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Exploring Pine Needle Fibers in Concrete to Mitigate Flexural Spalling in Rigid Pavements

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ABSTRACT

The growing demand for durable and low-maintenance transportation infrastructure has increased interest in cement concrete as an alternative to traditional bituminous roadways. Despite its extended lifespan, concrete faces challenges such as low ductility, tensile strength, and susceptibility to spalling, prompting the exploration of innovative solutions. This study explores using pine needle fibers in concrete to improve flexural strength. Various fiber dosages (0.5% to 5% by weight) are tested on specimens (cubes, cylinders, and beams) with a 28-day curing period to evaluate long-term effects. The study employs a comprehensive set of destructive tests, including compression, flexural, and tensile strength assessments, as well as non-destructive tests such as ultrasonic pulse velocity, to thoroughly analyse the structural behaviour of the concrete. Preliminary findings suggest that the addition of pine needle fibers positively influences the mechanical characteristics of the concrete, demonstrating promise in mitigating flexural spalling in rigid pavements. This research improves sustainable pavement materials and enhances concrete pavement performance. The study addresses challenges in transportation infrastructure, paving the way for resilient and sustainable solutions in rigid pavement construction. Early findings show pine needle fibers improve concrete mechanics, notably reducing flexural spalling in rigid pavements. This contributes to sustainable pavement knowledge and offers practical insights for concrete pavement enhancement.

KEYWORDS: Concrete Pavements, Pine Needle Fibers, Sustainable Construction, Flexural Strength, Spalling Mitigation

1. INTRODUCTION

The surging demand for robust and sustainable transportation infrastructure has propelled the exploration of alternatives to conventional bituminous roadways, with cement concrete emerging as a prominent contender. Despite its extended lifespan, concrete grapples with challenges such as low ductility, tensile strength, and susceptibility to spalling, necessitating innovative solutions [1] [2]. This research delves into the transformative potential of incorporating pine needle fibers into concrete mixtures to address these challenges and bolster flexural strength [3]. Emphasizing Fiber Reinforcement Concrete (FRC), the study introduces varying fiber dosages, ranging from 0.5% to 4% by weight [4], into specimens, including cubes, cylinders, and beams of diverse dimensions.

Curing periods of 28 days are meticulously implemented to thoroughly assess the enduring impact of pine needle fiber incorporation on the structural behavior of the concrete. This deliberate timeframe ensures a comprehensive understanding of how the introduced fibers contribute to the long-term performance and durability of the concrete, providing insights critical for sustainable transportation infrastructure.

To comprehensively scrutinize the impact, the research employs an array of destructive tests encompassing compression, flexural, and tensile strength assessments. Additionally, non-destructive tests, including ultrasonic pulse velocity measurements, contribute to a thorough analysis of the concrete's structural behavior [5]. Preliminary findings signify that the inclusion of pine needle fibers exerts a positive influence on the mechanical characteristics, offering a promising avenue for mitigating flexural spalling in rigid pavements [6]. This study not only advances our understanding of sustainable pavement materials but also provides practical insights into enhancing the performance of concrete pavements, aligning with the dynamic needs of transportation infrastructure.

In the broader context of pavement materials and structural integrity. Traditional cement concrete pavements, known for stiffness and mechanical resistance, face vulnerabilities leading to rapid deterioration [7, 8]. Shrinkage cracking, driven by stiffness behavior and limited fatigue resistance, is a major concern. In spite of its prolonged durability, concrete encounters issues such as limited ductility, tensile strength, and vulnerability to spalling, leading to the investigation of innovative remedies. This adds to the collective understanding of sustainable pavement practices and provides valuable practical insights for improving concrete pavement. Fibre Reinforcement Concrete (FRC), incorporating fibers like polypropylene, steel, and synthetics. offers a promising solution. The type and quantity of fibers in the concrete mixture play crucial roles in enhancing structural effects.

