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Enhancing Urban Runoff Quality with Iron Slag-Modified Pervious Concrete: A Study on Mechanical Properties and Pollutant Removal Efficiency

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ABSTRACT: This study explores the improvement of the performance of pervious concrete (PC) for enhancing urban runoff quality by incorporating fine-grained iron slag in varying proportions, from 0% to 15% of the coarse aggregate weight. The research addresses the pressing challenges of stormwater management in urban areas, where impervious surfaces contribute significantly to increased runoff and water pollution. To tackle these issues, the study aims to optimize PC composition. Mechanical and physical properties, including compressive strength, hydraulic conductivity, and void content, were assessed. The top-performing mixes were further evaluated for their ability to improve runoff quality using a rainfall simulator and PC slabs measuring 650×450×100 mm. Initial findings showed a positive relationship between higher iron slag content and increased compressive strength, with gains of up to 13%. However, this improvement came with reduced porosity and permeability as iron slag content increased. Notably, the sample with 15% iron slag demonstrated high pollutant removal efficiencies: 42.7% for chemical oxygen demand (COD), 43.68% for total suspended solids (TSS), and 33.95% for turbidity, due to the dual effects of pore filling and contaminant adsorption by the iron slag. No significant changes were observed in NaCl and electrical conductivity (EC) levels. This study highlights the potential of optimizing iron slag content in PC to enhance its role in urban runoff management, presenting a promising approach for improving water quality in urban settings.

KEYWORDS: Pervious concrete; iron slag; stormwater management; stormwater treatment

1. Introduction

The rapid urbanization in recent decades has led to the continuous spread of impermeable surfaces, which has decreased rainwater infiltration and increased urban runoff. This shift, as evidenced by various studies [1–3], has had a significant impact on the water environment and has posed risks to human health. Effective stormwater management is essential for mitigating the adverse effects of urban runoff on the environment and public health. By controlling the volume and quality of runoff, stormwater management practices help prevent flooding, reduce the transport of pollutants into water bodies, and promote groundwater recharge. Urban runoff, which is heavily influenced by human activities, transports pollutants such as heavy metals, nutrients, and organic substances [4–6]. As a result, the discharge of polluted runoff can have serious consequences for regional water environments and can hinder the socio-economic development of affected areas [2, 7]. Therefore, researching the management of urban runoff pollution is vital for controlling regional water contamination and enhancing water quality.

Urban planners and developers have traditionally relied on detention and retention basins, such as swales, bio-retention basins, settlement ponds, and wetlands, to improve stormwater quality. However, the water collected in these basins requires engineered treatment before it can be released into natural water bodies, making stormwater management economically inefficient [8–9]. Many of these methods involve open water storage, which can present drowning risks and become breeding sites for pests. During dry periods, stagnant water in these ponds can become anaerobic, leading to unpleasant odors [8, 10]. Additionally, groundwater recharge is limited to areas where these basins are built, resulting in uneven distribution. These structures also demand significant land use, which is impractical in densely urbanized areas [10]. Therefore, in such environments, treatment systems that require minimal water storage, facilitate groundwater recharge, and do not occupy additional land are preferable.

Permeable pavement (PP) systems are widely recognized as effective Low-Impact Development (LID) solutions to address urbanization challenges. By mimicking natural hydrology, they reduce runoff, prevent flooding, recharge groundwater, and ease the strain on conventional stormwater infrastructure, contributing to sustainable urban water management and climate resilience [11–13]. These systems are distinguished by their unique design, which incorporates minimal or no fine aggregates, resulting in a porous structure with interconnected voids. This design enables PPs to mimic natural ground conditions by allowing rainwater, air, and other fluids to infiltrate directly through the surface [14–16]. By facilitating water infiltration, PPs help mitigate surface runoff, enhance groundwater recharge, and improve urban water management; however, the clogging of PC systems should be taken into consideration, and proper maintenance should be provided [17]. Despite these advantages, there is a gap in understanding how to enhance the long-term performance of PC systems, particularly concerning pollutant removal and the effects of various aggregate substitutions. This study attempts to address this gap by incorporating fine-grained iron slag into PC mixtures to improve mechanical properties and pollutant retention, enhancing stormwater management while maintaining adequate permeability.

