

# Literature Review on Utilization of Industrial Pozzolanics By-Products in Porous Concrete

Radhika Deshpande<sup>a</sup>, Kuldeep Dabhekar<sup>b</sup>

<sup>a</sup>Ph.D. Scholar, Department of Civil Engineering, G.H. Rasoni College of Engineering, Nagpur.  
radhikaalkarideshpande@gmail.com

<sup>b</sup>Assistant Professor, Department of Civil Engineering, G.H. Rasoni College of Engineering, Nagpur.  
[Kuldeep.dabhekar@ghraisoni.net](mailto:Kuldeep.dabhekar@ghraisoni.net)

**Abstract:** Porous concrete is widely recognized as a green infrastructure solution for urban areas, primarily used in water-absorbing pavements to reduce runoff and enhance groundwater recharge. However, the lack of standardized guidelines for mix optimization and pavement design remains a significant challenge in its widespread application. To further improve sustainability, the partial replacement of cement with pozzolanic by-products, such as fly ash, GGBFS, Rise husk ash and silica fume, has emerged as an effective practice, enhancing durability and reducing environmental impact. This review paper explores these critical issues, highlighting the need for standardized design approaches and sustainable material utilization to optimize the performance of porous concrete pavements. Optimum cement aggregate ratio, aggregate shape and size, need of admixtures and effective industrial pozzolanic waste to be used as cement replacement material are discussed in detail.

**Keywords** - Fly Ash, GGBFS, Porous Concrete, Rise husk ash, Silica Flume

## 1. Introduction

Urban flooding in rainy season and low water table in summer is one of the major issues that cities are dealing with to ensure sustainable development. Upgrading the drainage systems is only measure that engineers have often used to reduce the risk of flooding. Because of climate change and urbanization, storm water management systems may be inadequate to convey generated overflow in their catchment, which results in severe flooding in many cities worldwide [1]. At the same point of time, ground water recharge is negligible causing drought like situations in same areas during summer. Porous concrete, often referred to as pervious concrete, constitutes a distinct category of concrete distinguished by its elevated porosity, which permits the passage of water, thereby rendering it a highly effective material for storm water management and mitigating surface runoff. This specific form of concrete is formulated from cement, coarse aggregates, water, and a minimal quantity or absence of fine aggregates, culminating in a network of interconnected voids that enhance rapid drainage capabilities. The equilibrium between its mechanical strength and permeability is imperative for its utilization in construction endeavors, particularly in regions susceptible to flooding or necessitating efficient drainage solutions. The distinctive characteristics of porous concrete not only facilitate effective water management but also foster sustainability by diminishing the reliance on conventional drainage systems and alleviating soil erosion. This innovative material can also enhance the aesthetic appeal of landscapes, allowing for the integration of greenery while maintaining functional performance.

Despite its environmental benefits, porous concrete often exhibits lower mechanical strength and durability compared to traditional concrete, necessitating the research on supplementary cementitious materials to enhance its properties. The increasing demand for sustainable construction materials has led to a growing interest in the use of industrial pozzolanic by-products, which not only enhance the mechanical properties of concrete but also contribute to environmental conservation by reducing waste. Among the various supplementary cementitious materials available, industrial by-products such as fly ash, silica fume, and ground granulated blast furnace slag have been widely explored for their potential to improve the performance of porous concrete. Understanding the influence of these by-products on porous concrete is crucial for optimizing porous concrete mix design and ensuring its practical applicability in modern construction [2].

This literature review aims to reveal how the incorporation of these materials can enhance not only the strength and durability of porous concrete but also its sustainability, paving the way for greener building solutions that

address both structural integrity and environmental impact.

