RESEARCH ARTICLE OPEN ACCESS

Evaluation of Mechanical Properties of Concrete Reinforced with Natural and Synthetic Fibers

Pawan Bairwa [1], Hemant Kumar Sain [2]

[1] M.Tech Student, Department of Civil Engineering, Arya College of Engineering & Research Centre, Jaipur, Rajasthan, India

[2] Assistant Professor, Department of Civil Engineering, Arya College of Engineering, Jaipur, Rajasthan, India

ABSTRACT

Concrete is a popular construction material due to its mechanical strength, ease of production, and affordability. However, it is brittle under tensile loads, leading to rapid crack propagation. Adding fibers to the cement matrix can mitigate these issues by acting as bridges at crack locations, enhancing performance. Fibers can be integrated as fabrics, textiles, or randomly distributed throughout the matrix. Fiber-reinforced polymer composites are increasingly used across various industries due to their attractive properties, and production has significantly increased with simple processing methods. There is a growing trend of using natural waste fibers, such as straw, rice husks, and banana leaves, in polymer composites.

In this study, concrete was prepared using natural powdered fibers combined with synthetic fibers to assess their properties. The results were compared to conventional concrete. Powdered bamboo fiber, ranging from 0% to 30%, was used as a cement substitute in M-30 concrete. Additionally, smples contained optimized bamboo fiber and varying amounts (0.0% to 2.0%) of polypropylene and nylon-66 fibers as admixtures..

Keywords **—**Concrete, Bamboo Fiber, Synthetic Fibers, Non-destructive Test, Fiber Reinforced Concrete, Nylon-66 etc.

I. INTRODUCTION

Fiber-reinforced concrete (FRC) has emerged as a pivotal material in the construction industry, offering enhanced mechanical properties that address the limitations of traditional concrete. The incorporation of fibers into the concrete matrix has revolutionized structural performance, providing improvements in tensile strength, ductility, and crack resistance. These advancements are particularly significant in the context of modern construction demands, which require materials that can withstand increased loads and environmental stresses.

The evolution of FRC began with the addition of steel fibers, but has since expanded to include a variety of synthetic and natural fibers, each contributing distinct benefits. The integration of fibers not only augments the intrinsic properties of concrete but also introduces new dimensions of performance, such as improved impact resistance and durability. As a result, FRC is increasingly utilized in a wide range of applications, from pavements and industrial floors to complex architectural structures and seismic-resistant buildings.

Recent Fiber-reinforced concrete (FRC) represents a transformative advancement in the realm of construction materials, providing notable improvements over traditional concrete. By incorporating fibers into the concrete matrix, FRC significantly enhances mechanical properties and addresses several inherent weaknesses of conventional concrete. This innovative material is distinguished by the inclusion of various fiber types, such as steel, glass, synthetic, and natural fibers, which are uniformly dispersed throughout the concrete mix. These fibers serve as micro-reinforcements, bolstering tensile strength, ductility, and crack resistance.

The concept of reinforcing concrete with fibers has a long history, dating back several decades. However, recent strides in material science and engineering have greatly expanded its potential applications and effectiveness. The introduction of fibers into the concrete mix transforms the typically brittle nature of concrete into a more ductile and resilient material, capable of withstanding greater stresses and deformations. This enhancement is particularly crucial for meeting the demands of modern construction, where durability, safety, and high performance are essential.

Fiber-reinforced concrete is utilized across a wide array of applications, including pavements, bridge decks, high-rise buildings, and structures designed to resist seismic activity. Beyond its improved mechanical properties, FRC also offers increased impact resistance, superior fatigue performance, and greater overall durability. These attributes make FRC an ideal choice for infrastructure projects that must endure heavy loads, severe environmental conditions, and dynamic forces.

II. METHODOLOGY

The details of the source materials are given below:

Cement (PPC-43)	JK Laxmi Cement
Aggregate	Krishna Material Supplier
Sand	Krishna Material Supplier
Bamboo Fibre	The Yarn Guru India Inc.
Polypropylene	Order online from India mart
Nylon-66	Order online from India mart
Admixture (Sica Plast)	Ghodela Traders, Jaipur

Fig 1: Vicat test apparatus

A. *Test on Concrete Used*

Compressive Strength Test (IS) 516:1959

Method of Cube casting

- Rinse and lubricating mounds.
- Place the concrete in the moulds in 5 cm thicker layers.
- By a tamping rod, compact each layer with at least 35 blows every layer (steel bar 16mm diameter and 60cm long, bullet-pointed at lower end).
- By using a soft cloth piece, clean the top surface.
- The test pieces are retained in moist air for 24hrs, following which they are labelled, extracted from the moulds, and preserved in clear freshwater until the test completion.
- The curing water should certainly be examined every 7days period, and the temperatures should be 27+-2°C.

