

Influence of Cementitious and Aggregate Replacements on the Compressive Strength of Pervious Concrete

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Abstract

Pervious concrete is a sustainable construction material designed to enhance stormwater management while maintaining adequate mechanical strength. This study investigates the compressive strength of pervious concrete cubes with various cementitious and coarse aggregate replacements. The research examines the effects of fly ash, silica fume, steel slag, and rubber chips on compressive strength at 7 and 28 days of curing. The results indicate that moderate fly ash replacement enhances compressive strength, but excessive content leads to strength reduction. Similarly, silica fume improves strength up to an optimal percentage. Steel slag shows a positive contribution up to 6% replacement but reduces strength beyond this threshold. Conversely, rubber chips significantly weaken the concrete due to poor bonding within the cement matrix. Additionally, three-component mix variations reveal that higher silica fume content enhances strength, while steel slag and fly ash have mixed effects depending on proportions. The findings suggest that controlled proportions of supplementary materials can enhance pervious concrete performance without compromising its structural integrity.

Keywords: Pervious concrete, compressive strength, fly ash, silica fume, steel slag, rubber chips, cementitious replacements, sustainable construction

INTRODUCTION

Cement concrete pavements (CCPs) are currently one of the most widely used types of road pavements in India. The key benefits of cement concrete pavements include their long service life, rigidity, and ability to support heavy vehicular loads. However, a major drawback of cement concrete pavements is their high initial construction cost [1].

Permeable Concrete Pavement (PCP) is a relatively new concept in road pavement engineering.

Unlike traditional concrete pavements, PCP uses minimal or no fine aggregates, making it highly effective for draining surface water. It is typically used in areas such as pedestrian pathways and parking zones. However, compared to conventional rigid concrete pavements (RCP), the strength of PCP is generally lower [2].

To reduce the overall cost of construction, the use of recycled and waste materials in the pavement mix has been proposed. However, this must be done cautiously to ensure that the strength and durability of the pavement are not significantly compromised, and that these parameters remain within acceptable standards. The supplementary materials considered for this study include fly ash, silica fume, steel slag, and rubber chips [3–5].

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OBJECTIVES

The primary objective of this study is to evaluate the influence of cementitious and aggregate replacements on the compressive strength of pervious concrete. This research aims to investigate the effects of fly ash, silica fume, steel slag, and rubber chips on the mechanical performance of pervious concrete cubes. By analyzing compressive strength at 7 and 28 days of curing, the study seeks to determine optimal replacement levels that enhance strength while maintaining the permeability characteristics of pervious concrete. Additionally, the study aims to identify the limitations associated with excessive replacements, particularly their impact on strength reduction and bonding properties. The research also examines the combined effects of multiple supplementary materials to understand their synergy in enhancing or diminishing strength properties. Ultimately, this study provides insights into sustainable material utilization in pervious concrete, contributing to improved structural performance and environmental benefits in modern construction practices [6–9].

MATERIALS

Cement

Ordinary Portland Cement (OPC) of 53 Grade was used as the primary binder. It conforms to the specifications of IS 12269:2013. Cement plays a crucial role in binding aggregates and providing strength to the concrete upon setting and hardening.

Fine Aggregate

Natural river sand was utilized as the fine aggregate in this study. The sand was sourced locally and conformed to IS 383:2016. The fine aggregate passed through a 4.75 mm sieve and was free from clay, silt, organic matter, and other impurities.

Coarse Aggregate

Crushed granite with a maximum size of 20 mm was used as the coarse aggregate. It complied with IS 383:2016 standards. The aggregates were clean, durable, and free from dust and deleterious substances.

Water

Potable water, free from impurities and adhering to the specifications of IS 456:2000, was used for mixing and curing the concrete specimens. The pH value of the water was recorded as 9, ensuring its suitability for concrete production.

Supplementary Materials

Three types of supplementary materials were incorporated to replace conventional cement and aggregates, enhancing the mechanical properties and sustainability of the concrete mixes [10].

Fly Ash

Class C Fly Ash, a byproduct of coal combustion in thermal power plants, was used as a partial replacement for cement. The chemical and physical properties of fly ash conformed to ASTM C618-93 standards.

Silica Fume

Silica Fume, obtained from the production of silicon and ferrosilicon alloys, was used as a partial cement replacement. It consists of fine spherical particles and significantly improves the strength and durability of concrete. The properties of silica fume were in accordance with ASTM C1240 [11].

Steel Slag

Steel Slag, a byproduct from steel manufacturing, was used as a replacement for both fine and coarse aggregates. The physical and chemical properties of steel slag were assessed to ensure suitability for concrete production. The slag was collected from a local steel manufacturing plant [12].

RESULTS

Compressive Strength of Pervious Concrete Cubes with Cementitious Material Replacements

The compressive strength tests conducted at 7 and 28 days demonstrated that increasing the proportion of Fly Ash led to a progressive increase in strength. However, the conventional mix exhibited 16% higher strength compared to a mix containing 20% Fly Ash. A notable drop in strength was observed at 25% Fly Ash replacement, likely due to excessive Fly Ash content, which may have resulted in poor bonding and reduced compaction. Figure 1 provides a comparative analysis of different mix proportions [13].

