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# A Comprehensive Review on the Ranking of Fibers in Porous Concrete Pavement

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## Abstract

Porous Concrete Pavements (PCPs) are increasingly recognized for their potential to address environmental challenges, particularly in urban settings, by mitigating water and air impacts and enhancing road safety. Despite their promising attributes, their widespread adoption remains limited due to gaps in comprehensive research and awareness about their multifaceted benefits. This review paper delves into the essential properties of PC mixtures to underscore their role in designing sustainable and multifunctional pavements. Drawing from recent literature, the paper synthesizes the environmental advantages of PCPs, encompassing benefits such as reduced stormwater runoff, enhanced underground water quality, mitigation of the heat-island effect, noise reduction, and improved skid resistance. The hydraulic efficacy of PCPs hinges on various factors including mix design, construction practices, and environmental conditions, making simultaneous optimization of mechanical attributes, durability, and infiltration challenging. Persistent issues like freeze/thaw damage, deicer impacts, and clogging hinder their broader application. Durability concerns, especially in colder climates, underscore the need for advancements across the PCP lifecycle stages. The review emphasizes the need for improved characterization techniques and predictive modeling to propel PCP technology forward. Additionally, the paper highlights emerging research areas, including nano-science and nano-engineering, as potential avenues to address durability challenges and amplify the environmental benefits of PCPs.

**Keywords:** Porous Concrete Pavements (PCPs), Environmental Benefits, Hydraulic Performance, Durability Challenges, Skid Resistance.

## 1. Introduction

Porous Concrete Pavements (PCPs) are gaining traction as a sustainable solution, acting as a pivotal component of Low Impact Development (LID) strategies to counteract the adverse environmental consequences of conventional infrastructure (Scholz and Grabowiecki, 2007; Bruinsma et al., 2017; Rodríguez-Rojas et al., 2018). Serving as an eco-friendly alternative, PCPs have the potential to supplant or augment traditional grey infrastructure, especially in areas characterized by slower speeds, lighter vehicles, and minimal truck traffic, such as certain roadways and parking lots (Cackler et al., 2006; Garber et al., 2011; Weiss et al., 2017). Often referred to as pervious concrete pavements, these structures are distinguished by their porous composition, facilitating the infiltration of stormwater into underlying layers (Wanielista et al., 2007; Lee et al., 2013; Ullate et al., 2011). While PCPs exhibit diverse properties, including air voids ranging from 15 to 30 percent, permeability spanning 20 to 500m/day, and compressive strength from 5.5 to 20.5MPa (Schaefer et al., 2006; Weiss et al., 2017), it's noteworthy that a standardized ASTM test method for their compressive strength is yet to be established, complicating their evaluation.

Amidst burgeoning urbanization, the significance of paved roads cannot be understated, serving as vital conduits for economic growth, facilitating efficient transportation, and ensuring safety and convenience for commuters. However, the escalating expansion of impermeable surfaces worldwide, constituting approximately 3% of the Earth's total area, poses environmental challenges, disrupting natural hydrological processes and exacerbating urban heat islands (Sinha et al., 2002; Hernandez et al., 2013). While PCPs offer a sustainable remedy to these concerns, their widespread adoption is hindered by durability issues and susceptibility to clogging, necessitating a comprehensive examination of their environmental benefits and long-term viability. This review aims to critically assess the existing literature on PCPs, emphasizing their environmental advantages and addressing pertinent durability challenges.

## 2. Methods

In recent times, while numerous studies have delved into the intricacies of Porous Concrete Pavements (PCPs), there remains a conspicuous gap in comprehensive review articles that encapsulate the multifaceted dimensions of this technology. Specifically, a holistic perspective encompassing environmental benefits, preparation methodologies, intrinsic properties, and maintenance protocols is conspicuously absent. Furthermore, a comprehensive evaluation of the environmental sustainability and longevity of PCPs remains conspicuously elusive in scholarly discourse.

Addressing this lacuna, the present study aims to consolidate recent advancements pertaining to the environmental ramifications of PCPs. Recognizing PCPs as an instrumental facet of green infrastructure and an efficacious environmental management tool, this article delineates their hydraulic efficacy, design intricacies, fabrication nuances, and maintenance imperatives. Moreover, the discourse extends to elucidate modeling strategies and advanced characterization techniques pivotal for refining design paradigms and augmenting the life cycle performance of PCPs. Crucially, this review endeavors to pinpoint salient findings, delineate knowledge lacunae, and underscore emergent research imperatives, contextualized within the prevailing state of scholarship.