2. EXPERIMENTAL METHODOLOGY

2.1 Raw Material for Pine Needle Fiber-Reinforced Concrete (PNFRC)

In crafting Pine Needle Fiber-Reinforced Concrete (PNFRC), careful consideration is given to the selection of raw materials. High-quality Portland cement is chosen, adhering to established standards, ensuring a solid foundation for the concrete mixture [9]. Local sources provide fine and coarse aggregates, meeting the specific requirements for concrete production. Sustainably sourced pine needle fibers are meticulously acquired, prioritizing cleanliness and uniformity in their selection. The water utilized in the concrete mixture strictly adheres to recommended guidelines, guaranteeing its purity and the absence of any impurities. This careful sourcing and adherence to quality standards contribute to the reliability and consistency of the experimental materials, laying a robust foundation for accurate assessments in the research.

2.2 Mix Design, Casting, and Specimen Details

Pine Needle Fiber-Reinforced Concrete (PNFRC) mix design explores fiber dosages (0.5% to 4% by weight) to optimize concrete properties, maintaining a consistent water-cement ratio for uniformity. Precision batching and mixing techniques ensure even distribution of pine needle fibers, enhancing homogeneity [9, 10]. The subsequent casting method, applied to cubes, cylinders, and beams, incorporates consolidation techniques. This comprehensive methodology forms the cornerstone for a thorough exploration of PNFRC's potential in enhancing concrete performance.

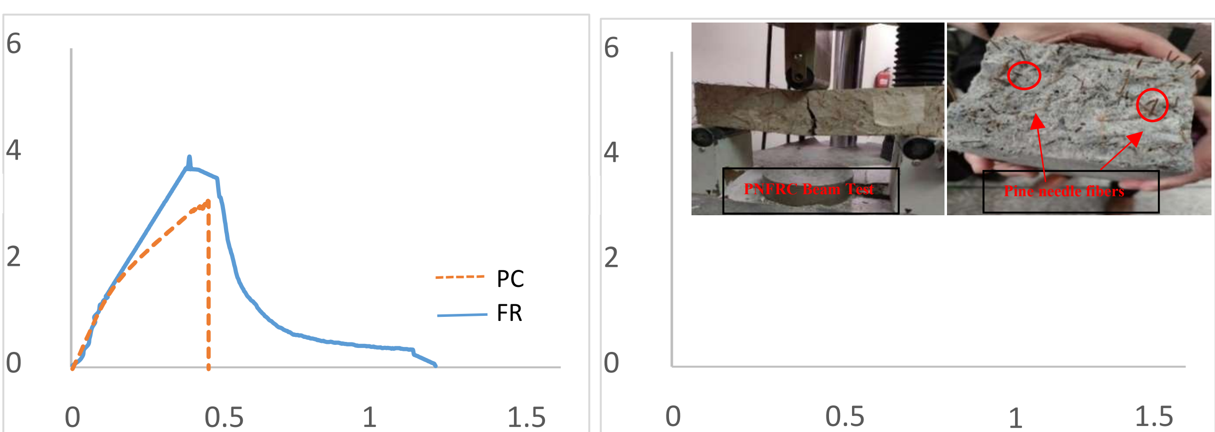
2.3 Testing Method

Specimens undergo rigorous testing using state-of-the-art compressive test machines to evaluate their structural integrity and mechanical properties. Employing standardized protocols, we subject the specimens to controlled compressive forces, allowing the measurement of factors such as compressive strength, modulus of elasticity, and deformation characteristics [11]. Destructive testing procedures, such as compression tests on cubes, flexural tests on beams, and tensile strength tests on cylinders, adhere to relevant standards [12]. Additionally, non-destructive testing methods, including ultrasonic pulse velocity testing, contribute to evaluating the internal quality of the specimens.

3. ANALYSIS AND RESULTS

3.1 Flexural Behaviour

In the exploration of Pine Needle Fiber-Reinforced Concrete (PNFRC) aimed at mitigating flexural spalling in rigid pavements, the flexural behaviour was a key focus. The load-time curves for Portland Cement (PC) and PNFRC are illustrated in Figure 1a) and b), respectively. Notably, the load displacement curve in PC remains stable, indicative of brittle behaviour [13, 14]. In contrast, PNFRC exhibits a distinctive increasing linear behaviour, suggesting enhanced ductility. A critical observation is the sudden drop in the load-carrying capacity of PC post-maximum load, highlighting its brittle nature. Conversely, PNFRC experiences a fall in load-carrying capacity



a) b)

Figure 1. Load Deformation Curve for PCC & PNFRC and Concrete Samples

after the maximum point, followed by a sudden jump. This crucial point signifies the concrete's crack initiation, with fibers taking on additional load, showcasing the material's inherent ductility. This property, significant in the context of utilizing Pine Needle Fibers, offers the potential to enhance the ductile behaviour of concrete in rigid pavements. As illustrates crushed specimens, with Pic 1 showing the three-point test arrangement for the beam-let, revealing flexural cracking initiation crucial for pavement durability. Pic 2 cross-section displays fiber particles, some pulled out and others broken, highlighting their role in enhancing material ductility.