## 2. Overview of Industrial Pozzolanics By-Products

In the context of cement manufacture, industrial pozzolanics by-products are compounds that function as supplemental cementitious materials. These materials are either synthesized from alternative source materials or produced as waste products from a variety of industrial operations. Examples of industrial pozzolanics by-products that serve as examples include A by-product of high-temperature combustion processes is fly ash; a by-product of silicon smelting is silica fume; blast furnace slag is an industrial by-product that may be used as a pozzolan; metakaolin is a highly reactive by-product of expanded glass granule production; palm oil fuel ash is a by-product of high-temperature combustion processes; and Rice husk ash is a silica-rich residue of burned organic matter [3]. The incorporation of these materials into cement serves to enhance its overall composition. Furthermore, they may also be employed as lightweight aggregates in the fabrication of lightweight concrete [4]. Research shows that industrial pozzolanics by-products are essential for reducing carbon emissions in the building industry. In addition to enhancing the mechanical properties of concrete, the use of these materials promotes a more environmentally friendly paradigm in the building sector, opening the door for creative methods that support environmental goals. This shift to using waste resources to make concrete represents a significant advancement in the search for environmentally friendly building solutions, which will eventually lead to more robust and sustainable infrastructure.

## 3. Importance of Sustainable Construction Practices

Sustainable construction is extremely important as it helps to reduce the environmental impact of the construction industry. Sustainable construction methodologies increasingly prioritize the substitution of cement with pozzolanics materials to mitigate environmental repercussions and enhance material performance. Also, climate change and urbanization, cause storm water management systems inadequate to convey generated overflow in their catchment, which results in severe flooding in many cities worldwide [5]. Porous concrete, has elevated porosity, which permits the passage of water, posing a solution for flood control.

## 4. Mix design for Porous concrete

The goal of designing a porous concrete mix is to produce a highly permeable substance that permits water to flow through, lowering surface runoff and encouraging groundwater recharge. With a void structure of 15–25% porosity, the mix usually comprises of coarse aggregate, Portland cement, water, and little to no fine aggregate. In order to provide sufficient bonding without sacrificing permeability, the water-to-cement ratio must be properly balanced between 0.27 and 0.34. Cement aggregate ratio should lie between 1:3 to 1:4 for optimum strength and permeability. Viscosity modifiers, superplasticizers, and air entrainers are examples of additives that can be employed to improve workability, strength, and durability. Proper curing techniques, including moisture retention for at least seven days, are essential to achieving the desired strength. The mix design must be tailored to specific project requirements, considering factors such as traffic load, climate, and environmental conditions. Various factors affecting mix design are discussed further.

### 4.1 Effects of Cement: Aggregate ratios on strength and durability

Cement aggregate ratio is the most important parameter to be considered for strength and durability of porous concrete. [6] analyses the properties of Green Porous Concrete through laboratory assessments of porosity, strength, permeability, and durability. Results affirm its efficacy in storm water management, enhancing groundwater recharge, and showcasing superior permeability compared to traditional concrete. Ultimately, green porous concrete emerges as a viable solution for sustainable urban infrastructure, facilitating rainwater harvesting and minimizing environmental impact. [7] employs a mixed design of 1:0.4:3.6, partially substituting Natural Coarse Aggregate with reused aggregate at varying percentages to optimize infiltration without sacrificing strength. The 10 mm aggregate yielded the highest compressive strength post-curing. An increase in reused aggregate correlates with decreased compressive strength and heightened infiltration rates. A 30% replacement of natural coarse aggregate with recycled coarse aggregate yields optimal outcomes, achieving an infiltration rate of 9737 mm/hr and a compressive strength of 8.67 MPa. [7] mentions that, despite its flood mitigation benefits, permeable pavement is characterized by lower strength, limiting its use on primary roads and highways. In Malaysia, its application is restricted to light traffic contexts such as walkways and parking areas. This paper examines strategies to enhance the strength properties of permeable concrete pavements with an emphasis on sustainable development. [8] conduct an experimental analysis to assess the impact of the cement-aggregate ratio on the porosity and compressive strength of pervious concrete, identifying an optimal cement aggregate ratio for