Compressive Strength of Pervious Concrete Cubes with Coarse Aggregate Replacements

The incorporation of steel slag in pervious concrete initially resulted in a decrease in compressive strength at 2% replacement. However, as the steel slag content increased to 6%, the strength improved due to enhanced bonding between the coarse aggregates and the cementitious matrix. Beyond 6% replacement, a decline in strength was observed, suggesting that 6% is the optimal replacement level for coarse aggregates using steel slag in pervious concrete [14].

In contrast, the inclusion of rubber chips led to a significant reduction in compressive strength, with reductions ranging from 61 to 70%. Even at a 2% replacement level, a 49% decrease in strength was observed. This trend continued with further increments, primarily due to the weak bonding between rubber chips, coarse aggregates, and the cement matrix. These findings indicate that rubber chips are unsuitable for improving the compressive strength of pervious concrete and may compromise structural integrity (Figure 2) [15].

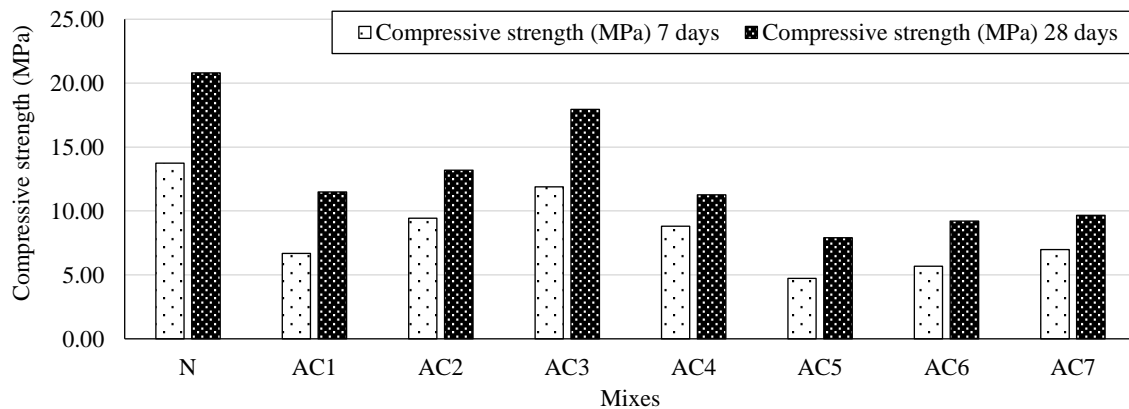


Figure 1. Comparison of cube compressive strength of pervious concrete with cementitious material replacements.

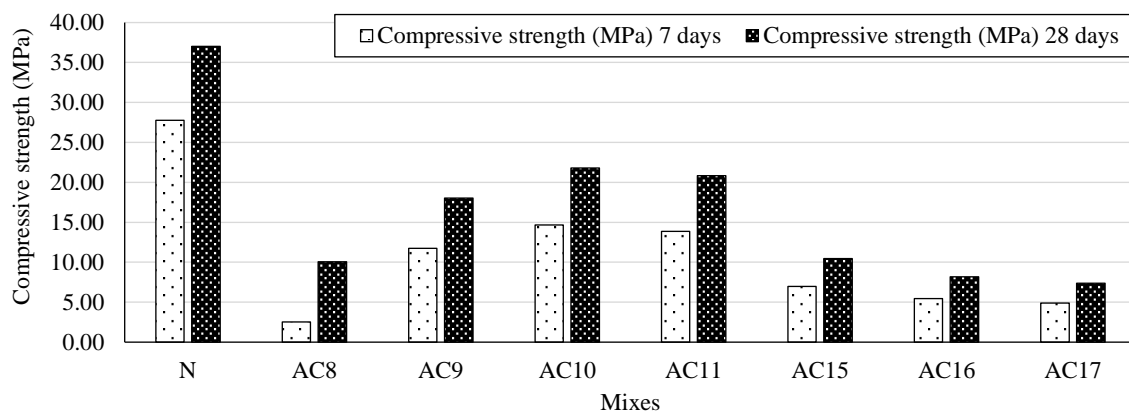


Figure 2. Comparison of cube compressive strength of pervious concrete with coarse aggregate replacements.

Compressive Strength of Pervious Concrete with Two Supplementary Material Replacements

The performance of these mixes varied based on the proportion of supplementary materials used. When 12% silica fume and 4% steel slag were introduced, a decrease in compressive strength was observed. However, increasing the silica fume content by an additional 2% resulted in improved strength, indicating that silica fume enhances the compressive strength of pervious concrete [16].