As a sustainable pavement solution, PPs contribute to creating resilient urban environments capable of addressing the challenges of urbanization and climate change [18]. PP surfaces can be categorized into three types: Pervious Concrete Pavement (PCP), Permeable Interlocking Concrete Pavement (PICP), and Pervious Asphalt Pavement (PAP). Among the latest advancements in permeable pavement technology, PurePave stands out as a cutting-edge system that overcomes many limitations of traditional PPs. Engineered with a proprietary resin binder and high-quality aggregates, PurePave offers exceptional strength, durability, and permeability, making it suitable for a wide range of applications beyond light-traffic areas [19]. The structure of PPs typically consists of a porous surface layer, a subbase made of coarse aggregate, often clear stone type 2, and a layer of geotextile or geogrid, depending on the project's specific requirements, as illustrated in Figure 1. Additionally, the design may include an underdrain system to manage water flow or rely solely on natural infiltration. This layered configuration ensures effective water infiltration, load distribution, and long-term performance. Apart from this, PP systems must demonstrate durability, particularly in frost resistance and cold climates. PurePave technology addresses this need by offering a permeable paving solution with exceptional freeze-thaw resistance, capable of withstanding temperature fluctuations from -40°C to +30°C without any loss in weight or flexural strength [19].

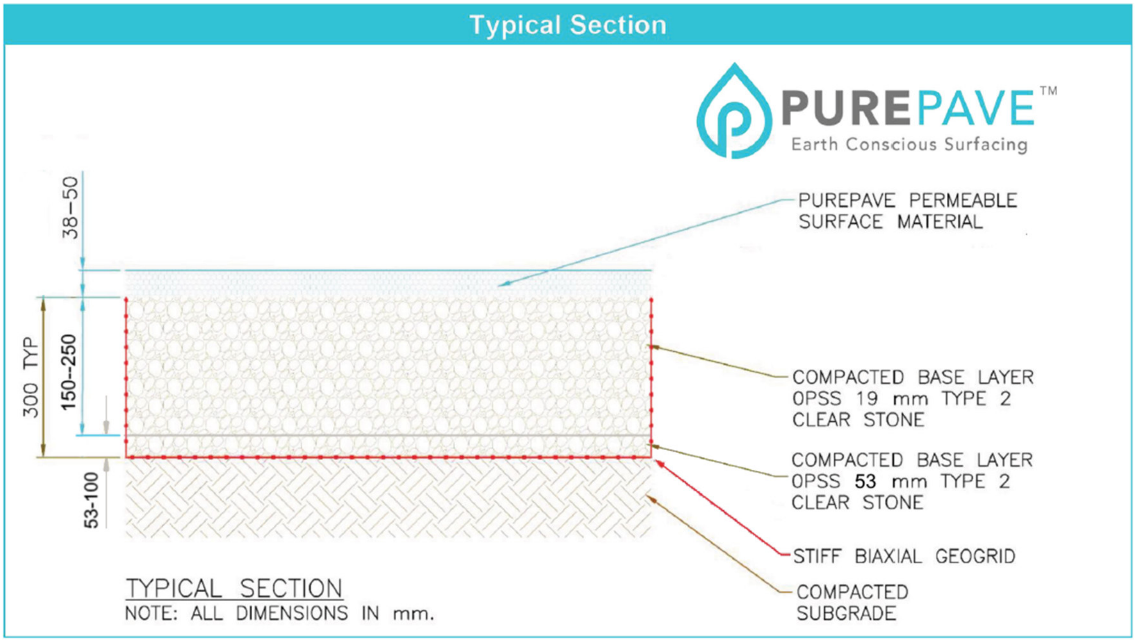

Figure 1. Typical structure of PPs (PurePave Technology Inc.)

Considering PC for paving surfaces, the main advantages of PC systems lie in their absence of open water storage and the elimination of the need for additional land acquisition. By utilizing PC, it becomes possible to attenuate runoff and reduce pollutant concentrations while simultaneously allowing the captured water to infiltrate the ground [20]. Chemical and physical reactions between the PC and microorganisms within its pores facilitate the removal of pollutants from stormwater and even wastewater [21]. A recent study highlights the effectiveness of permeable pavement systems (PPS) as a sustainable solution for managing stormwater runoff from roads and highways. The research demonstrates that PPS not only reduces runoff volumes but also enhances groundwater recharge and pollutant retention, significantly improving stormwater quality. Additionally, PPS mitigates urban heat island effects by minimizing heat absorption and promoting cooling, offering both environmental and financial benefits. These findings underscore the critical role of PPS in creating eco-friendly urban environments and advancing sustainable drainage systems (SuDS).