Table 1. Average dosage for the main components used in porous concrete mixtures. (Elizondo-Martinez et al., 2020)

| Component | Minimum | Maximum | Average |
|---|---|---|---|
| Cementitious materials (kg/m3) | 150.00 | 560.00 | 341.37 |
| Aggregates (kg/m3) | 565.00 | 2035.20 | 1507.73 |
| Aggregate size (mm) | 2.36 | 19.00 | 9.5–12.5 |
| Water to cement ratio | 0.20 | 0.42 | 0.30 |
| Aggregate to cement ratio | 1.26 | 12.00 | 4.76 |
| Fine to coarse aggregate ratio | 0.00 | 0.17 (if used) | 0.02 (if used) |

## 3. Ecological advantages

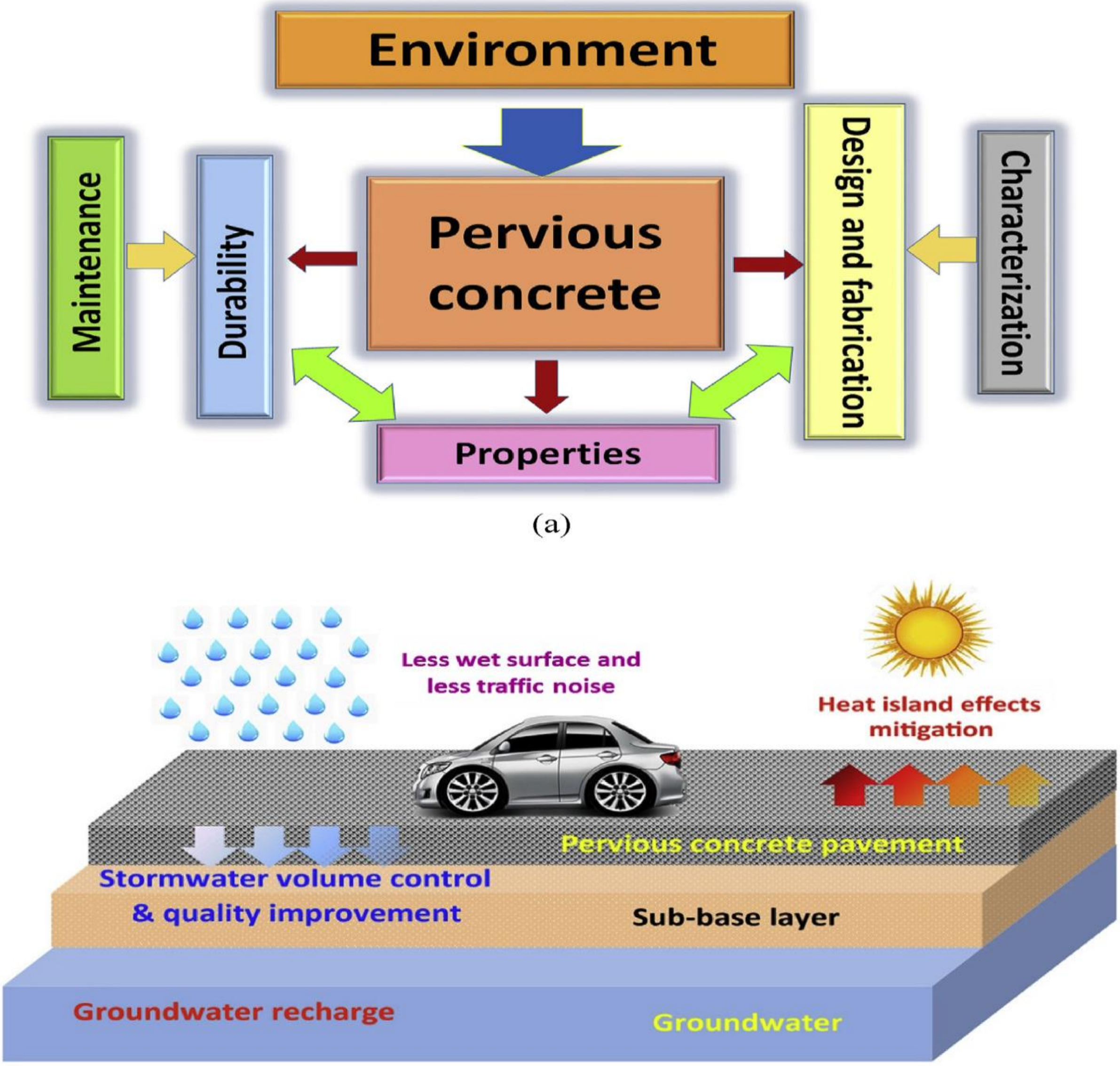
PCPs offer a range of ecological advantages, such as decreasing stormwater runoff, enhancing pavement surface grip, refining the quality of groundwater, and minimizing issues like hydroplaning, the heat-island effect, and traffic noise. These advantages bolster the resilience, environmental responsibility, and safety of local transit systems and communities. Numerous governmental bodies globally advocate for green infrastructure strategies to meet water regulations and standards. Within this framework, PCPs emerge as a valuable asset, seamlessly integrating simulated natural processes like infiltration into urban landscapes.