Similarly, a mix incorporating 15% fly ash and 4% steel slag exhibited a notable increase in strength. However, further increasing fly ash by 5% and steel slag by 2% led to a slight reduction in compressive strength, though this decrease was not significant. These findings suggest that while silica fume has a positive effect on compressive strength, excessive additions of fly ash and steel slag may result in diminishing returns (Figure 3) [17].

Compressive Strength of Pervious Concrete with Three Supplementary Material Replacements

A compressive strength evaluation of pervious concrete containing three supplementary material replacements was conducted. Among the tested mixes, the T3 mix exhibited the highest compressive strength compared to other three-component mix variations.

An increase in silica fume content contributed to higher compressive strength but also resulted in reduced permeability. Conversely, a higher percentage of steel slag led to a reduction in compressive strength. The influence of fly ash was relatively minimal, as its replacement percentage was limited to 15% [18].

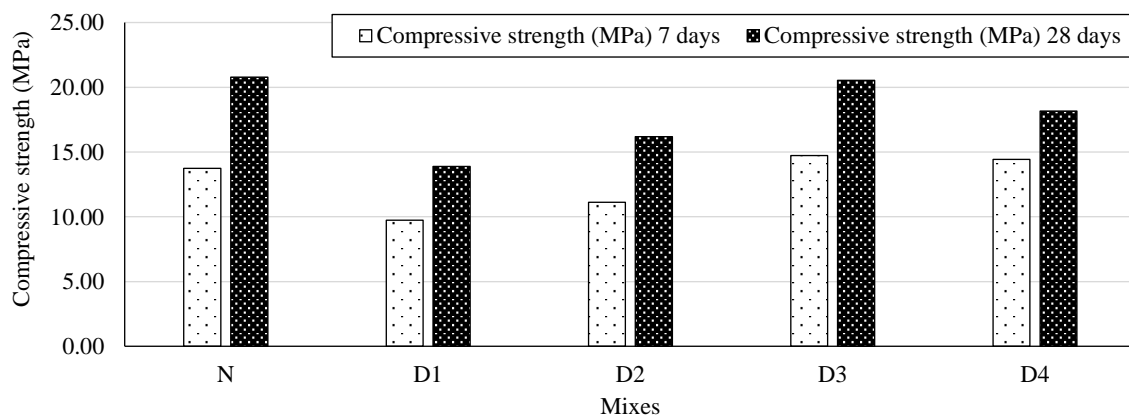


Figure 3. Comparison of cube compressive strength of pervious concrete with two-component replacements.

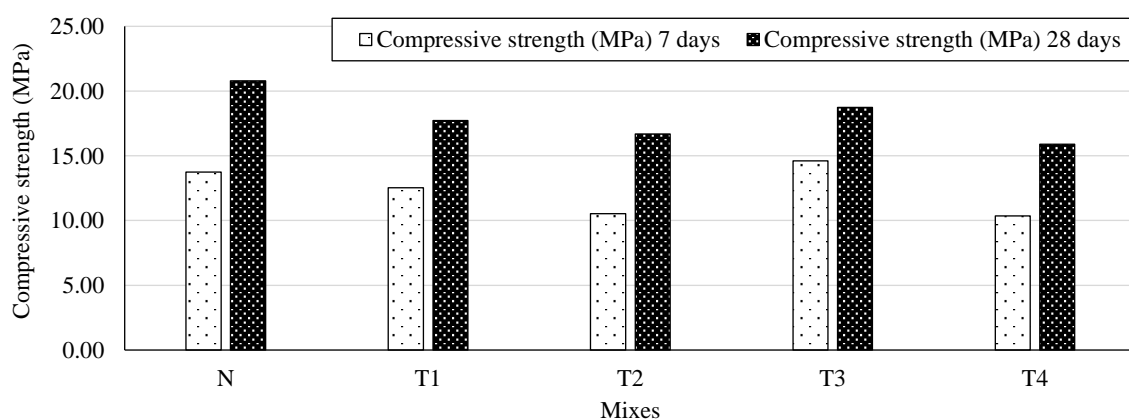


Figure 4. Comparison of cube compressive strength of pervious concrete with three-component replacements.

When compared to the nominal mix, the T3 mix demonstrated the second-highest strength, followed by T1, T2, and T4. It was observed that a 6% steel slag replacement yielded the lowest compressive strength among the three-component mix variations, likely due to the fixed proportions of fly ash and silica fume in the mix (Figure 4) [19, 20].

CONCLUSION

- *Fly ash replacement*: Strength increased up to 20% replacement but declined beyond 25%.
- *Steel slag replacement*: Optimal strength was achieved at 6% replacement; higher levels led to a decline.
- *Rubber chips*: Led to a severe reduction in strength due to poor bonding.
- *Two supplementary materials*: Increased silica fume content improved strength; excessive fly ash and steel slag caused minor reductions.
- *Three supplementary materials*: The T3 mix exhibited the highest compressive strength; excessive steel slag led to lower strength.

These findings emphasize the need for an optimal balance in cementitious and aggregate replacements to achieve the desired compressive strength in pervious concrete.

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