



(REVIEW ARTICLE)



Review on sustainable pervious concrete and its hydrological performance analysis

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International Journal of Science and Research Archive, 2026, 19(01), 202-207

Publication history: Received on 24 February 2026; revised on 04 April 2026; accepted on 06 April 2026

Article DOI: <https://doi.org/10.30574/ijrsra.2026.19.1.0709>

Abstract

Pervious pavement is an eco-friendly and sustainable pavement system that allows rainwater to infiltrate through interconnected voids in the concrete, thereby reducing surface runoff, minimizing waterlogging, and enhancing groundwater recharge. This project focuses on the development and performance evaluation of pervious concrete incorporating recycled aggregate, silica fume, and polypropylene glass (PP) fibre as a sustainable alternative for pavement construction. The main objective of the study is to investigate the suitability of these materials in improving the mechanical and functional properties of pervious concrete while promoting environmental sustainability through the reuse of construction materials. In this study, pervious concrete specimens were prepared using cement, recycled coarse aggregate, silica fume as a partial supplementary cementitious material, and polypropylene glass fibre in selected proportions. The specimens were cast and cured under standard conditions, and tests such as compressive strength test, split tensile strength test, and permeability test were conducted to evaluate their performance. The use of recycled aggregate helps in reducing the consumption of natural resources and supports waste management, while silica fume contributes to improved bonding and strength characteristics. The incorporation of Polypropylene glass fibre enhances crack resistance and improves the overall durability of the concrete. The experimental results indicate that the developed pervious concrete provides adequate strength along with effective water infiltration capacity.

Keywords: Previous pavement; Recycled aggregate; Silica fume; polypropylene glass fibre; Infiltration capacity

1. Introduction

Rapid urbanization and the extensive use of impervious pavements have resulted in increased stormwater runoff, urban flooding, and depletion of groundwater resources. Conventional concrete pavements prevent natural infiltration of rainwater, leading to environmental and hydrological issues. Pervious concrete has emerged as an effective and sustainable pavement material due to its interconnected void structure, which allows rainwater to percolate through the pavement and recharge groundwater.

In this project, pervious pavement has emerged as an eco-friendly solution that supports sustainable stormwater management while also contributing to environmental protection and improved pavement performance. The performance of pervious pavement is enhanced by incorporating silica fume, recycled aggregate, and polypropylene glass fibre as sustainable and performance-improving materials. Silica fume is used as a supplementary cementitious material to improve the bonding between cement particles, increase strength, reduce permeability of the cement paste, and enhance the overall durability of the concrete matrix. Recycled aggregate, obtained from construction and demolition waste, is introduced as a partial replacement for natural coarse aggregate in order to reduce the consumption of virgin materials, promote waste reutilization, and support sustainable construction practices. At the same time, the use of recycled aggregate helps in lowering environmental impact and construction waste disposal problems, making the pavement system more resource-efficient and economical.

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Additionally, polypropylene glass fibre is added to improve the mechanical behavior of pervious concrete by enhancing crack resistance, reducing brittleness, and increasing toughness and structural integrity. Since pervious concrete generally has lower strength compared to conventional concrete due to its high void content, the inclusion of PP fibre helps in controlling microcracks and improving resistance to shrinkage and stress concentration. Therefore, this study focuses on developing a more sustainable and durable pervious pavement by combining the drainage advantages of pervious concrete with the strength enhancement of silica fume, the environmental benefits of recycled aggregate, and the crack control capacity of PP fibre. The overall aim is to produce an efficient pavement material that satisfies both functional and environmental requirements for modern infrastructure applications.

2. Literature review

Concrete pavements often suffer from cracking and low tensile strength, which limits their long-term performance and durability. To overcome these issues, researchers have focused on fiber-reinforced concrete as an effective improvement technique.