3.2 Flexural Strength, Flexural Energy Absorbed, and Flexural Toughness Index

The analysis extends to quantifying flexural strength, flexural energy absorbed before maximum load (FEM), post-maximum energy absorption (FEP), total energy absorbed in flexure (FE), and Flexural Toughness Index (FTI), detailed in Table 1. The strength in flexure (σ) is derived from the maximum load on the load-time curve of Figure 1. FEM, representing the energy absorbed before the maximum load, is crucial in understanding the material's behaviour under stress [15]. FEP, accounting for post-maximum energy absorption, and FE, representing the total energy absorbed in flexure, provide comprehensive insights into the concrete's performance[16]. The FTI, a ratio between FEM and FE, elucidates the material's ability to absorb energy before maximum load relative to its overall energy absorption capacity. The comparison between PC and PNFRC in Table 1 offers a quantitative perspective on the superior flexural characteristics of Pine Needle Fiber-Reinforced Concrete, emphasizing its potential as a promising solution for mitigating flexural spalling in rigid pavements.

Table1: σ, FEM, FEP, FE and FTI for PC and PNFRC

Specimen	σ (MPa)	FEM (KN)	FEP (KN)	FE (KN)	FTI
PCC	4.1	191.56	0	191.56	1
PNFRC (5%)	4.1	28.85	1.5	24.35	1

4. PRACTICAL IMPLEMENTATION

Comparing Pine Needle Fiber-Reinforced Concrete (PNFRC) to regular concrete (PCC) reveals interesting findings. PNFRC's graph shows a more predictable behavior, especially in situations needing linear behavior, like in beams. Adding Pine Needle Fibers makes the concrete respond more predictably during design, particularly below the neutral axis. Test results also show PNFRC has slightly higher flexural strength than PCC, making it a robust material for pavements. After reaching the maximum load, PNFRC exhibits a subtle increase in resistance, indicating a ductile response. This ductility can potentially reduce the need for reinforcements, enhancing structural safety. Using Pine Needle Fibers as reinforcement is cost-effective and readily available, offering economic and structural advantages. This research encourages further development and implementation of techniques tailored for natural fibers like Pine Needle in concrete, promoting sustainable and economically viable alternatives for resilient transportation infrastructure.

5. CONCLUSIONS

Addressing sustainability in construction, the study explores Pine Needle Fiber-Reinforced Concrete, evaluating its feasibility as a sustainable alternative through material testing. Anticipated outcomes involve validating PNFRC as a sustainable construction material, thereby reducing reliance on concrete and steel. This research not only advances the understanding of innovative materials but also holds practical implications for fostering sustainability in construction, aligning with the imperative for eco-friendly construction practices. The exploration of Pine Needle Fiber-Reinforced Concrete (PNFRC) yields insightful conclusions:

- The incorporation of fibers into concrete significantly enhances its ductility by assuming load during the rupture phase, showcasing the potential to effectively mitigate structural failures.
- The exploration of Pine Needle Fiber-Reinforced Concrete reveals a more linear behavior, particularly up to the maximum load, providing a strategic advantage in applications demanding a predictable and linear response.
- The addition of fibers contributes to the tensile strength of Portland Cement below the neutral axis, playing a pivotal role in the load-carrying capacity of rectangular beams and suggesting potential reductions in reliance on steel reinforcements.

Positive outcomes validate the study on Pine Needle Fiber-Reinforced Concrete, marking the commencement of broader research. Developing a systematic model for integrating natural fibers is crucial for cost-effective designs. Embracing sustainable construction requires ongoing exploration and improvement, and Pine Needle Fibers offer a promising path in this pursuit.

6. ACKNOWLEDGEMENTS

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