The incorporation of adsorbent materials in PCP can enhance the performance of urban runoff systems, as indicated by research [21, 22]. For example, iron slag and zeolite, which are abundant mineral and industrial waste adsorbents, have shown promising performance in terms of both engineering properties and positive environmental aspects [21]. Iron slag, previously considered a waste material from iron factories, now has diverse applications, such as producing heavyweight concrete for shielding and storing radioactive sources, as well as being used in water and wastewater treatment, road construction as filler materials, and phosphatic fertilizer. Iron slag possesses porous surfaces and structures that enable it to adsorb contaminants in water and wastewater. Previous studies have utilized iron slag for the adsorption of lead, nickel, dye, and phosphorus [23–24]. Koupai et al. reported that the use of 15% fine-grained iron slag (0.6–2.0 mm) in PC mixtures led to improvements in compressive strength (16.12%), flexural strength (10.28%), splitting tensile strength (9.23%), reduced porosity (15.29%) and permeability (16.19%), and enhanced chemical oxygen demand (COD), total suspended solids (TSS), and turbidity reduction by 69.75%, 68%, and 69%, respectively, in urban runoff [25]. Moreover, incorporating iron slag into PC, along with a sand filter, resulted in a 42% reduction in lead concentration in stormwater. Teymouri et al. replaced the coarse aggregate of PC with the same size of iron slag in portions of 0–100%. The results indicated an improvement in the mechanical and physical properties of iron slag pervious concrete. Meanwhile, the use of natural zeolite as an adsorbent material in pervious concrete has demonstrated its effectiveness in applications such as soil improvement for water and nutrient retention, as well as water and wastewater treatment. Zeolite has been shown to significantly reduce water pollutants like heavy metals, with reported reductions of 99% in Zn, Cu, Cd, and Pb content in the runoff [9]. Additionally, zeolite can increase the adsorption capacity of concrete by 40% [24]. By replacing the coarse aggregate of PC with coarse adsorbents, it is possible to avoid the loss of porosity and permeability and enhance APC's ability to reduce impurities in stormwater and wastewater. This study aims to enhance the performance of pervious concrete (PC) in improving urban runoff quality by incorporating fine-grained iron slag as a partial replacement for coarse aggregate. Specifically, the objectives are to evaluate the effects of varying proportions of fine-grained iron slag (0–15% by weight of coarse aggregate) on the mechanical properties of PC, including unconfined compressive strength, hydraulic conductivity, and porosity. The study seeks to determine the optimal percentage of iron slag that balances improved mechanical performance with adequate permeability for effective stormwater management. Furthermore, the optimized PC mixtures will be tested for their ability to improve urban runoff quality by analyzing reductions in pollutants such as TSS, COD, total dissolved solids (TDS), NaCl, and electrical conductivity (EC) using a simulated rainfall setup. This research provides an innovative approach to enhancing the engineering and environmental performance of PC systems for sustainable urban stormwater management.

2. Experimental Program

2.1. Materials and mixing.

This research employed Portland Cement Type II, adhering to ASTM C150 standards [26]. The coarse aggregate used was crushed limestone, with sizes ranging from 4.75 to 9.5 mm, conforming to ASTM C33 specifications [27]. Figure 2A shows the grading of the coarse aggregate alongside ASTM C33 limits [27]. The study also utilized iron slag aggregate, depicted in Figure 2(b), with its Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) results presented in Figure 2(c) and Table 1. Due to its porous structure, iron slag significantly enhances the microstructure of pervious concrete (PC). Compared to typical limestone aggregates, iron slag's porous nature provides a larger surface area for capturing pollutants, improving the material's ability to adsorb contaminants from stormwater. Additionally, the porous structure of iron slag facilitates better bonding between the cement paste and the aggregate, enhancing the overall mechanical properties of the PC. The iron slag’s water absorption and specific gravity were 1.89% and 1785 kg/m³, respectively, consistent with previous studies [28]. The particle size of the iron slag ranged from 1 to 2 mm, with its grain size distribution shown in Figure 2A.

A basic mix design was chosen for creating PC samples, following the ACI 211.3R [29] guidelines. The aggregate and cement contents were set at 1600 and 315 kg/m³, respectively, with a water-to-cement ratio (W/C) of 0.30 for all samples. The study included treatments with four levels of iron slag content (0%, 7.5%, and 15% by weight) added to the mix. Each treatment was replicated three times. Table 2 details the mixing plan for the PC incorporated with iron slag.