enhanced compressive strength. [9] compares the strength of conventional and pervious concrete, maintaining consistent volume, water cement ratio, and aggregate cement ratio for both types. [10] introduces a novel porous concrete mixture design method, based on ACI standards, aimed at augmenting mechanical strength while ensuring adequate permeability for urban road applications. The approach yields mechanical strengths 30% greater than those achieved through traditional ACI methods, while maintaining sufficient permeability to address extreme storm events. [11] examines porous concrete beams with angular and round aggregates across three porosity levels under varying flexural fatigue loading stress ratios. Findings indicate that stress ratios primarily influence fatigue life, whereas porosity does not significantly affect flexural fatigue. [13] Involves in the preparation and experimental assessment of various pervious concrete mixes, yielding matrix strengths from 29 MPa to 174 MPa, with aggregate to binder ratios and sizes systematically analyzed. A comprehensive examination quantifies the impact of matrix strength, binder content, and aggregate size on the compressive strength of pervious concrete.[14] establishes correlations between crucial properties of pervious concrete—porosity, permeability, compressive and tensile strength—and cement paste thickness, achieved through controlled mix-design and laboratory techniques, alongside analysis of hardened concrete cross-sections.[15] explores the strength, fracture, and fatigue characteristics of pervious concrete, revealing enhanced strength compared to prior studies. The research addresses a gap by focusing on fracture and fatigue behaviour, highlighting the significant influence of specimen size on compressive strength, thus enriching understanding of the material's mechanical properties. [16] informed the identification of optimal mixtures for distinct projects. This suggests that various compositions were evaluated for their practical applicability, although specific formulations are not detailed within the context.

#### **4.2 Effects of Course Aggregate on strength and durability**

The main ingredient that influences the permeability, strength, and structural integrity of porous concrete is coarse aggregate. Porous concrete, in contrast to regular concrete, has little to no fine aggregate, enabling a system of linked voids that help drain water. The concrete's porosity and load-bearing ability are influenced by the coarse aggregate's size, shape, and gradation. Generally, to produce a well-connected void structure with enough compressive strength, single-sized aggregates between 9.5 mm and 19 mm are utilized. The right choice of aggregate guarantees longevity, lowers clogging, and improves the concrete's capacity to sustain loads from cars and pedestrians while preserving high infiltration rates. [8] examines the use of steel slag in place of natural aggregate in pervious concretes, evaluating characteristics such bulk density, porosity, water permeability, tensile and flexural strengths, and compressive strength. [17] examines the effects of using recycled concrete and coal bottom ash in place of natural aggregate on the properties of pervious concrete. It finds that recycled concrete improves thermal conductivity and sound absorption while slightly reducing strength, while coal bottom ash has compressive strength that is comparable to crushed limestone. [18] examines how pervious concrete can be internally cured using pre-wetted lightweight aggregates, showing increases in workability, compressive strength, and freeze-thaw durability to improve performance. [19] This invention details anti-corrosion pervious concrete for highway applications, comprising specific material percentages that yield higher porosity and permeability compared to conventional pervious concrete while also enhancing compressive strength and service life. [20] analyses how varying coarse aggregate sizes, water-to-cement ratios, cement content, and aggregate volumes influence the relationships among compressive strength, tensile strength, porosity, and permeability. [21] examines the effects of aggregate properties on the static modulus of elasticity in pervious Portland cement concrete, concluding that while compressive strength is influenced by aggregate characteristics, the static modulus remains stable, warranting further investigation.

#### **4.3 Effects of Admixture on strength and durability**

Admixtures play a crucial role in enhancing the strength and durability of porous concrete by improving its workability, bonding, and resistance to environmental conditions [22]. The permeability and compressive strength of pervious concrete are shown to be significantly impacted by aggregate size, type, and mineral admixtures; for both granite and dolerite, the ideal porosity and w/c ratios are found to be 18% and 0.25, respectively. [24] According to the findings, admixtures are generally more effective than increasing the cement aggregate ratio or fine aggregate content, though the latter exhibits a slight superiority over fine aggregate increases. Additionally, there is a strong correlation between apparent density and compressive strength in graded PCC with these admixtures. These findings suggest that adding admixtures improves the mechanical properties of pervious cement concrete. [23] elucidates how polymer admixture contents influence the physical and mechanical properties of latex modified concretes, revealing that increased latex content diminishes compressive strength while enhancing flexural and split tensile strengths, alongside improved water absorption barrier efficiency.

