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Improving the Design and Performance of Rigid Pavements with Fiber Concrete

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ABSTRACT

The road pavement structure supports vehicle loads and consists of layers designed for comfort, durability, and soil stress reduction. This research aims to enhance rigid pavement performance by adding fine needle fibres to concrete for improved mechanical properties like ductility, fracture toughness, flexural strength, shrinkage, cracking, and split tensile strength. Pine needle fibres are compared with steel and synthetic fibres for corrosion resistance and cost-effectiveness. Mix design of 1:4:2:0.8 (cement: sand: aggregate: water) is used for preparing PC. Pine needle fibres lengths of 37 mm are used for preparation of pine needle reinforced concrete. Improvements found in split energy absorption by 6.95 times, toughness index 6.86 times, maximum deformation up to 6.73 mm and decrease in split tensile strength observed by 13%.. Pine needles are effective in utilization in concrete structure has the potential to be used in cement concrete composites for different structural. The current investigation focuses on to develop low cost-efficient concrete keeping compressive performance. Practical benefits include enhanced durability, reduced structural failure, and guidance for future developments in rigid pavement construction for sustainable infrastructure.

KEYWORDS: Rigid Pavement, Mechanical Properties, Durability, Sustainable infrastructure

1 INTRODUCTION

The pavement structure in roadways, responsible for supporting vehicular loads, consists of layers designed to offer both comfort and durability to vehicles while mitigating stresses on the underlying soil. The primary objective of our research is to enhance the performance of rigid pavements through the incorporation of fine needle fibres as reinforcement materials. This enhancement will specifically target the improvement of various Mechanical Properties, such as Ductility, Fracture Toughness, Flexural Strength, Shrinkage and Cracking Properties, and Split Tensile Strength. Kabashi et al. (2018) reported is brittle material with a low tensile strength and strain capacity. Fibre reinforced concrete is a concrete containing dispersed fibres. a softening response is observed for fibre concrete after cracking. In contrast to plain concrete, the ductility is significantly increased as a result of fibres bridging cracks and its intrinsic brittleness is overcome. Farooqi and Ali (2023) utilized wheat straw, of approximately 18 mm in length and 1% content (by mass of wet concrete), to make the Wheat Straw Reinforced Concrete Road test section. The study is concluded with 34% and 16% more energy absorption capacity and load transfer efficiency, respectively, in the WSRC test section compared to that of the controlled section.

Nobili et al., (2013) carried an experimental investigation of a polypropylene-based fiber reinforced concrete for road pavement. It was reported fiber reinforced concrete technology provides an efficient, safe as well as cost effective design solution for roadways.Fibre-reinforced concrete, distinguished by the dispersion of fibres within the material, exhibits a unique behaviour compared to conventional reinforced concrete. Unlike the latter, which typically undergoes a hardening response post-cracking, fibre concrete displays increased ductility due to the bridging effect of fibres across cracks. This intrinsic brittleness is effectively overcome, contributing significantly to the durability of concrete structures. Maintaining small crack widths in the serviceability limit state is crucial for achieving a durable structure. Ali et al., (2012) Incorporated coconut fibers into concrete which improved its flexural toughness and can be used for low cost concrete structures. Ali and Chouw,(2009) reported coco fiber reinforced concrete with coir rope rebars has the potential to be used as main structural members due to its increased damping and ductility. Hussain and Ali (2018) applied steel fiber reinforced concrete in the tension zone of reinforced concrete slab, resulting in a significant reduction in steel reinforcement. Hayat et al. (2017) utilized pine needle reinforcement in mud houses in Kashmir, Pakistan, resulting enhancement of durability and structural strength. Long and Wang (2021) found that pre-treated Masson Pine Needle Fiber (MPNF) enhances compressive strength, splitting strength, MoR, ductility, and toughness of concrete, indicating feasibility for MPNF incorporation.

The current research aims to enhance rigid pavement performance by adding fine needle fibres to concrete for improved mechanical properties like ductility, fracture toughness, flexural strength, shrinkage, cracking, and split tensile strength. Pine needle fibres are compared with steel and synthetic fibres for corrosion resistance and cost-effectiveness. Mix design of 1:4:2:0.8 (cement: sand: aggregate: water) is used for preparing PC. Pine needle fibres lengths of 37 mm are used for preparation of pine needle reinforced concrete. Improvements found in split energy absorption by 6.95 times, toughness index 6.86 times, maximum deformation up to 6.73 mm and decrease in split tensile strength observed by 13%.. Pine needles are effective in utilization in concrete structure has the potential to be used in cement concrete composites for different structural. The current investigation focuses on to prepare low cost-efficient concrete keeping performance. Practical benefits include enhanced durability, reduced structural failure, and guidance for future developments in rigid pavement construction for sustainable infrastructure.