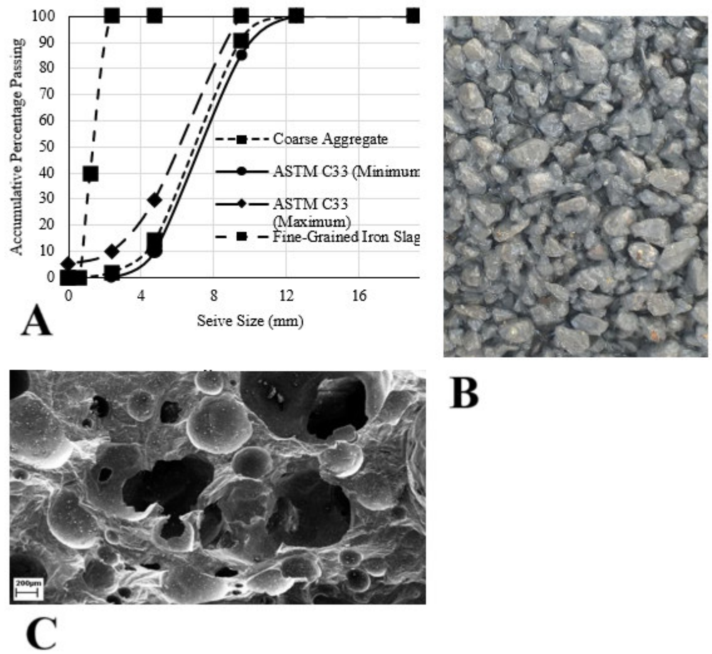

Figure 2. (A) Grain size distribution of coarse aggregate and iron slag, (B) Fine-grained iron slag, (C) SEM image of iron slag.

Table 1. EDS results of iron slag.

Element	Weight%	Atomic%
O	40.69	68.47
Mg	3.97	3.76
Al	7.27	6.19
Si	4.72	3.86
Ca	16.20	9.29
Ti	2.33	1.12
Fe	24.81	7.33
Totals	100.00	

Table 2. Mix design of pervious concrete containing iron slag.

Mix code	Cement content (kg/m³)	Water content (kg/m³)	Iron slag content (kg)	Aggregate content (kg/m³)
IP0	315	94.5	0.00	1600
IP7.5	315	94.5	120	1600
IP15	315	94.5	240	1600

2.2. Methods of testing.

The dry components, including coarse aggregate, cement, and iron slag, were weighed using a digital scale before being mixed in a Hobart mixer for one minute. Water was then added to the mix, and the wet mixing continued for another three minutes. Before pouring the fresh APC into molds, slump and fresh density were measured according to ASTM C143 [30] and ASTM C1688 [31], respectively. The compressive strength test was performed according to BS1881 [32] with 150 × 150 × 150 mm cube samples after 28 days of proper curing. To evaluate the physical properties of samples, porosity and permeability tests were performed. The porosity of samples was determined using equation (1) following the ASTM C1754 [33] standard. This test is based on Archimedes' principle of buoyancy, utilizing the dry and immersed weights of the samples.

$$A_t = \left(1 - \left(\frac{W_2 - W_1}{\rho_w V}\right)\right) \times 100 \quad (1)$$

In this equation, At is the porosity (%), V is the sample volume (cm^2),ρw is the density of water (g/cm^3), W_2 is the sample dry weight (g), and W_1 is the sample weight in water (g).

A falling-head apparatus, measuring 10.1×10.1×70 cm and made of plexiglass was designed to measure samples' permeability. A similar device is referenced in the ACI 522R standard [34]. The system comprises a 20 cm layer of coarse gravel at the bottom, the PC sample (tightly sealed against the walls), and a 50 cm water head above the sample. The permeability (hydraulic conductivity) of each sample was calculated by using equation (2), which is based on Darcy's Law. The average result of three tests on 10×10×10 cm cubic samples is reported for each treatment.

$$K = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right) \quad (2)$$

Where a is the cross-sectional area of the device in mm^2, l is the length of the PC specimen in mm, A is the cross-sectional area of the PC specimen in mm^2, t is the time elapsed in sec, h_1 is the initial head of water in mm, and h_2 is the final head of water in mm.