Fig. 1(a) depicts a flowchart showcasing the connections among different facets of PCPs, while Fig. 1(b) underscores their comprehensive ecological advantages.

### 3.1. Hydraulic efficacy, management of stormwater drainage, and water purity

This section delves into a concise exploration of the hydraulic performance of PCPs, encompassing aspects such as hydraulic conductivity assessments and the correlation between porosity and hydraulic conductivity. The efficacy of PCPs in managing stormwater runoff and bolstering the resilience of transportation systems and communities hinges significantly on their hydraulic capabilities.

The hydraulic characteristics of permeable concrete are markedly influenced by the methodology employed for testing (West et al., 2016; Brown and Borst, 2014; Li et al., 2013). Essentially, hydraulic conductivity, indicative of a material's permeability to water under a given hydraulic gradient, is routinely assessed through permeability tests conducted either in controlled laboratory settings or field conditions, aligning with established ASTM standards (ASTM 1688, 1701, 1747, 1754). Predominantly, the falling head permeability test is a prevalent laboratory technique where a sealed sample undergoes water application, and the elapsed time informs the calculation of hydraulic conductivity. Innovations such as the embedded ring infiltrometer by Chopra et al. (2010) and comparative studies by West et al. (2016) spotlight varying test methodologies and potential discrepancies between observed and actual permeability rates.



(a)

(b)

Fig. 1. Porous concrete pavement: (a) considerations, (b) environmental benefits. (Xie et al., 2019)

Emerging research elucidates the pivotal role of porosity in influencing the hydraulic efficacy of PCPs. Notably, studies by Kabagire and Yahia (2016) underscore the significant impact of cement paste volume on both permeability and strength. Concurrently, insights from Cipolla et al. (2016) and Montes and Haselbach (2006) delineate the intricate relationship between porosity, hydraulic properties, and structural integrity. Additionally, advancements like polymer latex incorporation, as indicated by Huang et al. (2010), and vertical porosity distribution insights from Martin et al. (2014) and Fwa et al. (2015) further enrich our understanding of PCP performance nuances.

Monitoring endeavors, such as those by Kumar et al. (2016) and Crookes et al. (2017), underscore the sustained effectiveness of PCPs in attenuating stormwater runoff, even amidst challenges like pore clogging. Furthermore, the efficacy of PCPs in enhancing stormwater quality through contaminant removal mechanisms both mechanical and biological has garnered substantial attention. Groundbreaking studies by Haselbach et al. (2014), Holmes et al. (2017), and Lee et al. (2013) affirm the capacity of PCPs to significantly mitigate pollutant concentrations, underscoring their multifaceted environmental benefits.