Test Procedure

- After the curing period, withdraw the specimen from the water and wipe away any water that remains on its exterior.
- Determine the specimen's dimension to the nearest 0.2m.
- Wash the examination machine's bearing surfaces.
- Set up the specimen in a device that applies load to opposite sides of the cast cubes.
- Position the specimen in the middle of the device's bottom panel.
- Rotate the moveable piece by hand until it reaches the upper area of the specimen.
- Load the specimen progressively and reliably at 140 kg/cm2/min until failure occurs.
- Identify any unexpected features of the failure and indicate the maximum load.

Fig 2: Determine compressive strength of cube sample

Flexural Test (IS) 516:1959

- To make a test specimen, fill the mould with concrete in three equal parts of comparable thickness. Tamp each layer 35 times with the tampered bar, as indicated. Tamping should be done evenly over the beam mould's segment while maintaining the depth of each layer.
- Remove any loose sand or dirt from the specimen's surfaces that will contact the rolling elements, as well as the bearing surface of the sustaining and loading rollers.
- Steel rollers with a diameter of 38 mm will be used to support and load samples at particular locations.
- The rolling elements should be at least ten mm longer than the examination specimen's breadth.
- The span, or distance across the external rollers, is three times the distance between the internal rollers.
- To function properly, the inner roller must be uniformly distanced from the outside rollers. The water-filled specimens must be assessed immediately after removal while still wet. The test sample must be properly positioned in the machine, with the axis at an appropriate angle to the rollers.
- The load should be given at a rate of 400 kg/min for 15cm specimens and 180 kg/min for 10cm specimens, with the direction of the load being normal to the direction in which the mould is filled with the moulded specimens.

Rebound hammer [IS 13311(2)-1992]

The initial phase in analyzing concrete with a rebound hammer is to set it. The rebound hammer has been evaluated on a steel test hammer with a Brinell hardness of approximately 5000 N/mm2. Following proper testing on the test hammer, the rebound hammer is set up at an exact angle to the surface of the concrete structure in order to take measurements. As seen in the image below, the test can be carried out horizontally on a vertical surface, in addition to vertically upwards or downwards on a horizontal surface. If the rebound hammer is held in the middle position, the rebound value for the given concrete will vary. The compressive strength of concrete cannot be directly determined from rebound hammer tests. However, the rebound hammer test can provide an estimate or indication of the concrete's compressive strength based on empirical correlations established through calibration and validation against actual compressive strength measurements.

- To estimate the compressive strength of concrete using the rebound hammer test, you can follow these steps:
- Calibrate the rebound hammer using a calibration anvil or a reference concrete surface with known compressive strength. This calibration process establishes a correlation between the rebound value (measured by the rebound hammer) and the compressive strength of concrete.
- Choose representative locations on the concrete surface where you want to estimate the compressive strength. Ensure these locations are clean, free from loose particles, and have a uniform surface texture.
- Hold the rebound hammer perpendicular to the concrete surface at the selected test locations. Release the spring-loaded plunger to allow the hammer to impact the concrete surface. Note and record the rebound value displayed on the rebound hammer for each test location.
- Refer to the calibration chart provided by the manufacturer or relevant standards. This chart correlates the rebound values obtained from the test with estimated compressive strength values.
- Use the chart to find the corresponding estimated compressive strength values for the rebound values recorded at each test location.
- Analyze the estimated compressive strength values obtained from the rebound hammer tests.
- Compare these estimated values with the project requirements, specifications, or standards to assess the quality and suitability of the concrete.
- It's essential to remember that rebound hammer tests provide only an estimate of the concrete's compressive strength and should be used as a supplementary tool for quality control and assessment rather than a substitute for direct compressive strength testing.