To evaluate the effect of PC incorporating iron slag on reducing urban runoff contaminations, it was attempted to simulate the rainfall on the surface of samples. For this purpose, a simple rainfall simulator was designed and built. This device has iron plates on three sides and a transparent side made of glass to monitor the process of experiments. The samples were mixed according to the regulations of ACI 211/3R [29]. The sizes of slabs were 650×450×100 mm which could simulate the actual situation of pervious pavement. The polluted runoff was collected from the street after rainfall, and its quality parameters include COD, TSS, EC, NaCl, and turbidity with a concentration of 305 mg/L, 641 mg/l, 6.42 ds/m, 11.8%, and 268 NTU, respectively. To conduct the experiments, each slab was placed into the device and then a grid screen with a considerable number of small holes (to simulate the condition of rainfall) was placed above it. About 10 liters of contaminated runoff was used for each test and it was poured over the upper grid screen. In this situation, the contaminated runoff falls on the surface of pervious concrete like rainfall and after passing through the pervious concrete, they were collected for evaluating quality parameters via the bottom drainage valve (Sampling hole). The process of the experiments is illustrated in Figure 3.

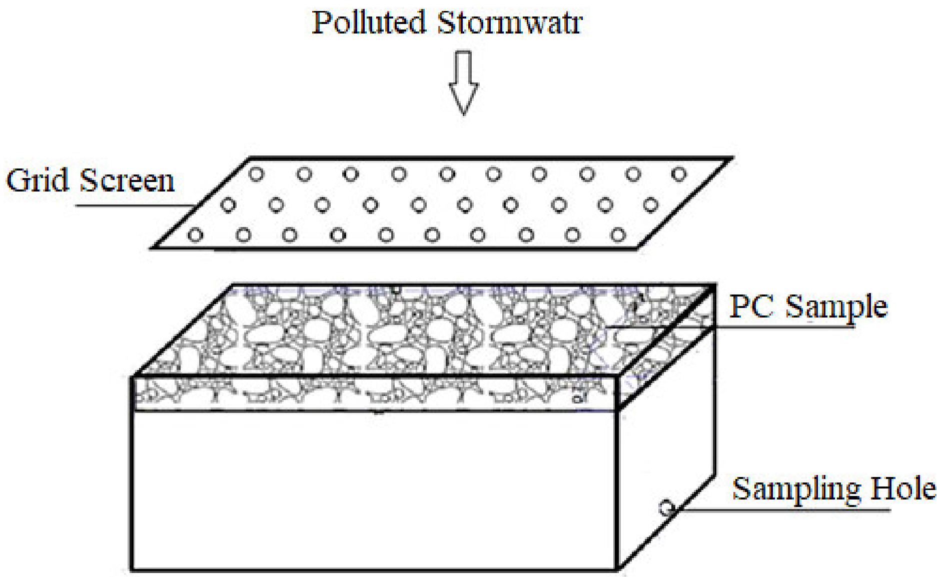

Figure 3. Experimental setup of the rainfall simulator used to assess the impact of PC including iron slag on urban runoff contamination.

3. Results and Discussion

3.1. Slump and fresh density.

Table 3 shows the slump and fresh density results for various pervious concrete (PC) samples incorporating different proportions of iron slag. The IP0 sample, representing the control mix with no iron slag, exhibited a slump of 165 mm, indicating moderate workability suitable for applications requiring manageable placement and compaction. As the iron slag content in the mixture increased, no significant change in slump was observed for additions up to 7.5%. This suggests that the introduction of small amounts of iron slag does not drastically alter the consistency or workability of the mix. However, when the iron slag content was increased to 15%, a notable decrease in slump was recorded. This reduction is likely due to the angular and rough texture of the iron slag particles, which can increase internal friction within the mixture, thereby reducing its flowability.

The fresh density of the PC samples exhibited a clear trend of increasing with the addition of iron slag. This behavior can be attributed to the higher specific gravity of iron slag compared to traditional aggregates. For instance, adding 7.5% iron slag to the mixture resulted in an approximate 4% increase in fresh density. This increase highlights the significant contribution of the heavy iron slag particles to the overall density of the mix. Consequently, mixtures with higher iron slag content are expected to have greater material weight per unit volume, which could impact their mechanical properties and performance in specific applications.

Table 3. Slump and fresh density of PC samples containing iron slag.

