3rd International Conference on Advances in Civil and Environmental Engineering (ICACEE-2024)

University of Engineering & Technology Taxila, Pakistan

Conference dates: 21st and 22nd February 2024; ISBN: 978-969-23675-2-3

Flexural Characteristics of Pine Needle Reinforced Concrete

Waseem Akram[1,*], Majid Ali[2]

[1]Capital University of Science and Technology, Islamabad, Pakistan

*Corresponding author: wwaseem45@gmail.com

ABSTRACT

The utilization of Fiber Reinforced Concrete as a structural material is steadily on the rise. Conventional concrete is characterized by its brittleness, displaying a flexural strength that falls within the range of 10-15% of its compressive strength. Incorporation of fibers into concrete enhances various mechanical properties, including tensile strength, flexural strength, and ductility. In current investigation mix design of 1:4:2:0.8 (cement: sand: aggregate: water) is used for preparing PC. Pine needle fibers hybrid lengths of 37mm, 50 mm and 62.5 mm are used for preparation of pine needle reinforced concrete. Improvement observed in flexural energy absorption by 2.5 times, toughness index 5 times, maximum deflection up to 13 mm and decrease in modulus of rupture observed by 28%. Ductile behavior also observed with respect to the reference specimens. In general, pine needle fibers has the potential to be used in cement concrete composites for different structural applications. The aim of the present research work is to develop an economically efficient concrete keeping its flexural performance.

KEYWORDS: Flexural strength, Compressive strength, Slump, Toughness

1 INTRODUCTION

The concrete brittleness and poor crack resistance can be controlled up to some extent by reinforcement of randomly distributed fibers. Cracks formation micro- to macro level can be prevented by use of fibers reinforcement. The fibers help to resist the initiation and crack growth from micro- to macro level and provide bridging effect resulting in enhancement of strength and toughness. Huang et al. (2022) reported that conventional concrete also has the disadvantages of high self-weight, low tensile strength, high brittleness, and low toughness. Steel reinforcements are used to increase the flexural strength and reduce deflection. Steel reinforcement is typically the most costly material to utilize. It is now necessary to meet the needed strength while lowering costs. Deng and Zhao (2011) investigated the use of basalt fiber as one of the advanced fibers used in the field of fiber- reinforced concrete, and its potential in improving mechanical properties and contributing to sustainable development. Due to its excellent effects, it has attracted the attention of concrete engineers. Farooqi and Ali (2023) reported efficient energy absorption and load transfer using wheat straw fiber reinforced concrete as compared to reference concrete.

Tayeh et al. (2023) found synthetic waste fibers enhance energy absorption in high-performance concrete. Shen et al. (2023) demonstrated that incorporating polypropylene fibers into

Ultra-High- Performance Concrete (UHPC) resulted in an increase in tensile strength and flexural toughness but led to a decrease in elastic modulus. Wang et al. (2023) showed steel fibers prevent crack propagation and refine patterns. Cogurcu(2022) discovered red pine needle fibers in self-compacting UHPC improve strength; 30 mm and 40 mm enhance both compressive and flexural strength, while 50 mm fibers decrease compressive strength but improve flexural strength. Afraz and Ali (2021) in a study revealed that the flexural toughness index increase while the modulus of rupture (MoR) of banana fiber reinforced concrete decreases as compared to ordinary concrete.

Khan et al. (2018) observed increase in flexural energy absorption for basalt fiber reinforced concrete with increasing length of basalt fiber as compared to reference concrete. Mashri et al. (2021) noted a 1% increase in optimum flexural strength with brown pine fiber, but higher fiber content decreased strength. Green pine fiber reduced flexural strength, and excessive fiber caused bonding loss. Red pine needles enhanced concrete ductility. Chaudhary and Goyal (2015) observed that while flexural strength initially increases, it eventually reaches a limit and starts decreasing. 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.

To the best of author's knowledge, no research has been done on flexural behavior of pine needle reinforced concrete. Pine needle fibers has the potential to be used in cement concrete composites for different structural applications. The aim of the present research work is to develop an economically efficient concrete keeping its flexural performance. The compressive strength and split tensile strength are outside the scope of this paper. The current study employed cement: sand: aggregate: (1:4:2:0.8) water for producing PC. Pine needles of varying lengths (37 mm, 50 mm, and 62.5 mm) are utilized in preparing Pine Needle Reinforced Concrete. Improvement in flexural energy absorption by 2.5 times, toughness index 5 times, maximum deflection up to 13 mm and decrease in MoR observed by 28%. The reason for using this fiber in concrete composites is its low price, local and abundant availability.

