance, meeting mechanical and hydrological requirements without the need for additives.

(4) Higher porosity correlates strongly with increased permeability, facilitating water drainage. However, excessive porosity diminishes mechanical strength, emphasizing the need for careful mix proportioning.

(5) Smaller aggregate sizes and higher cement dosages decrease resistivity, enhancing durability. However, higher porosity in 8 mm aggregates leads to increased resistivity, suggesting that these mixes may be more susceptible to degradation over time.

The findings support the research objectives by demonstrating that a high-performing mix can be achieved using only natural aggregates and moderate cement dosages.

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NOMENCLATURE

PC	Pervious concrete
D_{max}	The maximum aggregate size
EDX	Energy Dispersive X-ray Spectroscopy thermal conductivity
fcm	Compressive Strengths
fct	Tensile strength