The Influence of Cementitious Materials on the Performance of Porous Concrete: A Review

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ABSTRACT

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| Porous concrete is an eco-friendly building material that harmonizes with nature, and it has been extensively studied due to its excellent permeability, breathability, sound absorption, and dirt cleaning properties. Based on a comprehensive review of the literature, this study summarizes the current research status on the effects of various cementitious materials on the mechanical, permeability, and durability properties of porous concrete (PC). The results indicate that a rational combination of cementitious materials and supplementary cementitious materials (such as cement, silica fume, fly ash, metakaolin, etc.) helps to balance and optimize the mechanical, permeability, and durability properties of porous concrete. For example, silica fume at 8% replacement improved the compressive strength to 25.6 MPa, while fly ash at 40% replacement achieved a compressive strength of 32.1 MPa. The study also explores various factors affecting the performance of porous concrete, laying a theoretical foundation for its practical application in engineering projects. |

*Keywords: Porous concrete, cementitious materials, performance impact*

1. INTRODUCTION

With the extensive use of concrete and asphalt pavements in urban areas, the proportion of impermeable surfaces has significantly increased. When impermeable surfaces account for more than 75% of the total pavement area, rainwater becomes runoff, and if the volume of runoff exceeds the drainage system's capacity, it can lead to catastrophic flooding [1]. Additionally, the impermeability of urban surfaces exacerbates the urban heat island effect, contributing to issues such as pavement glare, road noise, and structural deterioration [2,3]. To mitigate these challenges, China has introduced innovative strategies such as "Sponge City" and "Smart City" initiatives [4,5].Porous concrete, an eco-friendly building material, is characterized by its high porosity (typically 15%–25%), which endows it with excellent permeability (permeability coefficient of 1.0–10.0 mm/s) and lightweight properties (density of 1,600–2,200 kg/m³). While its mechanical properties (compressive strength of 10–40 MPa) are generally lower than those of traditional concrete, its versatility makes it suitable for various applications, including pavements, base layers, urban streets, sidewalks, parking lots, permeable walkways, and drainage trenches. Existing research indicates that factors such as raw material composition, water-reducing agent usage, reinforcing materials, and mix design significantly influence the mechanical properties, microstructure, porosity, permeability, and durability of porous concrete [15,16].

The raw materials for porous concrete mainly include aggregates, cementitious materials, water, and water-reducing agents. Research has shown that using geopolymer as the cementitious material for preparing porous concrete results in poor strength and performance, with compressive strength values typically below 15 MPa. This is attributed to the lower reactivity of geopolymers compared to traditional cement [7]. Therefore, ordinary Portland cement is currently widely used as the primary cementitious material. However, up to now, there have been few systematic studies on the effects of the composition and mix design of porous concrete materials on the mechanical and permeability properties of porous concrete [17,18]. The rapid growth of porous concrete pavement technology both domestically and internationally has prompted an increasing number of studies on the porous concrete material itself and the structure of porous concrete pavements. This paper summarizes the effects of cementitious materials on the performance of porous concrete and provides theoretical references for its application in practical engineering.

2. Cementitious materials and supplementary cementitious materials

　　Porous concrete is composed of cementitious materials, supplementary cementitious materials, aggregates, water, and admixtures, with a certain amount of pores [19,20]. The cementitious materials and supplementary cementitious materials include cement, silica fume, fly ash, blast furnace slag, metakaolin, etc. Common forms of these materials are shown in Figure 1. Cement, as a commonly used cementitious material, can enhance the strength and durability of porous concrete. However, the production of cement generates a large amount of carbon dioxide, which pollutes the environment. Using supplementary cementitious materials such as silica fume, fly ash, blast furnace slag, metakaolin, and industrial solid wastes to partially replace cement can reduce the amount of cement used and also affects the performance of porous concrete. Moreover, the amount of materials used will also impact the performance of porous concrete. For example, the amount of water used is directly proportional to the fluidity of the concrete and inversely proportional to the mechanical properties. In summary, the amount of cementitious and supplementary cementitious materials, as well as the quantities of each component, will have a significant impact on the performance of porous concrete.

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| **(a)** | **(b)** | **(c)** | **(d)** | **(e)** |
| **Figure 1: (a) Cement (b) Silica fume (c) Fly ash (d) Blast furnace slag (e) Metakaolin** |

Porous concrete is composed of a cementitious material, supplementary cementitious materials, and water that combine to form a paste that binds the aggregates. The type and particle size of the cementitious and supplementary cementitious materials are important factors affecting the properties of porous concrete. Researchers often use cement as the primary cementitious material when preparing porous concrete and partially replace it with supplementary cementitious materials such as silica fume, fly ash, blast furnace slag, metakaolin, etc., to explore their impact on the performance of porous concrete. The chemical compositions of these materials are shown in Table 1.