## 5. Pozzolanic by-product's as Cement replacement materials in Porous concrete

According to a thorough analysis of the use of industrial by-products as cement substitutes in pervious concrete [2], adding fly ash, silica fume, ground granulated blast-furnace slag, and metakaolin up to a 20% threshold significantly reduces porosity and permeability while simultaneously increasing compressive strength and durability [25]. The effects of waste powders (fly ash, volcanic ash, and blast furnace slag) and recycled aggregates (recycled concrete aggregate and recycled brick aggregate) on the mechanical characteristics, water permeability, water filtration capabilities, and durability of pervious concrete are summarized in this manuscript. Possible directions for the future are also suggested. The literature review reveals that the incorporation of an appropriate quantity of solid waste or the implementation of suitable treatment methodologies for solid waste does not yield adverse effects; conversely, it tends to enhance the performance characteristics of pervious concrete. Consequently, the integration of solid waste into pervious concrete holds significant promise for urban development and environmental sustainability.

### 5.1 Fly ash

The effects of fly ash and silica fume on the characteristics of vegetated porous concrete were examined in a study by [26]. The results showed that FA decreased compressive strength because of its decreased reactivity with cement. Fly ash was observed to reduce compressive strength [27]. According to the study's findings, C/A has a major impact on the characteristics of pervious concrete; for high strength, C/A (0.20–0.24) and 20% fly ash are advised. Three pervious concrete mixtures were evaluated for technical qualities, costs, and environmental effects by [29]. They found that mixtures including fly ash or slag had lower mechanical strength than ordinary concrete but comparable freeze-thaw resistance. In their analysis of the effects of fly ash cement replacement, water-binder ratio, and water-reducing agent on the parameters of porous concrete, [30] found that a 28-day compressive strength of 4.37 MPa was achieved with the best results at a ratio of 0.32, 30% fly ash, and 0.65% water-reducing agent. According to (Aoki et al. 2012), there were no appreciable differences in the characteristics of pervious concrete including fly ash compared to that made entirely of cement.

### 5.2 Silica Flume

[26] assessed the effects of Silica Fume and Fly Ash, noting that silica fume's pozzolanic reaction improved porous concrete strength.

### 5.3 GGBFS

[32] Provides a comprehensive review of GGBFS as a cement replacement, detailing its effects on various concrete properties based on published studies. [29] evaluated the engineering properties, costs, and environmental impacts of pervious concrete mixtures, finding that fly ash and slag mixtures displayed similar freeze-thaw resistance but reduced mechanical strength, alongside slightly higher hydraulic conductivity due to increased air void ratios.

### 5.5 Rice Husk Ash

The evaluation of flexural strength utilizing varying proportions of nano rice husk ash replacements was conducted. It is evident that the optimal strength achieved at the ages of 7, 28, and 90 days for the 10% nano rice husk ash replacements is quantified as 3.70 MPa, 4.43 MPa, and 4.85 MPa, respectively [35].

### 5.6 Technical Challenges in Utilizing By-Products

Despite the substantial benefits conferred by pozzolanic by-products, including silica fume, fly ash, ground granulated blast furnace slag (GGBFS), and rice husk ash (RHA), with respect to strength, durability, and sustainability, their implementation is fraught with a multitude of technical obstacles. These obstacles primarily arise from the intrinsic material properties, essential processing conditions, compatibility with cementitious systems, and concerns regarding workability. Although the integration of pozzolanic by-products significantly augments the sustainability and durability of concrete, their application is impeded by technical difficulties related to material variability, workability, processing requirements, long-term performance, and compatibility with supplementary concrete components. Addressing these challenges necessitates the formulation of optimized mix designs, the execution of suitable processing techniques, and the careful selection of replacement ratios.

**Variability in Composition and Reactivity:** The ultrafine particle dimensions of silica fume pose considerable challenges pertaining to handling and dispersion, necessitating the employment of specialized additives such as superplasticizers to ensure a homogenous distribution [36]. The compositional properties of fly ash are influenced

by the specific coal source utilized, with Class F fly ash (noted for its low calcium content) exhibiting a slower reactivity rate in comparison to Class C fly ash (characterized by high calcium), which may incite flash setting occurrences [3]. The optimal performance of Ground Granulated Blast Furnace Slag (GGBFS) is contingent upon alkali activation, and the use of excessive replacement ratios (surpassing 50%) can impede strength development [38]. The pozzolanic reactivity and silica content of rice husk ash are determined by the combustion process, wherein incomplete combustion may result in carbon contamination, thereby reducing its efficacy [39].