2 MATERIALS

2.1 Raw Material

To make plain concrete with standard materials: Portland cement, Lawerencepur sand, and aggregate (max size: 12mm, mix of 12mm and 6mm), using potable water. Pine Needle Fibre Reinforced Concrete (PNFRC) followed the same recipe but added a key component: 37mm pine needle fibres. This addition aimed to evaluate its impact on the properties and performance of the resulting fibre-reinforced concrete.Mature pine tree leaves from Shakar Paria, Islamabad, wash to eliminate surface dust, the pine needles are meticulously dried for optimal usage. The fibres were then manually cut to a precise 37mm length, ensuring uniform dimensions. The detailed process enhances fibre quality, contributing to the overall effectiveness of the resulting material in construction applications.

2.2 Mix proportion and casting procedure

PC Mix: 1:4:2 (cement: sand: aggregate), w/c ratio 0.82. The components are mixed simultaneously in a drum mixer, and water is added after 1 minute, followed by rotation for 5 minutes. For the Fiber-Reinforced Concrete (FRC) mix, 0.5% pine needles are added, maintaining the same w/c ratio. The layering technique involves placing 1/3 of the materials in 4 layers, mixing 2/3 of the water for 4 minutes, and then mixing the remaining 1/3 of water for 2 minutes. The mixture is compacted in moulds in 3 layers. The specimens include cylindrical ones (height 200mm, diameter 100mm) for compressive and split tensile tests, and beams (100mm x 100mm x 450mm) for flexural strength tests. Refer to Table 1 for precise specimen dimensions.

2.3 Testing Procedure

Concrete properties were evaluated through standardized testing procedures aligned with ASTM standards. Slump tests for Plain Concrete (PC) and Fibre Reinforced Concrete (FRC) followed ASTM C143 guidelines. Split tensile tests, assessing resistance to tensile forces, adhered to ASTM C494/496M-11 standards. These systematic testing methods guarantee consistency and facilitate accurate comparisons between PC and FRC, ensuring well-defined and widely accepted methodologies in the construction and materials testing industry.

3 ANALYSIS OF TEST RESULTS

3.1 Slump

Table 1 compares slump values between Plain Concrete (PC) and Fibre Reinforced Concrete (FRC), with PNRC exhibiting a lower slump. The table also shows a higher water-to-cement (w/c) ratio in PNRC, primarily due to increased water needs for workability with pine needle fibres. The decreased slump in Mix Pine Needle Fibre is linked to water absorption by the pine needles during mixing, reducing workability. Despite the lower slump, pine needle fibres enhance mechanical properties, compensating for reduced workability and contributing to improved strength and durability.

Table 1: Slump Result

S. No	Concrete Type	Water Cement ratio	Slump (mm)
1	**PC**	0.82	57
2	**PNRC**	0.82	44

3.2 Split Behaviour

Table 2 shows Split Tensile Strength values for Plain Concrete (PC) and Pine Needle Fibre Reinforced Concrete (PNRC). PNRC exhibits a roughly 13% decrease in Split Tensile Strength compared to PC. In testing, PC undergoes abrupt failure, while PNFRC continues to bear load post-maximum load, with a deflection reaching up to 6.73 mm (Figure 1). PNRC's observed ductility, attributed to fibre presence, allows it to withstand deformation and carry load post-maximum load—a crucial feature for applications requiring controlled deformation and resistance to sudden failure. Figure 1 visually illustrates specimen failure, highlighting the distinct behaviour between PC and PNRC in Split Tensile Strength testing.

