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(REVIEW ARTICLE)

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Review of Strengthening of Porous Concrete for Storm Water Management

Nayana Gopan *, Resmi R S, Fathimath Suhara, Arathi Shaji and Aiswarya A

Department of Civil Engineering, Vidya Academy of Science and Technology, Technical Campus, Kilimanoor, Thiruvananthapuram, Kerala, India

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Abstract

Pervious concrete is an environmentally sustainable pavement material widely used for stormwater management due to its high permeability and ability to recharge groundwater. However, its major limitation is low mechanical strength, which restricts its application to low-traffic areas. Numerous studies have attempted to improve the strength characteristics of pervious concrete using various admixtures, fibers, mineral additives, and modified mix designs without significantly affecting permeability. This review paper critically examines existing literature and experimental studies focusing on strength enhancement techniques for pervious concrete, with particular emphasis on the use of polypropylene (PP) fibers. Based on the comparative evaluation of methodologies and results from selected journals and reference documents, this paper concludes that polypropylene fiber reinforcement is one of the most effective and practical methods to improve compressive and tensile strength of pervious concrete while maintaining adequate permeability, making it suitable for low-volume roads and sustainable pavement applications.

Keywords: Pervious concrete; Storm water management; Polypropylene fibre; Compressive strength; Tensile strength

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.

Unlike conventional concrete, pervious concrete contains little to no fine aggregate, resulting in high porosity and permeability. Despite these environmental benefits, its application is largely limited to low-load areas because of its relatively low compressive, tensile, and flexural strength. This limitation has motivated extensive research into improving its mechanical performance without compromising permeability.

Various methods such as aggregate gradation optimization, water–cement ratio control, use of mineral and chemical admixtures, and fiber reinforcement have been explored. Among these techniques, polypropylene fiber reinforcement has proven to be one of the most practical and effective solutions. This review paper critically analyzes selected studies and journals to evaluate the role of polypropylene fibers in enhancing the strength of pervious concrete.

* Corresponding author: Nayana Gopan

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. 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.

2.3. Experimental study on increasing the strength of pervious concrete for its use on rural roads

This research paper, published by International Journal of Engineering Research & Technology (IJERT) (Vol. 11, Issue 07, July 2022) focuses on improving the strength of pervious concrete to make it suitable for use in rural roads. Pervious concrete is an eco-friendly pavement material that allows rainwater to pass through it, reducing surface runoff and helping groundwater recharge, but its low strength limits practical application. To overcome this issue, polypropylene fibres and manganese metal powder were added to pervious concrete mixes prepared with water–cement ratios of 0.36, 0.38, and 0.40. Experimental tests showed that the modified pervious concrete achieved higher compressive and flexural strength than conventional pervious concrete, while still maintaining adequate permeability. Strength was found to decrease with an increase in water–cement ratio, whereas permeability increased. Among the mixes, a water–cement ratio of 0.36 provided the best balance between strength and permeability. Although the improved concrete did not fully meet the strength requirements for rural roads, the study concludes that it can be effectively used when combined with reinforced road mesh, making it a promising sustainable solution for low-volume rural pavements.

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. Experimental investigation and monitoring of a polypropylene-based fiber reinforced concrete road pavement

This paper, titled “Experimental investigation and monitoring of a polypropylene-based fiber reinforced concrete road pavement” was published in 2013.This study investigates the experimental performance and field monitoring of a road pavement constructed using polypropylene-based fiber reinforced concrete. Polypropylene fibers were incorporated into conventional concrete to improve its mechanical properties and durability, and laboratory tests were carried out to evaluate compressive strength, tensile strength, flexural strength, and crack resistance. The results showed that the addition of fibers significantly enhanced tensile and flexural behavior, reduced shrinkage and cracking, and improved post-crack performance without adversely affecting compressive strength. A trial pavement section was then monitored under actual traffic and environmental conditions, where reduced crack formation, better load distribution, and improved long-term performance were observed. The study concludes that polypropylene fiber reinforced concrete is an effective and sustainable option for rigid road pavements, offering improved durability, reduced maintenance, and extended service life.

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: 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. Impacts of permeable interlocking concrete pavement on the runoff hydrograph: Volume reduction, peak flow mitigation and extension of lag times

This study investigates how permeable interlocking concrete pavement (PICP) influences stormwater runoff characteristics, with a focus on runoff volume reduction, peak flow mitigation, and lag time extension. Using monitored field-scale PICP systems, the authors compared hydrologic responses of permeable pavement to conventional impervious surfaces under various rainfall events. The results demonstrate that PICP significantly reduces total runoff volumes by promoting infiltration and temporary storage within the pavement structure and underlying aggregate layers. Smaller and moderate storm events often produced little to no surface runoff, highlighting the effectiveness of PICP as a low-impact development (LID) practice.

In addition to volume reduction, the study shows that PICP substantially attenuates peak discharge rates, lowering the risk of downstream flooding and reducing stress on stormwater infrastructure. The permeable pavement delayed the timing of runoff, resulting in extended lag times between rainfall onset and peak flow. This delay is attributed to infiltration through the joints, storage within the pavement base, and gradual exfiltration into the subsoil. Even during larger storm events that exceeded the system's storage capacity, peak flows were still noticeably lower than those from traditional pavements.

Overall, the findings confirm that permeable interlocking concrete pavement can effectively restore more natural hydrologic behavior in urbanized areas. By reducing runoff volumes, flattening hydrographs, and delaying peak flows, PICP serves as a practical and resilient stormwater management strategy. The authors conclude that widespread implementation of PICP can contribute to improved flood control, enhanced groundwater recharge, and more sustainable urban drainage systems, particularly when properly designed and maintained.

2.10. The Microstructure and Thermochemical Evaluation Properties of Polypropylene-Modified Asphalt Concrete for Enhanced Performance

This study evaluates the impact of incorporating recycled polypropylene (PP) from waste plastic chairs into asphalt concrete to enhance pavement performance and address plastic pollution. By testing varying proportions of polypropylene (5%, 10%, 15%, and 20%), the researchers found that the modifier significantly improved the physical, chemical, thermal, and rheological properties of bitumen. Key improvements included increased Marshall stability (peaking at 15.80 kN for 20% PP), higher softening points (indicating better heat resistance), and increased viscosity, which ensures better adhesion between the binder and aggregates. Microstructural analysis further revealed that the modified asphalt exhibits a more homogeneous behavior and lower porosity compared to unmodified versions, concluding that polypropylene modification is a sustainable method for strengthening flexible pavements

3. Conclusion

This review paper analyzed various experimental and review studies focused on improving the strength of pervious concrete while maintaining its permeability. Among the different techniques reviewed, the incorporation of polypropylene fibers consistently demonstrated significant improvement in compressive, flexural, and tensile strength.

Polypropylene fibers effectively control micro-crack propagation, enhance load distribution, and improve post-cracking behavior of pervious concrete. Unlike certain chemical admixtures and geopolymer binders, polypropylene fibers offer a cost-effective, easily available, and construction-friendly solution without introducing environmental or durability concerns.

Based on the comparative evaluation of methodologies and performance outcomes, it can be conclusively stated that polypropylene fiber is the best option for increasing the strength of pervious concrete while preserving adequate permeability. Therefore, polypropylene fiber reinforced 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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