**Processing and Handling Challenges:** The propensity of silica fume to agglomerate necessitates the establishment of controlled storage and dispersion systems, which complicates the handling processes [40]. Proper classification of fly ash is imperative to eliminate unburnt carbon and heavy metal contaminants, as these can adversely affect the hydration process of cement [41]. The effective substitution of cement with GGBFS requires grinding to a designated fineness, thereby increasing processing costs [42]. The combustion of rice husk ash must occur at optimal temperatures (ranging from 500-700°C) to eliminate organic impurities, while inadequate grinding may yield large particle sizes, consequently diminishing pozzolanic activity.

**Compatibility with Admixtures and Alkali-Silica Reaction Issues:** Pozzolanic materials, including fly ash, silica fume, and glass powder, are recognized for their capacity to alleviate Alkali-Silica Reaction (ASR) through their interaction with calcium hydroxide, resulting in the formation of calcium silicate hydrate (C-S-H), which diminishes the availability of alkalis that facilitate ASR. The efficacy of these materials is contingent upon their compositional characteristics and the particular conditions under which they are utilized in concrete formulations. While pozzolanic by-products demonstrate substantial effectiveness in mitigating ASR, their compatibility with admixtures and overall performance can fluctuate based on the specific chemical and physical attributes of the materials employed. The selection of pozzolanic material and its corresponding dosage necessitates meticulous consideration to optimize ASR mitigation and to guarantee the structural durability of concrete edifices [43]. The influence of waste powders (such as fly ash, volcanic powder, and blast furnace slag) and recycled aggregates (including recycled concrete aggregate and recycled brick aggregate) on the mechanical properties, water permeability, water filtration, and durability of pervious concrete has been systematically reviewed and delineated by [42]. It is discerned that the incorporation of an appropriate quantity of solid waste or the application of suitable treatment methodologies to solid waste does not yield adverse effects; rather, it can enhance the performance characteristics of pervious concrete. Consequently, the utilization of solid waste in pervious concrete presents significant prospects for urban infrastructure development and ecological preservation.

## 6. Drainage characteristics of porous concrete (Permeability and Porosity)

[22] Devised a predictive model for concrete porosity through component analysis utilizing machine learning. The design variables include fly ash, superplasticizer, water-to-binder ratio, curing time, ground granulated blast furnace slag, binder, and coarse-to-fine aggregate ratio. [44] employs experimental techniques to evaluate the water penetration resilience and structural stability of pervious concrete under varied conditions. [45] outlines an experimental framework for assessing the water drainage performance of porous concrete filled with soil and sand, aiding in its application for low traffic roads in flood-prone regions. [46] The hydrological dynamics of pervious pavements during rainfall are influenced by multiple factors, leading to the creation of 16 laboratory models to analyse runoff attenuation based on varying surface types and subbase materials through rainfall simulations. [47] employs a straightforward experimental approach to investigate the evaporation rates of various pavement materials outdoors, identifying key factors affecting these rates. [48] introduces a rapid surface infiltration test for evaluating pervious concrete maintenance on small sites, revealing maintenance practices can significantly enhance infiltration rates. [49] findings demonstrate that porous pavements can diminish runoff volumes by over 30% relative to conventional pavements, with potential reductions exceeding 60% when extended detention is incorporated, while also achieving over 90% suspended solids removal from runoff.

## 7. Applications of porous concrete

Porous concrete pavement enhances urban environments by facilitating rapid rainwater infiltration and groundwater renewal. Its permeability maintains soil moisture beneath the surface. This material improves road surface environmental conditions. Additionally, porous concrete reduces vehicle noise, fostering a tranquil atmosphere. During rainfall, the surface remains non-leaky and non-reflective at night, enhancing driver comfort and safety. The material's porosity enables heat absorption, regulating surface temperature and humidity, thereby mitigating urban heat island effects [5].

