

## Strength and Durability Assessment of Composite Road Pavements with Nano-Enhanced and Polypropylene Fiber-Reinforced Concretes

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### Abstract

Due to Iran's abundant oil resources, asphalt concrete pavements have traditionally been favored in road construction, as well as sidelining alternatives like Portland cement concrete, which is widely used globally. However, with increasing demands on transportation infrastructure and the limitations of traditional materials, there was a growing need for innovative solutions. This study aimed to explore the potential of advanced materials for road pavement construction, specifically focusing on nano-enhanced Fiber-Reinforced Concrete (FRC) as an alternative to conventional materials. The primary objective was to evaluate and compare the mechanical and durability properties of composite road pavements constructed with nano-enhanced FRC and polypropylene fiber-reinforced concrete. The research involved testing the compressive strength, flexural strength, crack resistance, and performance under acidic conditions of concrete samples containing varying percentages of polypropylene fibers (12 mm and 18 mm) and Nano-silica (ranging from 0.3% to 2.5% by weight of cement). The results revealed that while polypropylene fibers reduced compressive strength by 10% and 11% (for 12 mm and 18 mm fibers, respectively), they enhanced crack resistance and cohesion. On the other hand, nano-silica improved compressive strength by up to 7.3% at 1.5% by weight of cement, providing a more durable alternative for road pavements. The combination of polypropylene fibers and Nano-silica was recommended for optimal performance, offering a balanced enhancement of strength, flexibility, and durability.

**Keywords:** *Polypropylene Fiber, Nano-Silica, Road Pavements, Strength, Durability.*

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## Extended Abstract:

### 1. Introduction

The use of additives such as traditional materials, pozzolans (Eshghi et al., 2025), waste materials (Eshghi et al., 2022; Eshghi and Jafary, 2022), and nanomaterials (Eshghi et al., 2024, Eshghi et al., 2024) have attracted the attention of many engineers in recent years to improve the properties of materials used in construction project (Arabani et al., 2017). Reliance on bitumen has limited the exploration and adoption of alternative materials, such as Portland cement concrete, in infrastructure design. However, as the world's second most utilized material, concrete possesses unique properties and is composed of readily available constituents, highlighting its potential as a strategic choice for road construction. In this context, the escalating demands on transportation networks and the inherent challenges posed by traditional road construction methods, especially in asphalt concrete pavements, have prompted a critical reassessment of materials and techniques. Concrete, with its diversified formulations such as High-Performance Concrete (HPC), Ultra-High-Performance Concrete (UHPC), fiber-reinforced, nano-enhanced, self-compacting, and roller-compacted concrete, emerges as a compelling alternative (Mosavinejad et al., 2020). This paradigm shift in material selection, prompted by the continuous evolution of technology, introduces the prospect of enhanced strength, durability, and longevity in road pavements. The deterioration of asphalt concrete pavements due to factors like traffic loads, environmental conditions, and material aging underscores the urgency for innovative solutions. This study embarks on an exploration of advanced materials, specifically focusing on the integration of nano-enhanced Fiber-Reinforced Concrete (FRC) in road pavement construction. This exploration is motivated by the limitations inherent in traditional approaches and seeks to usher in a new era of materials science for sustainable infrastructure. The primary objective of this research is to comprehensively evaluate and compare the performance of composite road pavements constructed with nano-enhanced FRC against those reinforced with polypropylene fiber. The study aims to quantify the mechanical and durability properties of these materials, providing insights into their potential advantages and limitations. This study focuses on the practical application of nano-enhanced FRC in road pavements, addressing gaps in current knowledge regarding its feasibility and advantages over conventional methods. The findings hold significance for civil engineers, infrastructure planners, and policymakers involved in the design and maintenance of road networks.

### 2. Materials and methods

This section will provide an in-depth exploration of the characteristics, properties, and manufacturing considerations associated with Nano-Enhanced FRC and Polypropylene Fiber. Subsequent discussions will extend to the blending of these materials, shedding light on the methodologies employed to achieve an optimal composite mix for road pavement applications. Through a meticulous examination of the materials used, we aim to elucidate the scientific underpinnings that guide our study and contribute to the advancement of composite road pavement technology.

### 3. Result and Conclusion

#### 3.1. Summary of Findings

This study aimed to investigate and evaluate fiber-reinforced concrete and compare it with concrete made with nanomaterials (Nano-silica) for use in road pavements. Compressive strength, flexural strength, and durability tests were conducted on 15×30 cm cylindrical specimens and 7×7×28 cm beams at ages 7, 14, 28, and 90 days. The addition percentages of polypropylene fibers (with

lengths of 12 and 18 mm) and Nano-silica were 0.3, 0.5, 0.7, 1, 1.5, 2, and 2.5% by weight of cement. Durability tests were performed on samples treated in a calcium chloride solution at 7, 14, 28, and 90 days.

### 3.2 Implications for Practical Applications

The threefold test results lead to the following conclusions:

1. Polypropylene fibers, with a 2.5% addition, induce a noteworthy 10% and 11% decrease in compressive strength for 12 mm and 18 mm fibers, attributed to the voids they create. This finding necessitates caution when incorporating polypropylene fibers into road pavement concrete mixes, especially in load-bearing areas where compressive strength is pivotal.
2. On the contrary, Nano-silica exhibits a commendable enhancement in compressive strength across all age categories, achieving a maximum growth of 7.3%, with optimal performance at 1.5% by weight of cement. This signifies Nano-silica's potential contribution to improving the load-bearing capacity of road pavements, making the specified optimal percentage a crucial parameter in mix design for road construction projects.
3. The combined use of polypropylene fibers and Nano-silica is suggested for enhanced concrete performance. This recommendation implies a synergistic effect that could harness the positive attributes of both materials. This combination warrants exploration in road pavement applications to achieve a balanced enhancement between polypropylene fibers and Nano-silica.
4. The incorporation of longer polypropylene fibers (12 and 18 mm) results in a substantial growth of 31% and 38% in flexural strength, showcasing their potential to enhance the pavement's resistance to bending and cracking. This is particularly crucial in areas prone to tensile stresses, such as pavements subjected to heavy traffic or thermal cycling.
5. Visual and structural comparisons highlight that polypropylene fibers significantly improve crack resistance and enhance concrete cohesion. This improvement in crack resistance is vital for the durability of road pavements, suggesting a positive role for polypropylene fibers in minimizing and controlling crack formation.
6. Nano-silica, when compared to polypropylene fibers, demonstrates superior performance in acidic environments. Given that road pavements may be exposed to acidic conditions, such as acid rain, Nano-silica's robust performance in such environments positions it as a valuable additive for enhancing the durability of concrete in road pavements.
7. Both polypropylene fibers and Nano-silica offer economic and environmental advantages, presenting potential applications in reducing road deterioration, surface irregularities, and greenhouse gas emissions. Their utilization aligns with modern construction principles, contributing to sustainable road pavement practices through cost savings and environmental benefits.

### 3.3 Limitations and Future Research Directions

The project's limitations include its non-native nature and expensive import of nano-silica to Iran, which affects the examination of higher percentages. The absence of a specialized road laboratory in Guilan province led to the use of ordinary devices, impacting the research's quality. Future research suggestions include combining polypropylene fibers and Nano-silica, testing chloride ion permeability, investigating tensile strength in fiber-reinforced concrete, using higher percentages of Nano-silica, employing larger-sized aggregates, conducting ultrasonic tests, dynamic loading, and assessing electrical resistance in fiber-reinforced and Nano-silica-enhanced concrete.

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