2.1. Stormwater management using pervious geopolymer concrete with recycled aggregates: Leaching potential and contaminant removal efficiency

The experimental examination of Pervious Geopolymer Recycled Aggregates Concrete (PGRAC) involved a multi-staged methodology beginning with a statistical meta-analysis of forty-three previous studies to establish baseline concentrations for typical stormwater contaminants in arid regions. The performance evaluation phase assessed eight distinct PGRAC mixtures by testing their mechanical strength specifically 28 day compressive and flexural strength and their hydraulic properties, including porosity and falling head permeability. To evaluate environmental safety, long-term water quality was analyzed through tank leaching tests conducted over 64 days according to the NEN 7345 standard to track the release of alkali and heavy metals. Additionally, the researchers utilized a pilot-scale rainfall simulator to measure contaminant removal efficiency by subjecting the concrete slabs to simulated rainfall events that represented up to ten years of natural precipitation. These combined methods allowed the study to provide a comprehensive assessment of how variations in binder blends, design porosity, and recycled concrete aggregate (RCA) replacement impact the material's suitability for sustainable stormwater management.

2.2. Silica fume as partial replacement of cement in concrete

This research paper, published by International Research Journal of Multidisciplinary Technovation (IRJMT) in November 2019. The journal focuses on the use of silica fume as a partial replacement for cement in concrete to improve its strength, durability, and environmental sustainability. Silica fume, a by-product of the silicon and ferrosilicon industry, is rich in silicon dioxide and acts as a pozzolanic material that enhances the bonding properties of concrete. The study highlights that replacing a portion of cement with silica fume not only helps in reducing industrial waste and environmental pollution but also improves the mechanical properties of concrete. Various research studies reviewed in the paper indicate that the addition of silica fume significantly increases compressive strength, split tensile strength, and flexural strength up to an optimum level, generally between 10% and 15% replacement, beyond which the strength may decrease. Experimental investigations conducted using different percentages of silica fume (0%, 5%, 10%, 15%, and 20%) show that the highest strength values are achieved at around 15% replacement for both 7-day and 14-day curing periods. Although the incorporation of silica fume enhances strength and durability by making the concrete denser and less permeable, it tends to reduce workability due to its very fine particle size, requiring proper mix design and sometimes the use of superplasticizers. Overall, the study concludes that silica fume is an effective and sustainable supplementary cementitious material that can partially replace cement to produce high-performance concrete with improved structural properties and reduced environmental impact

2.3. Application Of Pervious Concrete as An Alternative Road to Mitigate Flooding in Don Honorio Ventura State University (DHVSU) Main Bacolor, Pampanga

The journal, titled "Application Of Pervious Concrete as An Alternative Road to Mitigate Flooding in Don Honorio Ventura State University (DHVSU) Main Bacolor, Pampanga" was published in International Journal Of Progressive Research In Science And Engineering in 2022. The study explains that flooding in Don Honorio Ventura State University (DHVSU) Main Campus in Bacolor, Pampanga is largely caused by intense rainfall, low-lying terrain, and conventional impervious road pavements that prevent proper water infiltration, leading to surface runoff and water accumulation. To address this problem, the study investigates the application of pervious concrete as an alternative road material, emphasizing its composition of coarse aggregates, cement, and minimal fine aggregates that create interconnected voids allowing water to pass through the pavement and infiltrate the underlying soil. The journal further explains that pervious concrete not only reduces surface runoff and flooding but also lessens the burden on existing drainage systems,

improves water quality by filtering pollutants, and supports groundwater recharge. Laboratory tests and performance evaluations discussed in the study show that pervious concrete provides adequate strength and durability for light to moderate traffic conditions commonly found within university campuses. Based on these findings, the journal concludes that the use of pervious concrete roads in DHVSU is a practical, cost-effective, and environmentally sustainable solution that significantly mitigates flooding, enhances drainage efficiency, and promotes resilient and sustainable campus infrastructure.

2.4. Stormwater retention using pervious concrete pavement: Great Western Sydney case study

The journal presents a detailed case study on the use of pervious concrete pavement for stormwater retention in Great Western Sydney, an area experiencing increasing urbanization and frequent stormwater management challenges. The authors explain that conventional impervious pavements contribute to excessive surface runoff, flooding, and pressure on drainage systems, prompting the need for sustainable urban drainage solutions. Through field observations and performance analysis, the study evaluates how pervious concrete pavements capture, store, and infiltrate stormwater, reducing runoff volume and peak flow during rainfall events. The journal highlights the role of pervious concrete in mimicking natural hydrological processes by allowing rainwater to pass through the pavement into underlying layers for temporary storage and gradual infiltration into the soil.