2. METHODOLOLGY

Ordinary Portland cement, local sand, crushed stone, potable water used for preparation PC and addition of pine needles having hybrids length for preparation of PNRC. All the materials were put simultaneously in mixer for preparation PC while in case of PNRC layering technique used.

2.1 Materials

The natural fibers were removed from the pine needle trees. Firstly, pine needles were washed to remove the dust on the surface of pine needles and then they were well dried. Secondly, the fibers were cut manually into length of 37 mm, 50 mm and 62.5 mm respectively. For the preparation of PC, ordinary Portland cement, locally available sand, normal size aggregate (≤12 mm with mixed sizes of 12 mm and 6 mm) and drinking water was used. The preparation of PNRC, same ingredient were used with addition of pine needle fibers having varying length 37 mm, 50 mm and 62.5 mm.

2.2 Mix proportions and casting procedure

The mix proportion for PC was 1:4:2 (cement: sand: aggregate). For making PNRC the pine needles were added in 05% by mass of cement. The w/c ratio of 0.82 is kept same for both PC and PNRC. For the preparation of PC mix all the ingredients were simultaneously put into the drum type mixer and the mixer was rotated for one minute. The water in required quantity was then poured into the mixer and the mixer was rotated again for five minutes until a homogeneous mixture was obtained. In case of PNRC, one-third of cement, sand, aggregates and pine fibers were put in the mixer in four layers. The remaining quantities were then added using the same layering technique. After that, two-third of water was added, and the mixer was rotated for about four minutes. The one-third of the remaining water was added, and the drum mixer was again rotated for two minutes. For preparation of PNRC specimens, the prepared homogeneous mixture is then poured in the respective moulds. Each mould is filled in three layers with compaction of 25 blows per layer with the help of temping rod. For compressive and split tensile strength tests, cylinders with height of 200 mm and diameter of 100 mm were cast for both PC and PNRC. For flexural strength test, 100 mm wide, 100 mm deep and 450 mm long beams were cast.

2.3 Testing procedure

Slump test was performed conforming to ASTM standard C143. Beamlets were tested according to ASTM standard C78. Tests are carried out to find the modulus of rupture (MoR), corresponding deflection (Δc), load at first crack (Pcrack) and maximum deflection (Δc) are determined.

3. RESULTS

Results shown decrease in slump and Modulus of rupture for PNRC as compared to the PC. Flexural toughness increased adding reliability to PNRC use. Maximum deflection was observed for PNRC due to bridging effect created by pine needles preventing sudden failure.

3.1 Slump

Slump values noted for PC and PNRC were 57 mm and 13 mm respectively. Note from Table 1. that in case of PNRC there is less slump then that of PC. Water cement ratio remained 0.82 of Plain concrete and PNRC. Increased water cement ratio of PNRC was observed as compared to PC because more water required to make it workable. The less value of slump for Mix pine needles fiber is due to absorption of water by pine needles which resulted in reduced workability. Moreover fiber length was more than the aggregate size resulting in the increased congestion.

Table 1: Slump values

Sr#	Concrete	W/C	Slump (mm)
1	PC	0.82	57
2	PNRC (Hybrid Lengths)	0.82	13

3.2 Flexural behavior

Load deflection curve is shown in the Fig.1. It is to be noted from the Fig. 1 (a) that reference concrete (PC) reaches it ultimate failure quickly without going deformation while PNRC shows ductile behavior by bridging effect. From figure 1(b) it is to be noted that tested specimen of broken in to halves while the specimen of PNRC reached ultimate failure and fiber shown bridging effect resulting in ductile failure. Specimen on the left shows 1st crack development reaching 50% of the depth of flexural member and on the right at ultimate failure it reaches up to 80% of the depth of the member. Deflection up to 13 mm was also observed for PNRC samples. PC has higher flexural strength as compared to PNRC made by Pine needles but the. This strength loss might be due to the weak bonding between fibers and concrete as the fibers were easily pulled out from the failed specimens. Ductile behavior is observed that due to bridging effect created by Pine Needle fiber. However, it needs further investigation into the bonding behavior of pine needle fibers with concrete. This created enhanced toughness in the concrete. The modulus of rupture for PC and PNRC is calculated from load deflection curve. 28% decrease in MoR was observed for PNRC as compared to PC. In a similar type of investigation Afraz and Ali (2021) reported that the flexural toughness index increase while the modulus of rupture of banana fiber reinforced concrete decreases as compared to ordinary concrete.