Sample code	Slump (mm)	Fresh density (g/cm^3)
IP0	165	1.925
IP7.5	160	2.032
IP15	125	2.141

3.2. Compressive strength.

One of the critical characteristics of pervious concrete (PC) is compressive strength, which plays a key role in determining its structural performance. Compressive strength in PC typically ranges from 3 MPa to 28 MPa, depending on the mixture composition and compaction methods used [6, 34–36]. Based on the ANOVA analysis (one-factor method), with $F(1,1) = 94.11$, $P = 0.0002$, and $R^2 = 0.949$, adding iron slag to PC significantly affected the compressive strength, as indicated by the high F-value and model significance. Adding 15% iron slag resulted in an approximately 13% increase in compressive strength. Figure 4 illustrates the compressive strength of the PC samples at 28 days of curing. Proper curing ensures adequate hydration and enhances the overall performance of the concrete. As shown in the figure, increasing the proportion of iron slag in the mix leads to a noticeable improvement in compressive strength. This can be attributed to the fine-grained nature of iron slag, which acts as a filler material within the concrete matrix. By occupying void spaces and reducing the size and number of pores, iron slag promotes the formation of a denser and more uniform paste structure [13]. This denser structure contributes to improved load-bearing capacity and resistance to compressive forces.

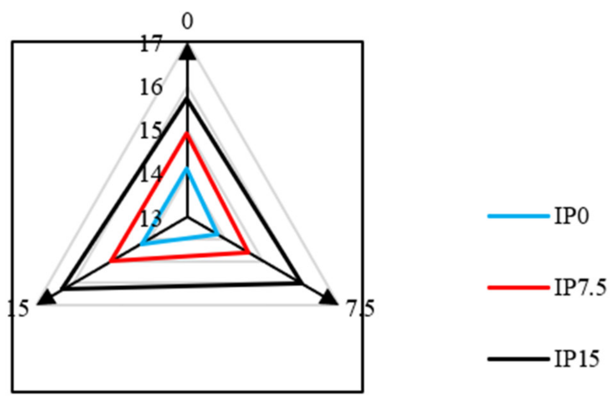

Figure 4. Effect of iron slag potion on the compressive strength of PC.

Table 4. ANOVA analysis of variance for porosity.

Source	Sum of Square	DF	Mean Square	F Value	Prob>F
Model	4.84	1	4.84	94.11	0.0002*
Iron Slag Portion	4.84	1	4.84	94.11	0.0002
Residual	0.26	5	0.051		
Lack of Fit	0.080	1	0.080	1.82	0.2484**
Pure Error	0.18	4	0.044		
Cor Total	5.10	6			

* Significant ** Not Significant Std. Dev.=0.23 C.V.%=1.52 R^2=0.9496 Adj R^2=0.9395

3.3. Porosity and permeability.

The average porosity of the control PC sample (IP0) was approximately 24%, which falls within the typical range for PC. However, as the proportion of iron slag increased in the mix, a significant reduction in porosity was observed, with the average porosity decreasing to about 15% in the sample containing 15% iron slag (IP15). This reduction reflects the effect of fine-grained iron slag filling the void spaces in the PC structure, effectively reducing the number and size of pores. Figure 5a illustrates this trend, showing the inverse relationship between iron slag content and porosity in the samples.

Similarly, the permeability of the PC samples decreased as the iron slag content increased. The average permeability values were 1.38 mm/s, 1.29 mm/s, and 1.15 mm/s for IP0, IP7.5, and IP15, respectively. The reduced porous structure caused by the addition of fine iron slag accounts for this decline, as fewer and smaller pores allow less water to pass through the concrete matrix. Based on the ANOVA analysis ($F(1,1) = 225.52$, $P < 0.0001$, $R^2 = 0.978$), the presence of iron slag significantly impacts the permeability of PC samples, as indicated by the high F-value and model significance. Figure 5b depicts the effect of varying iron slag proportions on the permeability of PC samples. Adding 15% iron slag resulted in a 15% decrease in permeability, while the reduction in porosity at the same iron slag content was about 40%. This indicates that although porosity and permeability follow the same trend as the mix design changes, their rates of change are not identical [3].