The findings demonstrate that pervious concrete pavement is highly effective in improving stormwater retention and reducing flood risks in urban environments like Western Sydney. The study also emphasizes additional benefits such as improved water quality through pollutant filtration, reduced load on stormwater infrastructure, and long-term environmental sustainability. Overall, the journal concludes that pervious concrete pavement is a practical and efficient solution for integrated stormwater management and should be considered an essential component of sustainable urban design, particularly in flood-prone and rapidly developing regions.

2.5. Development of pervious concrete having strength enhancement admixtures for managing stormwater runoff

Pervious concrete is a special type of concrete that allows rainwater to pass through its porous structure, helping to reduce stormwater runoff and urban flooding. It is commonly used in pavements, parking areas, and walkways to promote groundwater recharge. However, one major limitation of pervious concrete is its low strength compared to conventional concrete, which restricts its application in areas subjected to higher loads.

This research focuses on improving the strength of pervious concrete by incorporating a strength-enhancement admixture into the concrete mix. Different mix proportions were developed and tested to study the effect of the admixture on compressive strength, permeability, and void content. The aim was to achieve a balance between maintaining sufficient water infiltration capacity and increasing mechanical strength.

The study concluded that the use of a strength-enhancement admixture significantly improves the structural performance of pervious concrete without compromising its permeability. As a result, the developed pervious concrete can effectively manage stormwater runoff while being suitable for broader practical applications. This makes it a sustainable and efficient solution for urban infrastructure and stormwater management systems.

2.6. Pervious Concrete Made with Recycled Coarse Aggregate and Reinforced with Date Palm Leaves Fibers

This paper, titled "Pervious Concrete Made with Recycled Coarse Aggregate and Reinforced with Date Palm Leaves Fibers" was published in 2023. The study investigates pervious concrete made using 100% recycled coarse aggregate (RCA) from demolition waste and reinforced with natural date palm leaf fibers to improve sustainability and performance. Pervious concrete is a porous material that allows water to pass through, helping reduce stormwater runoff and recharge groundwater, but it generally has lower strength due to its high void content. The research developed 12 different mix designs by varying the amount of fine aggregate (sand) and fiber content, and tested properties such as compressive strength, tensile strength, permeability, porosity, and density. Results showed that using recycled aggregate alone significantly reduced compressive strength (by about 36%) and tensile strength (by about 57%) compared to natural aggregate concrete. However, adding small amounts of fine aggregate (up to 11.7%) and natural fibers (up to 0.64%) improved strength, with an optimal mix even exceeding the control concrete's compressive strength. Fine aggregate helped fill voids and improve bonding, while fibers enhanced tensile strength and crack resistance. At the same time, increasing fine aggregate reduced permeability and porosity, showing a trade-off between strength and drainage performance. The study also found a clear relationship between density, porosity, and permeability, and proposed an equation to estimate tensile strength from compressive strength. Overall, the research concludes that recycled aggregate pervious concrete reinforced with natural fibers is a viable, eco-friendly construction

material with balanced mechanical and hydraulic properties suitable for applications like pavements and drainage systems.

2.7. The application of permeable pavement with emphasis on successful design water quality benefits and identification of knowledge and data gaps

This report, published in June 2015 by the National Center for Sustainable Transportation, evaluates the application of permeable pavements specifically porous asphalt (PA), pervious concrete (PC), and permeable interlocking concrete pavers (PICP) as a sustainable urban drainage solution. It defines these pavements by their ability to store stormwater in underlying aggregate layers until it infiltrates the subgrade soil while simultaneously supporting traffic loads. While the technology is well established for low speed, light load environments like parking lots, the report highlights that its integration into high speed highway environments remains a primary research focus. Key benefits identified include significant stormwater runoff management, improved water quality through natural filtration, noise reduction from tire-pavement interaction, and mitigation of the urban heat island effect. However, potential trade-offs such as higher initial construction costs, the necessity for regular vacuum sweeping to prevent surface clogging, and concerns regarding moisture damage and long-term groundwater contamination must be managed. The document concludes that while demonstration projects from the Minnesota Department of Transportation and simulations by the University of California have shown promising structural and hydrologic results for highway use, critical knowledge gaps in long-term maintenance and specialized design standards still need to be addressed to ensure broader implementation.