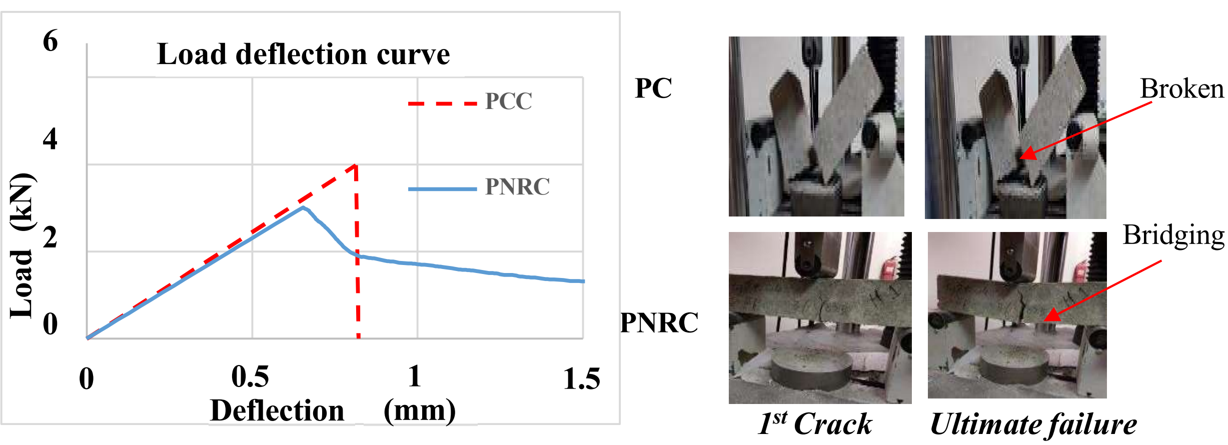

Figure. 1: Flexural behavior (a) Load deflection curve, (b) Tested specimen

3.3 Flexure energy absorption

Energy absorption is found by calculating the area under load-deflection curve. Table 2. Shows that PNRC made by pine needles absorbed 3.3 times more energy than that of ordinary PC.

Toughness index remained 6.4 times higher than that of PC. Addition of fibers made the specimens to withstand the load after the peak value and prevented the brittle failure. It is also to be noted from the Table 2. that load capacity for the PNRC decreased in comparison to that of PC. Resultantly the MoR for the specimen got decreased. Load, MoR and deflections reported are average values for the specimens. PC specimen shown higher load capacity as compared to PNRC but abruptly failed after reaching the maximum load.

Table 2: Max load, Max Deflection, MoR, Flexural Energy and Toughness Index

SR #	Concrete Type	Load (kN)	MoR (MPa)	Deflection (mm)	Em (Nm)	Eu (Nm)	TE (Nm)	TI (-)
1	PC	3.75±0.07	2.25±0.04	5.46±1.21	2.29	-	2.29	1
2	PNRC (HL)	2.70±0.17	1.62±0.1	9.9±2.72	1.20	6.48	7.68	6.40

Em= energy absorbed up to max. load, Eu= energy absorbed from max. load to ultimate load
T.E = total energy absorbed, T.T.I = Total toughness Index = T.E / Em

4 PRACTICAL APPLICATION

Pine Needle Reinforced Concrete (PNRC) presents a promising avenue for sustainable construction practices, offering both structural benefits and environmental advantages. PNRC incorporates pine needles, a renewable and abundant resource, as a substitute for traditional reinforcing materials like steel. This innovative approach not only enhances the performance of concrete structures but also contributes to reducing carbon emissions associated with construction processes. Pine needles are readily available in forests and often considered waste material. By repurposing these needles as reinforcement in concrete, PNRC helps to mitigate the environmental impact of traditional construction practices that rely heavily on non-renewable resources like steel. This aspect aligns with principles of sustainability and resource conservation.

PNRC resistance to cracking and deterioration extends the service life of concrete structures, reducing the frequency of replacements and the consumption of additional materials over time. This aspect is particularly significant in the context of sustainable construction, where longevity and minimal resource depletion are paramount considerations. Overall, Pine Needle Reinforced Concrete represents a compelling solution for eco-conscious construction projects seeking to balance structural integrity with environmental sustainability.