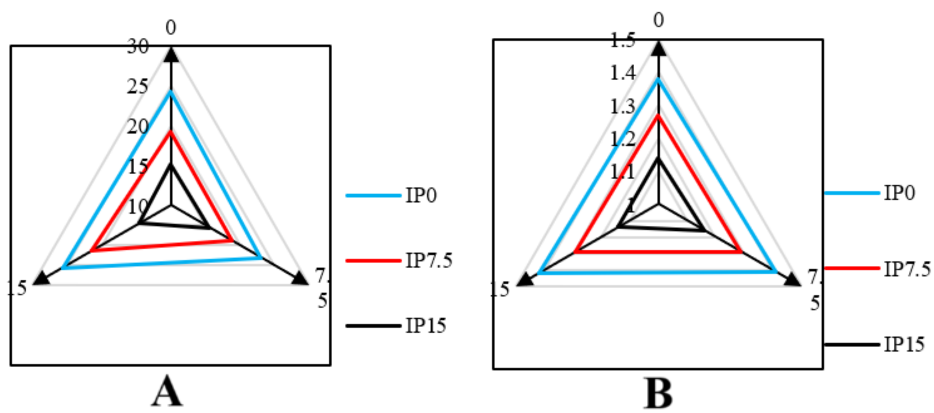

Figure 5. Effect of iron slag portion on the porosity (A) and permeability (B) of PC.

3.4. Urban runoff contamination removal.

As urban runoff infiltrates through pervious concrete, it naturally filters out various pollutants. The impact of pervious concrete slabs incorporating fine aggregate iron slag on COD, TSS, EC, NaCl, and turbidity was examined.

3.4.1. Removal of organic matter and suspended solids.

Figure 6 illustrates the changes in COD and TSS concentrations in rainfall after passing through different PC slabs containing iron slag. The initial COD and TSS concentrations were 325 mg/l and 641 mg/l, respectively. The addition of iron slag significantly enhanced the removal of these pollutants. While the control sample without iron slag achieved modest removal rates of 10.7% for COD and 21.68% for TSS, the inclusion of iron slag substantially improved performance. The slab with the highest iron slag content (IP15) achieved removal efficiencies of 42.7% for COD and 43.68% for TSS. This improvement is primarily due to reduced porosity and the adsorption properties of iron slag. The lower porosity creates a more effective filtration medium for capturing suspended solids, while the inherent adsorption capacity of iron slag contributes to the removal of organic matter and particulates. PC were used for contamination removal in past studies as well. Faisal et al. reported that a control sample of PC achieved a 54% reduction in COD [37]. Additionally, Teymouri et al. investigated various adsorbents, including zeolite, lignite, LECA, perlite, and pumice, demonstrating that incorporating these materials into the PC mixture can effectively reduce COD by 27% to 50% and TSS by 17% to 45% [38].

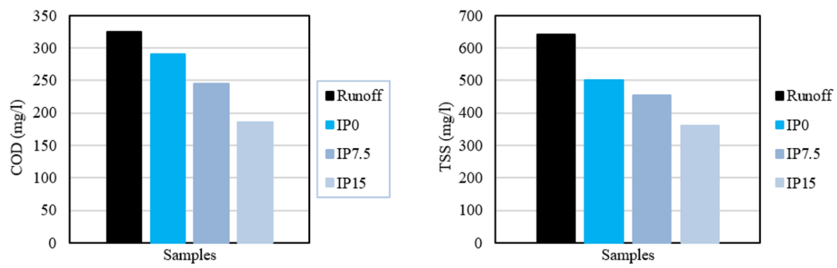

Figure 6. COD and TSS reduction in rainfall through iron slag-enhanced PC slabs.

3.4.2. Turbidity, EC, and NaCl reduction.

Turbidity, a key indicator of water quality, reflects the cloudiness or haziness of a fluid caused by numerous fine particles that are not visible to the naked eye. Elevated turbidity often signals the presence of pollutants such as sediments, organic matter, and microorganisms, which can harm aquatic ecosystems and degrade water quality [39]. Incorporating iron slag into PC has been shown to significantly improve its ability to reduce turbidity in stormwater runoff, achieving a 33.95% reduction compared to 13.8% with standard PC, as shown in Figure 7. This improvement is attributed to enhanced filtration due to changes in pore structure, the adsorptive properties of iron slag capturing fine particles, and possible chemical interactions that promote particle agglomeration, which aligns with findings by Teymouri et al. [40]. These results underscore the potential of iron slag-enhanced PC to improve water quality, support aquatic health, and promote sustainable construction through the reuse of industrial byproducts. Figure 7 also illustrates the changes in NaCl and EC levels in rainfall after passing through PC samples incorporating iron slag. Interestingly, the addition of iron slag did not significantly impact the removal of NaCl or affect the EC of the treated runoff. This observation is consistent with previous research suggesting that pervious concrete, regardless of composition or thickness, has a limited capacity (around 10%) to reduce stormwater salinity [25, 41–42].