Table 2: Max Load, Split Tensile Strength and Deformation

Sr. No.	Concrete Type	Max Load (KN)	Split Tensile Strength (Mpa)	Max Deformation (mm)
1	**PC**	30.55	0.97	4.73
2	**PNRC**	26.96	0.85	6.73

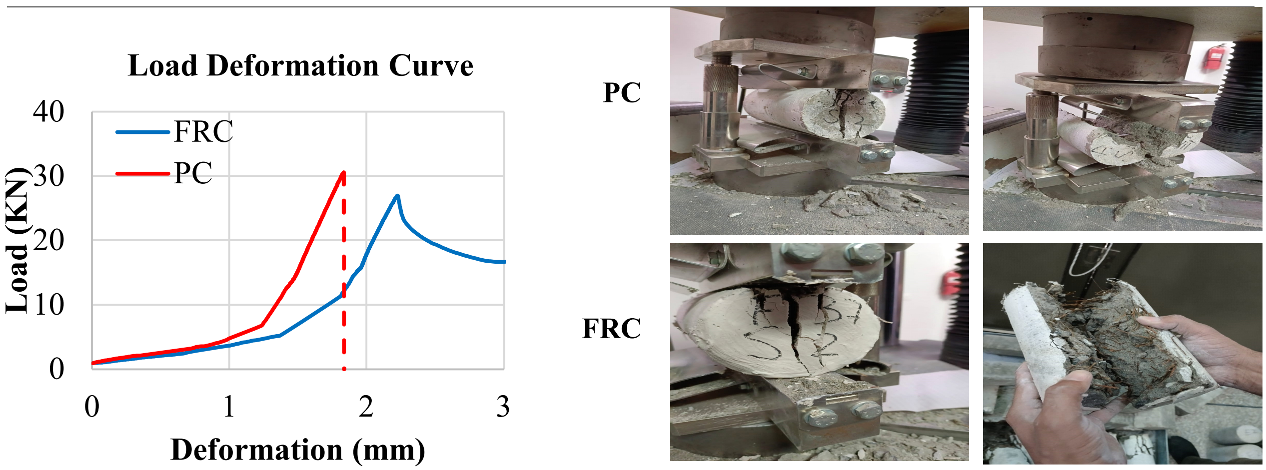

Figure1: a. Split tensile behaviour *b. Tested Specimens*

3.3 Split energy absorption

Fibre Reinforced Concrete (FRC), especially with pine needle reinforcement, offers about 6.9 time's higher energy absorption than Plain Concrete (PC) as shown in table 3, showcasing improved toughness. The toughness index consistently remains 6.86 times higher for FRC, underlining its superior performance and resilience. Pine needle fibres enhance energy absorption, making FRC ideal for robust and durable applications.

Table 3: Split Energy Absorption and Total Index

Sr. No.	Concrete	E1 (Nm)	E2 (Nm)	TE (Nm)	TI(-)
1	**PC**	14.77	0	14.77	1
2	**FRC**	15.01	87.93	102.94	6.86

4 PRACTICAL APPLICATION

The study evaluates the influence of Pine Needle Fibre Reinforced Concrete (PNFRC) on mechanical properties, including ductility, fracture toughness, flexural strength, shrinkage, cracking, and split tensile strength. PNFRC, derived from natural pine needle fibers, enhances tensile strength and strain capacity, displaying increased ductility through fiber bridging across cracks. Compared to steel and synthetic fibers, PNFRC offers potential advantages like corrosion resistance and cost-effectiveness. The research explores various concrete samples, including traditional plain concrete, to understand how different fibers affect mechanical properties, anticipating improvements in pavement design and durability. Despite a decrease in split tensile strength, PNFRC exhibits unique behavior with heightened ductility and energy absorption, showcasing the potential of pine needle fibers in structural applications. This research contributes to sustainable and resilient infrastructure in rigid pavement construction, suggesting future developments.

5 CONCLUSIONS

The experimental study conducted to investigate the impact of incorporating Pine Needles Mix design of 1:4:2:0.8 (cement: sand: aggregate: water) is used for preparing PC. Pine needle fibres lengths of 37 mm are used for preparation of pine needle reinforced concrete. Specimen were cast for both PC and PNRC and their behavior under flexure were studied.

- Slump values decreased for PNRC as compared to PC
- Split tensile strenght for PNRC decreased by 13%
- PNRC absorbed 6.9 times more energy and toughness index observed to be 6.86 times higher than that of PC.
- Despite PNRC's decrease in split tensile strength increased ductility and energy absorption, showcasing the potential of pine needle fibers in structural applications..

PNFRC exhibits lower split tensile strength but unique behaviour, including increased ductility and energy absorption, making it promising for structural use. The study highlights practical benefits, emphasizing enhanced energy absorption, toughness, ductility and overall durability. The research explores using pine needle fibres to overcome concrete brittleness, offering corrosion resistance and cost-effectiveness.

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