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Improving the Concrete Slab Insulation by using Pine Needle Fiber

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ABSTRACT

Improving the thermal efficiency of roof slabs is crucial in tropical climates to mitigate the operational energy consumption of buildings, as heat transfer through roofs significantly influences this aspect. Incorporating passive solutions becomes imperative to address and optimize the thermal performance of roof slabs in such environments. Cracks in the slabs increases the thermal conductivity, adversely increases the heat transfer rate through slabs. Enhancing the flexural, compressive, and splitting tensile strengths of concrete presents a viable approach to controlling the rate of cracking in concrete slabs by using pine needle fibre, thereby mitigating thermal conductivity. Results indicates that longer fibres and higher fibre content provide higher energy absorption. It finds application in slabs for insulation purposes due to its lightweight nature reducing the overall density of the concrete, making it suitable for insulating properties.

KEYWORDS: Thermal efficiency, Roof slab. Passive solutions, Pine needle fibre, Thermal conductivity

1 INTRODUCTION

Reducing building energy consumption, particularly in terms of heat loss, not only lowers cooling and heating expenses but also contributes to improved sustainability. The enhancement of thermal insulation is a key factor influencing the energy efficiency of concrete structures. In contemporary construction and the building industry, there is a notable emphasis on providing high thermal insulation concrete to enhance the long-term energy performance of buildings. Insulating buildings is crucial for saving energy in homes, businesses, and public spaces [1]. The development of insulated concrete aims to minimize heat losses or gains across the building envelope. It involves using materials with high thermal inertia, capable of storing and delaying the conduction of heat through structural elements. Achieving thermal conductivity involves establishing a zero temperature difference across the gap and the necessary temperature difference across the specimen pieces. This approach contributes to more energy-efficient and sustainable buildings in service. To ensure construction sustainability, prioritize organic materials safe for human health. [2]. Sustainable building design emphasizes cutting energy use, greenhouse gas emissions, and using natural, renewable, recyclable, and locally available eco-friendly materials. [3].

Fiber-reinforced concrete (FRC) is a composite building material comprising a cement-based matrix with randomly dispersed fibers. The incorporation of these fibers enhances the post-cracking tensile strength and positively influences the fracture energy, thereby improving the structural response at both the serviceability (SLS) and ultimate (ULS) limit states. [4]. Over the years, Fiber-Reinforced Concrete (FRC) has predominantly found application in elements where the ramifications of possible failure are minimal. In recent years, the exploration of sustainable and eco-friendly materials in construction practices has gained significant attention. One promising avenue is the integration of natural fibers into concrete formulations to enhance both structural performance and environmental sustainability. Among these natural fibers, pine needles have emerged as a unique and renewable resource that exhibits potential benefits, particularly in improving the insulation properties of concrete slabs.

Concrete, a widely utilized construction material, possesses excellent compressive strength but often falls short in terms of thermal insulation. The incorporation of pine needle fibers into concrete slabs offers an innovative solution to address this limitation. Pine needles, as a by-product of forestry activities, are abundant and renewable, making them an attractive candidate for sustainable construction practices. Utilization of pine needle reinforcement in mud houses in Kashmir, Pakistan, resulting enhancement of durability and structural strength [5]. Pre-treated Masson Pine Needle Fiber (MPNF) enhances compressive strength, splitting strength, MoR, ductility, and toughness of concrete, indicating feasibility for MPNF incorporation [6]. Concrete specimens containing 20% pine reduced thermal conductivity by 24.7% [7]. In the study, adobe blocks without fibers showed the highest thermal conductivity at 0.769 W/m.K, while those with 4% fiber content, specifically straw or pine needle, exhibited lower values: 0.589 W/m.K and 0.682 W/m.K, respectively. [8]

The performance of concrete slab relies significantly on the compressive, tensile, and flexural strengths of concrete, with particular emphasis on the crucial role played by tensile strength in crack control. Acting as effective "crack arresters," these fibers contribute to the overall mechanical stability and impact resistance, even with relatively low proportions of natural fibers incorporated into the composite material. PNRC's slump reduced compared to Plain Concrete (PC) due to fiber absorption of water, while its split tensile strength dropped by 12.2%. Despite this, PNRC absorbs 6.9 times more energy than regular concrete, showcasing its potential for insulation in slabs due to its lightweight and energy-absorbing properties.

2. EXPERIMENTAL PROCEDURES

2.1 Research Resources

The preparation process of pine needle fibers involved initial washing to eliminate surface dust. Subsequently, the cleaned pine needles were thoroughly dried. The fibers were then precisely cut to a length of 62.5 mm, as illustrated in Fig. 1. For the formulation of plain concrete, a mixture of ordinary Portland cement, local sand, and normal-sized aggregates (12mm and 6mm) was employed, along with water. In the development of Pine Needle Fiber Reinforced Concrete (PNFRC), the same fundamental components traditionally used in concrete were employed. Additionally, pine needle fibers were introduced into the mixture to improve the material's characteristics. These fibers were of different lengths, with a specific emphasis on using fibers that measured 62.5mm. This particular length was selected to optimize the reinforcing properties and enhance the overall performance of the concrete.

Figure 1a. Pine Needle fibers *b. Cement, sand, aggregate and PNF*

2.2 Mix proportions and casting procedure.

For Plain Concrete (PC), the mix ratio was 1:4:2 (cement: sand: aggregate). In Fiber Reinforced Concrete (FRC), 5% pine needles were added to the mass of cement, maintaining a constant water-to-cement ratio of 0.82 for both. PC ingredients were simultaneously mixed for one minute, followed by water addition and five more minutes of mixing. FRC utilized a layering technique, with water added in two stages. Specimens were cast in, split tensile strength test.