### 3.2.Skid resistance improvement

PCPs are believed to offer superior traction compared to traditional impermeable surfaces, as indicated by studies such as McCain et al. (2010), Izevbekhei (2008), and Schaefer and Kevern et al. (2011). However, comprehensive data supporting this claim in literature remains limited. Contrarily, research by Nguyen et al. (2014) suggested that cement PCPs exhibit notably enhanced skid resistance, which enhances road safety. Yet, evaluations using a British pendulum tester (ASTM E303) in a Pennsylvania parking area showed that PCPs have skid resistance levels comparable to conventional asphalt and porous asphalt pavements (Houle, 2008). Furthermore, Yeih et al. (2015) observed that substituting gravel with air-cooled arc furnace slag in PCPs led to improved skid resistance, increased strength, and enhanced permeability.

Additionally, PCPs appear to mitigate slip-induced accidents. Kevern (2011) noted that PCP offers better foot traction, leading to more controlled walking motions and reduced slipping incidents, especially during winter. This advantage is attributed to factors like increased contact pressure, friction coefficient, and minimized risks of water accumulation and freezing on PCP surfaces. King et al. (2013) further corroborated these findings, emphasizing PCP's role in diminishing slip hazards through biomechanical assessments.

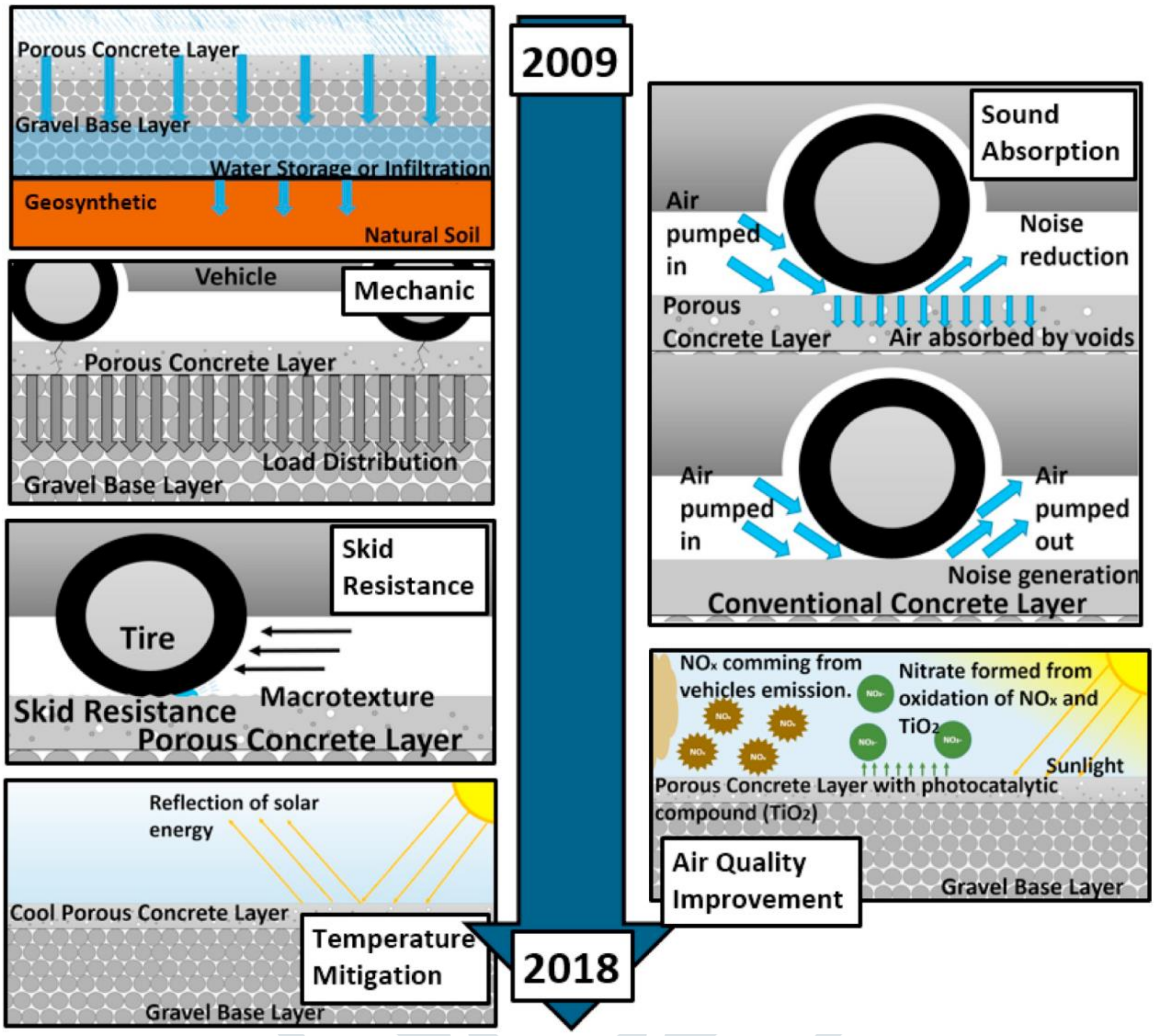


Fig. 2. Scheme of the main aspects considered in the review of porous concrete pavements. (Elizondo-Martinez et al., 2020)

## 4. Factors Influencing the Effectiveness of PCP

Table 2. Key parameters affecting the performances of PCP, as reported by case studies.

| Parameters | Permeability | Mechanical Properties | Durability | Porosity | Clogging |
|---|---|---|---|---|---|
| Mix Design | 1.1 mm/s using the variable head test and 0.8 mm/s with the constant head test (Nguyen et al., 2014). | As porosity increased, both peak stresses and peak-stress strains consistently declined (Deo and Neithalath, 2011). | To achieve a robust and long-lasting PCP, one can employ minimal fine aggregate, incorporate polypropylene fibers, adjust to a slightly elevated water-to-cement ratio, enhance compaction to reduce porosity, introduce air entrainment, amplify paste volume, substitute a portion of Portland cement with fly ash or silica fume, or utilize | The porosity and overall porosity stood at 17.2% and 26.5%, respectively (Nguyen et al., 2014). | Permeable concrete samples with comparable porosity, featuring either very large pores (5e6mm) or extremely small pores (1e2mm), demonstrated reduced vulnerability to clogging (Deo et |

| | | | | | |
|---|---|---|---|---|---|