2.8. Application of permeable pavements in highways for stormwater runoff management and pollution prevention:

2.8.1. California research experiences

The article titled "Application of permeable pavements in highways for stormwater runoff management and pollution prevention: California research experiences" was published International Journal of Transportation Science and Technology in 2019. This research paper provides a comprehensive review of decade-long studies conducted in California regarding the use of full depth permeable pavements (FDPP) for highway stormwater management. The authors demonstrate that FDPP serves as an effective "best management practice" (BMP) for capturing runoff and preventing pollution, particularly when applied to highway shoulders. The research covers critical aspects such as hydraulic performance, where it was found that an aggregate base thickness of 0.15 m to 2.9 m is sufficient to handle seasonal rainfall, and surface permeability, noting that while ASTM and NCAT measurement methods differ, both are viable for field testing. Furthermore, the study addresses clogging, revealing that most sediment accumulation occurs in the top 50 mm and can be mitigated by vacuuming. Finally, water quality analysis confirmed that FDPPs significantly reduce the discharge of harmful pollutants into natural water bodies through soil filtration and microbial activity, with the pavement materials themselves contributing negligible chemical constituents compared to actual highway runoff.

2.9. Mechanical Properties and Microstructure of Polypropylene–Glass-Fiber-Reinforced Desert Sand Concrete

This study investigates the mechanical properties and microstructural behavior of desert sand concrete reinforced with polypropylene fiber and glass fiber. The research mainly focuses on improving the performance of desert sand concrete by combining two types of fibers to enhance its strength, durability, and crack resistance. Different proportions of polypropylene and glass fibers were added to the concrete mix, and various mechanical tests such as compressive strength, splitting tensile strength, and flexural strength were conducted. The results showed that the inclusion of hybrid fibers significantly improved the tensile and flexural performance of desert sand concrete compared to conventional mixes. Polypropylene fibers helped in controlling micro-cracks and improving ductility, while glass fibers contributed to higher strength and stiffness. Microstructural analysis further revealed that the fibers enhanced the internal bonding and reduced the formation of pores and cracks within the concrete matrix. The study concludes that the hybrid use of polypropylene and glass fibers is an effective method to improve the overall mechanical performance and structural integrity of desert sand concrete.

2.10. Study of pervious concrete using silica fumes

The study focuses on the behavior and performance of pervious (no-fines) concrete when partially replacing cement with silica fume, a highly reactive industrial by-product rich in amorphous silica. Pervious concrete is characterized by high porosity, allowing water to pass through it, making it suitable for low-traffic areas like pavements, parking lots, and pathways, while also helping in stormwater management and environmental sustainability. However, due to its porous structure, it generally has lower strength compared to conventional concrete. The research investigates the effect of different percentages of silica fume (0% to 25%) on mechanical properties such as compressive strength, splitting tensile strength, and flexural strength for M30 grade concrete. Experimental results show that silica fume significantly

enhances strength due to its filler effect and pozzolanic reaction, which improves bonding and reduces voids in concrete. The strength of concrete increases steadily with the addition of silica fume up to an optimum level of 15% replacement, beyond which the strength begins to decrease due to reduced workability and excess fineness. At this optimum percentage, maximum improvements in compressive, tensile, and flexural strengths are observed for 7, 14, and 28 days. The study also highlights that although silica fume improves strength and durability, it reduces workability, requiring the use of superplasticizers. Overall, the research concludes that incorporating silica fume in pervious concrete is both technically beneficial and economically viable, enhancing strength and sustainability while maintaining permeability, making it a suitable solution for eco-friendly construction practices.

3. Conclusion

This review paper analyzed various experimental and review studies focused on improving the strength of pervious concrete while maintaining its permeability. The use of recycled aggregates effectively reduces the consumption of natural resources, promoting eco-friendly construction without significantly affecting strength. The partial replacement of cement with silica fume enhances bonding, durability, and overall performance of the concrete. Furthermore, the addition of polypropylene and glass fibers improves crack resistance, load distribution, and mechanical strength.

It can be conclusively stated that the combined use of recycled aggregates, silica fume, and fibers such as polypropylene and glass fiber is an effective approach for enhancing the strength of pervious concrete while preserving adequate permeability. The incorporation of recycled aggregates helps in reducing natural resource consumption, while silica fume as a partial replacement of cement improves bonding and durability. The addition of fibers further enhances crack resistance and load distribution. Therefore, this sustainable pervious concrete is highly suitable for applications such as rural roads, parking areas, walkways, and other low-volume traffic pavements, contributing to sustainable and resilient infrastructure development.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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