5 CONCLUSIONS

PC and PNRC were made with same mix design of 1:4:2:0.8 and 5% pine needles by mass of cement were added to PNRC. Beamlets were cast for both PC and PNRC and their behavior under flexure were studied. After the analysis of experimental results, following are the conclusions

- Slump decreased for PNRC as compared to PC due to water absorption and congestion created by fibers.
- MoR for PNRC decreased by 34%
- PNRC absorbed 3.3 times more energy and toughness index observed to be 6.4 times higher

than that of PC.

- PNRC can be applied where enhanced durability are essential. Industrial Floors, Seismic Resistant Structures and Precast Concrete Elements.

Slump and MoR decrease for PNRC while the energy absorption and toughness index increase as in comparison to PC.

ACKNOWLEDGMENT

The authors would like to thank all those who helped during the entire research work.

REFERENCES

1. Huang, L., Su, L., Xie, J., Lu, Z., Li, P., Hu, R., & Yang, S. (2022). Dynamic splitting behaviour of ultra-high-performance concrete confined with carbon-fibre-reinforced polymer. Composite Structures, 284, 115155.
2. Deng, W. Q., & Zhao, J. (2011). Structure Characteristics and Mechanical Properties of Fiber Reinforced Concrete. *Advanced Materials Research*, *168*, 1556-1560.
3. Farooqi, M. U., & Ali, M. (2023). A study on natural fibre reinforced concrete from materials to structural applications. Arabian Journal for Science and Engineering, 48(4), 4471-4491.
4. Tayeh, B., Hadzima-Nyarko, M., Riad, M. Y. R., & Hafez, R. D. A. (2023). Behavior of Ultra-High-Performance concrete with Hybrid synthetic fiber waste exposed to elevated temperatures. *Buildings*, *13*(1), 129
5. Shen, D., Liu, C., Luo, Y., Shao, H., Zhou, X., & Bai, S. (2023). Early-age autogenous shrinkage, tensile creep, and restrained cracking behavior of ultra-high-performance concrete incorporating polypropylene fibers. Cement and Concrete Composites, 138, 104948.
6. Wang, X., Wu, Q., & Chen, W. (2023). Experimental Study on the Impact Resistance of Steel Fiber Reinforced All-Lightweight Concrete Beams under Single and Hybrid Mixing Conditions. *Buildings*, *13*(5), 1251
7. Cogurcu, M. T. (2022). Investigation of mechanical properties of red pine needle fiber reinforced self-compacting ultra-high performance concrete. Case Studies in Construction Materials, 16, e00970.
8. Afraz, A., & Ali, M. (2021). Effect of Banana Fiber on Flexural Properties of Fiber Reinforced Concrete for Sustainable Construction. Engineering Proceedings, 12(1), 63.
9. Khan, M., Cao, M., & Ali, M. (2018). Experimental and Empirical Study of Basalt Fibber Reinforced Concrete. Proceedings of the Building Tomorrow's Society, Fredericton, NB, Canada, 13-16
10. Mashri, M. O., Johari, M. A. M., Mijarsh, M. J. A., Ahmad, Z. A., & Elbasir, O. M. (2021). Mechanical Behaviour of Normal Concrete using Fibre of Pine Tree Needle Leaves. Int J. Eng. Adv. Technol., 10, 99-102.
11. Chaudhary, S., Goyal, K., & Shukla, A. (2015). Study of the Properties of Concrete using Pine Needles a natural supplement.
12. Hussain, T., & Ali, M. Utilization of RFC Tension Zone for reinforcement Reduction in Slabs-A Simplified Approach.
13. Hayat, A., Khan, H., Haq, R. U., & Ali, M. Use of Pine-Needle Reinforced Composites in

Kashmir, Pakistan–A Critical Review.
14. Long, W., & Wang, Y. (2021). Effect of pine needle fibre reinforcement on the mechanical properties of concrete. *Construction and Building Materials*, *278*, 122333.
15. ASTM, 1998. Annual Book of ASTM Standards. Designation: C 143/C 143M-97 Standard Test Method for Slump of Hydraulic-Cement Concrete, vol. 04.02, Concrete and Aggregates, ASTM, 89 – 91.
16. ASTM C78/78M, "Standard test method for flexural strength of concrete (using simple beam with third-point loading), ASTM International West Conshohocken, PA.