| | | | latex (Bonicelli et al., 2015a, 2015b; Schaefer et al., 2006; Deo and Neithalath, 2011). | | al., 2010). |
| Aggregates | Adding a modest quantity of sand or latex can enhance the workability, strength, and freeze/thaw resistance of PCP without compromising its permeability (Kevern et al., 2005). | Examine the relationship between the splitting tensile strength and compressive strength of pervious concrete cylinders and cores (Gaedicke et al., 2016). | The freeze/thaw durability of pervious concrete made with crushed shells as aggregates is suitable for pavements with low traffic loads (Nguyen et al., 2017). | The connected porosity was primarily determined by the type of aggregates rather than their size (Cosic et al., 2015). | Particles within the size ranges of 0.15e0.3mm and 1.18e2.36mm significantly influence water permeability (Chen et al., 2015). |

## 5. Conclusions

Recent times have witnessed a growing emphasis on Porous Concrete Pavements (PCPs). This review offers a comprehensive insight into their environmental advantages, design intricacies, maintenance, and longevity. Serving as an eco-friendly alternative to conventional infrastructure, PCPs play a pivotal role in sustainable development initiatives. Table 2 encapsulates the crucial factors shaping PCP performance, as evidenced by various case studies.

PCPs demonstrate remarkable potential in addressing environmental challenges. They effectively manage stormwater runoff, enhance groundwater quality through infiltration processes, and eliminate various pollutants. Moreover, studies highlight their efficacy in reducing slip-related accidents, enhancing road grip, minimizing urban noise, and mitigating urban heat island effects. However, challenges such as potential clogging and freeze-thaw (F-T) damage, especially in regions with winter maintenance practices, pose threats to their long-term viability.

The effectiveness and longevity of PCPs hinge on various factors like mix design, construction methods, environmental conditions, and maintenance protocols. Crucial design elements include aggregate size, aggregate modulus, and the bond strength between the binder and aggregate. Additionally, the porosity and its distribution significantly influence the hydraulic and mechanical properties of PCPs. Bridging the existing knowledge gaps in these domains is crucial to optimizing both hydraulic efficiency and durability.

In conclusion, while PCPs offer a promising solution for sustainable urban development, there's a pressing need for continued research and innovation. Future endeavors should focus on refining technologies to amplify the environmental advantages of PCPs without compromising their durability or necessitating extensive maintenance.

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