### **7.1 Removal of Pollutants from stormwater**

[50] Aggregate sizes between 4.75 and 9.50mm demonstrated optimal biological oxygen demand removal, achieving approximately 79%. [51] Incorporating 40% zeolite significantly enhanced porous concrete's capacity to reduce chemical oxygen demand and heavy metals, achieving reductions of 38.6%, 99%, 99%, 99%, and 99%, respectively. [52] summarizes the photo-induced redox responses and hydrophilic conversions facilitating pollutant degradation in stormwater through pervious concrete for purification purposes. The zeolite-containing porous concrete with a sand filter exhibited removal efficiencies exceeding 70%, 90%, 98%, and 70% for COD, turbidity, lead, and TSS, respectively, compared to control porous concrete with significantly lower efficiencies.

### **7.2 Reduction in urban heat Island Effect**

[53] Explains a novel green roof integrating porous concrete and hydroponics, aims to mitigate urbanization impacts through storm water management, pollution control, runoff delay, and biomass production on a reusable substrate. [54] indicate that porous concrete pavement maintains higher daytime temperatures and lower night time temperatures with a larger temperature gradient, demonstrating its role in mitigating near-surface air heating effects.

## **8. Review papers on porous concrete**

[11] The study reviews waste materials and industrial by products for designing pervious concrete mixtures and assesses their mechanical performance impact. [55] This review analyses the properties and advantages of Porous Concrete (PC) pavements, noting their limited adoption due to insufficient research and awareness. Mechanical and hydraulic capacities are identified as the primary properties studied, with respective focuses of 36% and 41%. The geographical distribution of PC research is evaluated, highlighting global interest and trends. An anticipated annual growth rate of 2.51% in PC-related research publications from 2019 to 2030 indicates a burgeoning field. A total of 171 publications were identified in the Scopus database, representing research activity from 2009 to 2018. [56] This review encompasses research advancements in pervious concrete, focusing on experimental investigations of its mechanical and hydrological properties. The findings suggest that pervious concrete mitigates the need for retention ponds and reduces associated costs. Its primary application lies within the pavement industry, although it is versatile for multiple uses. [57] The research culminates in a comprehensive review of porous pavement technology, supported by extensive literature and expert interviews. The resulting volume organizes the field, illustrating that well-designed porous pavements offer ecological benefits and cost savings, while poor design leads to failures such as clogging and structural issues.

## **9. Case studies and life cycle assessment on porous concrete**

[58] Delineates fundamental attributes of pervious concrete and reviews prominent global research, emphasizing its potential application in road construction within Western Balkan nations, specifically Serbia. [59] The authors propose that the Sponge City framework and its associated guidelines foster integration of eco-hydrology concepts, climate change assessments, and long-term socio-environmental considerations in urban planning.

## **10. Future Directions in Research**

Comprehensive assessments of pervious concrete with pozzolanic by-products are essential for evaluating its sustainability benefits throughout its design life. Such evaluations will inform models for analysing CO<sub>2</sub> emissions and cost considerations, providing a holistic view of environmental and economic impacts.

Meticulous assessment of leaching performance in pervious concrete with pozzolanic materials is crucial for establishing its safe and effective use as a construction material.

An investigation into the thermal and sound insulation properties of pervious concrete is necessary to enhance its application in various pavement scenarios.

Rigorous durability tests under harsh conditions are essential for understanding the long-term performance of pervious concrete, emphasizing its potential as a sustainable construction alternative.

## **11. Conclusion**

- 1:3 to 1:4 cement aggregate ratio gives optimum strength and porosity in porous concrete.
- Shape and size of coarse aggregate plays a crucial role in strength of porous concrete.
- 9.5mm to 19mm size and uniformly graded round shaped coarse aggregate are considered to give good compressive strength as well as porosity.
- Use of admixtures such as superplasticizers and water reducers is crucial for increasing workability of

porous concrete.

- Pozzolan by products such as Fly ash, GGBFS, Silica fume and Rice husk ash helps to make porous concrete more sustainable and durable but does not help significantly to increase compressive strength.
- Use of Porous concrete in urban areas has proved to be effective in reducing urban heat island effect as well as in case of flood mitigation.

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