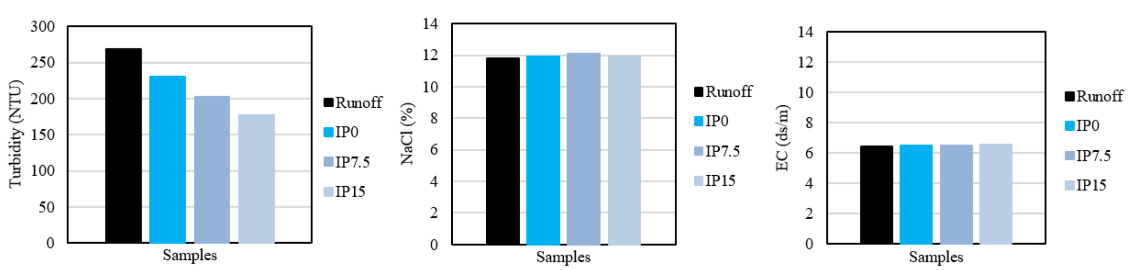

Figure 7. Turbidity, EC, and NaCl changes of rainfall after passing PC containing iron slag slabs

3.5. Maintenance approach to prevent clogging.

Clogging can occur in PC over time as contaminants such as sediments, debris, and organic matter accumulate on the surface, leading to the obstruction of the pavement's pores. This blockage reduces the infiltration capacity of the pavement, hindering its ability to effectively manage stormwater [17]. To mitigate this issue, regular maintenance is essential. Effective methods include vacuum sweeping, pressure washing, and a combination of both. Vacuum sweeping uses suction to remove surface debris and reopen clogged pores, while pressure washing employs high-pressure water to dislodge and relocate contaminants. Studies have shown that vacuum sweeping is effective for surface-level clogs, and when combined with pressure washing, it can address more severe blockages. Researchers recommend performing 2 to 5 maintenance sessions annually to maintain long-term functionality and prevent the loss of infiltration capacity [43].

4. Conclusions

This study highlights the significant potential of incorporating fine-grained iron slag into pervious concrete (PC) slabs to enhance their performance in managing urban runoff and improving water quality. By systematically varying the iron slag content (0%, 7.5%, and 15%), the research demonstrated that the mechanical and physical properties of PC, such as compressive strength, porosity, and permeability, are strongly influenced by the addition of iron slag. Specifically, the inclusion of iron slag resulted in up to a 13% increase in compressive strength, making the material more robust while simultaneously reducing porosity and permeability. These changes in material properties enhanced the filtration efficiency of the PC slabs, leading to improved removal of key pollutants, such as COD, TSS, and turbidity, from urban runoff. The IP15 mix, containing 15% iron slag, achieved the highest removal efficiencies, showcasing its dual role in improving PC performance: reducing pore size to enhance filtration and leveraging the adsorptive properties of iron slag to capture fine contaminants. This indicates the suitability of iron slag-enhanced PC for applications where both structural performance and pollutant removal are critical. However, the study also found that the incorporation of iron slag had a limited effect on reducing salinity-related parameters, such as NaCl and EC, consistent with the known limitations of pervious concrete in mitigating stormwater salinity. In addition to its functional benefits, the use of iron slag as an industrial byproduct promotes sustainability by recycling waste materials, aligning with global efforts to reduce environmental footprints in construction. The findings suggest that optimizing iron slag content in PC not only improves urban runoff management but also offers an innovative, eco-friendly solution to addressing water quality challenges in urban environments. Future studies could explore the long-term durability of iron slag-enhanced PC under real-world conditions and its effectiveness in mitigating a broader range of pollutants, further advancing its potential as a sustainable urban water management tool.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution:

Ehsan Teymouri: Conceptualization, Experiments, Formal Analysis, Methodology, Investigation, Resources, Supervision, Writing – Original Draft, Visualization, Validation; Taylor Davis: Conceptualization, Investigation, Writing – Review & Editing, Validation.

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