2.3 Testing Procedure

Slump test was performed for both PC and FRC as per ASTM C143 [9]. All specimens underwent a 28-day curing period before testing. To facilitate clear crack identification, a white wash was applied to all specimens prior to testing. For the determination of split tensile strength in concrete cylinders, universal testing machine with a 5000 kN capacity was utilized. Due to the non-smooth surfaces of FRC specimens, plaster of Paris was applied to cap all cylinders, ensuring uniform loading. The testing of PC and FRC concrete cylinders for split tensile strength adhered to the ASTM C494/496M-11 standard [10].

3. ANALYSIS OF TEST RESULTS

3.1 Slump test

Slump test performed for PC and FRC are shown in Figure-2. It is to be noted that FRC has less slump then that of PC. Table 1 shows the w/c ratio of Plain concrete and FRC and slump results. The less value of slump for Mix pine needles fiber is due to absorption of water by pine needles which resulted in reduced workability.

Figure. 2 Slump Measurement

Table 1: Slump Test Result

S. No	Concrete Type	w/c ratio	Slump (mm)
1	**PC**	0.82	57
3	**PNFRC**	0.82	25

3.2 Split Behaviour

Table 2 shows Split Tensile Strength values for Plain Concrete (PC) and Pine Needle Reinforced Concrete (PNRC). PNRC exhibits a roughly 13% decrease in Split Tensile Strength compared to PC. In testing, PC undergoes abrupt failure, while PNRC continues to bear load post-maximum load, with a deformation reaching up to 6.7 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**	30.5	0.9	4.7
2	**PNRC**	26.9	0.8	6.7

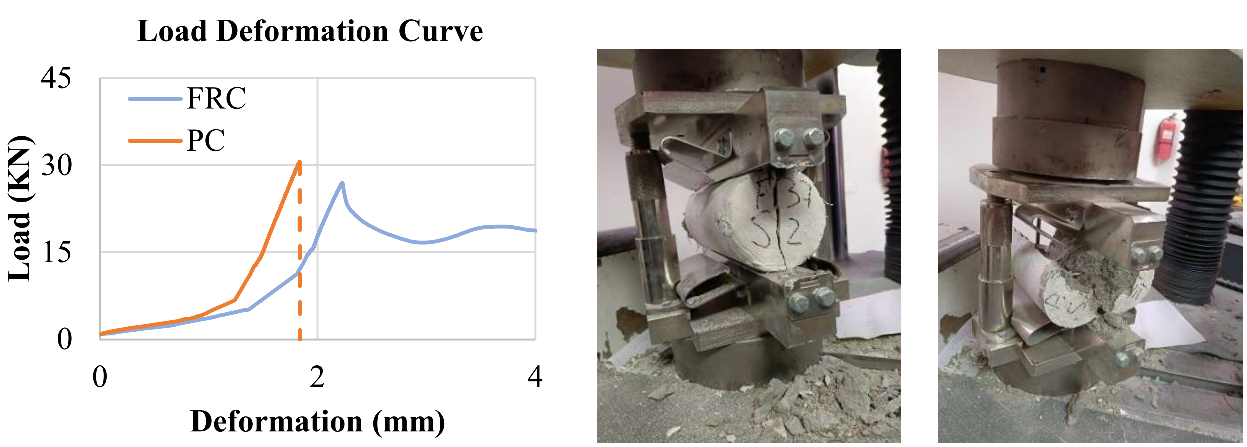

Figure 3: a. Split tensile behaviour, b. Tested Specimens

3.3 Split energy absorption

Fibre Reinforced Concrete (FRC), particularly when reinforced with pine needles, demonstrates a significantly heightened capacity for energy absorption compared to Plain Concrete (PC), as evidenced by the data presented in table 3. This enhancement in energy absorption translates to approximately sevenfold greater resilience in FRC compared to PC, thus illustrating a notable improvement in toughness. Across various scenarios and tests, the toughness index consistently registers at 6.86 times higher for FRC, underscoring its superior performance and resilience in practical applications. The incorporation of pine needle fibres plays a pivotal role in augmenting the energy absorption capabilities of FRC, rendering it an optimal choice for endeavours requiring robustness and long-term durability.

Table 3: Split Energy Absorption and Total Index

Sr. No.	Concrete	E1 (Nm)	E2 (Nm)	TE (Nm)	TI(-)
1	**PC**	14.7	0	14.7	1
2	**PNRC**	15.0	87.9	102.9	6.96

4. PRACTICAL IMPLEMENTATION

Pine needle reinforced concrete (PNRC) slabs find practical applications in sustainable building construction, offering improved thermal insulation, reduced cracking, and enhanced durability. Their use is beneficial in areas requiring enhanced flexural strength, erosion control on sloped surfaces, and cost-effective construction. FRC is also suitable for aesthetic and decorative applications, providing a natural appearance. Additionally, it offers fire resistance, making it applicable in structures prioritizing fire safety. Thorough testing ensures compliance with standards, and ongoing research may expand its applications in the construction industry.

5 CONCLUSIONS

In an experimental investigation to assess the impact of Pine Needle Fibers on the mechanical properties of concrete, the following conclusions were drawn from the obtained results:

- The slump PNRC decreased in comparison to Plain Concrete (PC), attributed to water absorption by the fibres.
- Split tensile strength of PNRC was decreased by 12.2 %.
- PNRC demonstrated the absorption of 6.9 times more energy than reference concrete

Despite PNRC's decrease in split tensile strength it finds it application in slabs for insulation purposes due to its lightweight nature reducing the overall density of the concrete, making it suitable for insulating properties.

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