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|  | 42.5Cement | 52.5Cement | Silicon fume | Fly ash | Blast furnace slag | Metakaolin |
| SiO2 | 21.6 | 21.2 | 90.12 | 42.10 | 30.7 | 54.3 |
| CaO | 63 | 64.18 | 0.87 | 6.26 | 47.5 | 0.39 |
| Al2O3 | 2.35 | 4.6 | 0.94 | 28.60 | 9.8 | 40.26 |
| Fe2O3 | 0.2 | 3.5 | 1.62 | 14.40 | 2.1 | 2.28 |
| MgO | 2 | 3.5 | \* | 2.60 | 3.8 | 0.08 |
| K2O | \* | \* | 1.21 | 2.40 | \* | 0.5 |
| SO3 | 2.8 | 2.2 | 0.29 | 0.61 | 4.4 | \* |
| Na2O | \* | \* | \* | \* | 1.07 | 0.12 |
| LOI | 4 | 1.4 | 2.87 | \* | 0.63 | \* |
| References | [8] | [9] | [10] | [11] | [12] |
| **Table 1: Chemical Composition of Cementitious Materials** |

3. The Influence of Cementitious Materials and Supplementary Cementitious Materials on the Performance of Porous Concrete

Silica fume, fly ash, blast furnace slag, and metakaolin contain components such as silicon dioxide, calcium oxide, and aluminum oxide. These components, when combined with water, form C-S-H gel and ettringite, filling the pores and cracks in concrete, providing concrete with better mechanical properties and durability.The Comparative Study of the Influence of Replacement Ratio of Supplementary Cementitious Materials on the Properties of Porous Concrete as Shown in Table 2. In the experiment using silica fume as a substitute for cement, Sujit Kumar Pradhan[9] found that replacing 8% of cement with silica fume resulted in the highest mechanical properties. The compressive strength of the porous concrete reached 25.6 MPa, while the flexural strength and tensile strength increased by 18.2 MPa and 3.1 MPa, respectively. In the experiment using fly ash as a substitute for cement, Jemimah Carmichael[10] studied the effect of 0%-50% nano-fly ash content on the mechanical properties of porous concrete. The experiment showed that when the replacement amount of fly ash is 40%, the compressive strength of the porous concrete is the highest, which is 9% higher than the mixture without nano-fly ash; in addition, Gelong Xu[4]’s research showed that the long-term hydration performance of fly ash reduces the initial hydration heat of porous concrete, reducing the formation of micro-cracks in the early stage of curing, and ultimately further contributes to improving compressive strength, durability, and resistance to drying shrinkage. In the experiment using metakaolin as a substitute for cement, S. Bright Singh and M. Murugan[12] studied the effect of 0%-20% metakaolin content on the properties of porous concrete. The results showed that the optimal content of metakaolin is 15%, at which point, the compressive strength, splitting tensile strength, and flexural strength of the admixture are increased by 39.25%, 15.26%, and 18.70% respectively compared to the conventional cement admixture of the corresponding aggregate size, and at the optimal content, the porous concrete showed good bearing capacity, crack resistance, and energy absorption in static load tests, cyclic load tests, and impact load tests.

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| Material | Replacement (%) | Compressive Strength (MPa) | Flexural Strength (MPa) | Tensile Strength (MPa) |
| Silica Fume | 8 | 25.6 | 18.2 | 3.1 |
| Fly Ash | 40 | 32.1 | 19.5 | 3.5 |
| Metakaolin | 15 | 28.3 | 17.8 | 3.3 |

**Table 2: Comparative study on the properties of porous concrete with different blending material replacement ratios**

Scholars have also studied the preparation of porous concrete using industrial solid waste and geopolymer as cementitious materials. Xingliang Yao et al. [13] utilized industrial solid waste to prepare lightweight porous concrete (RLPC), obtaining a cementitious material by sintering a mixture of aluminum dust, desulfurization gypsum, carbide slag, and red mud. Subsequently, they mixed this with other solid wastes (14.26% flue gas desulfurization gypsum, 9.9% fly ash, 1% carbide slag) to produce lightweight porous concrete with a 28-day compressive strength of 3.57 MPa. Lifecycle assessment comparisons indicated that the preparation of RLPC has a lower environmental impact than traditional foam concrete. J.G. Jang [14] used geopolymer as the cementitious material and coal bottom ash as the coarse aggregate to prepare porous concrete, investigating the heavy metal leaching performance of geopolymer porous concrete. Studies have shown that the heavy metal leaching concentration of concrete prepared using the self-compacting properties of geopolymer is below the MCL/MAC standards, meeting regulatory requirements.

4. Conclusion

　　Based on a review of domestic and international research achievements, this paper investigates the impact of cementitious materials on the properties of porous concrete. The conclusions are as follows: When preparing porous concrete, it is necessary to control the reasonable dosage range of different cementitious materials. When using a single auxiliary cementitious material, a silica fume content of 8%, a fly ash content of 40%, and a metakaolin content of 15% are beneficial for improving the mechanical and durability properties of porous concrete. Additionally, it is feasible to prepare porous concrete using industrial solid wastes (such as flue gas desulfurization gypsum, fly ash, and carbide slag) and geopolymer materials.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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