III. RESULTS AND DISCUSSION

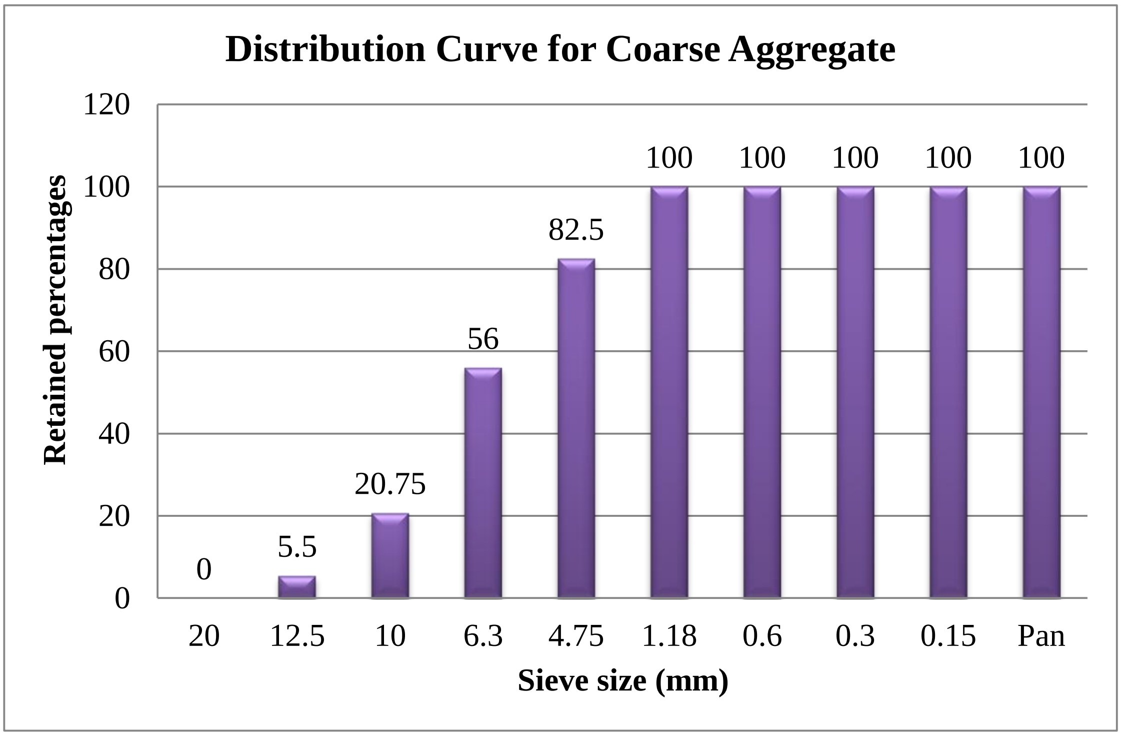

Fig 3: Distribution Curve for Coarse Aggregate

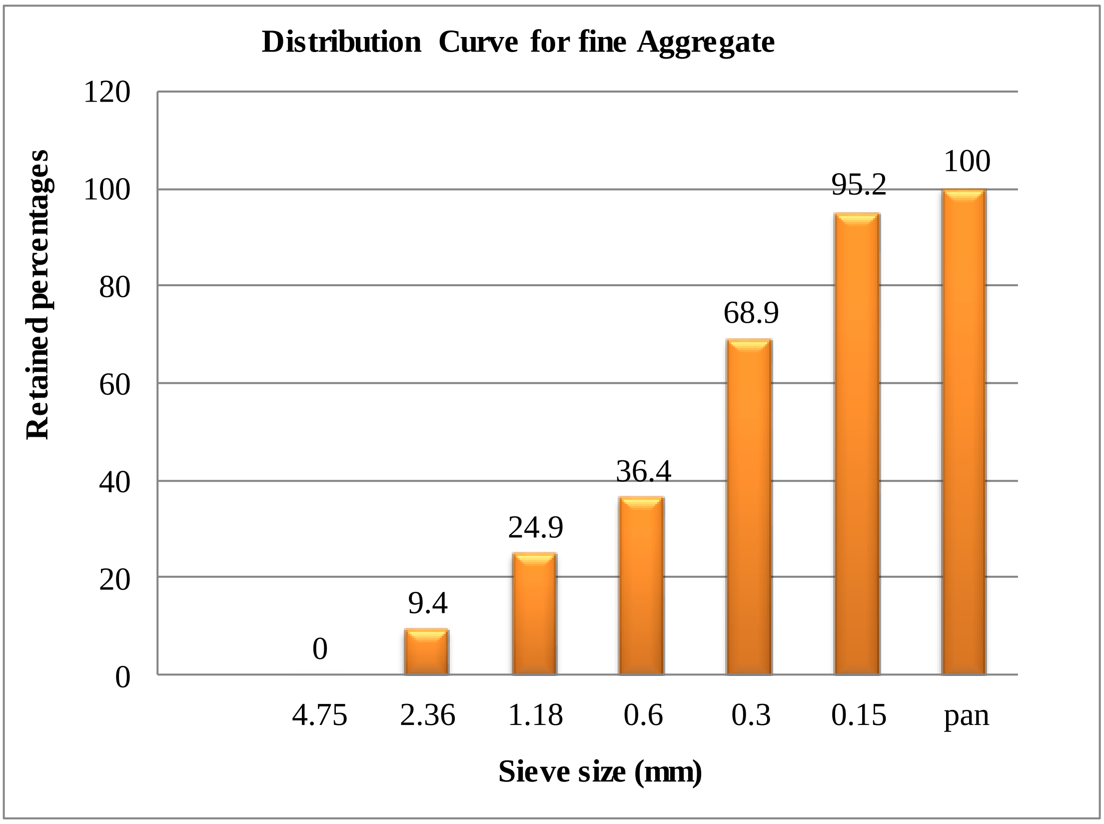

Fig 4: Distribution Curve for Fine Aggregate

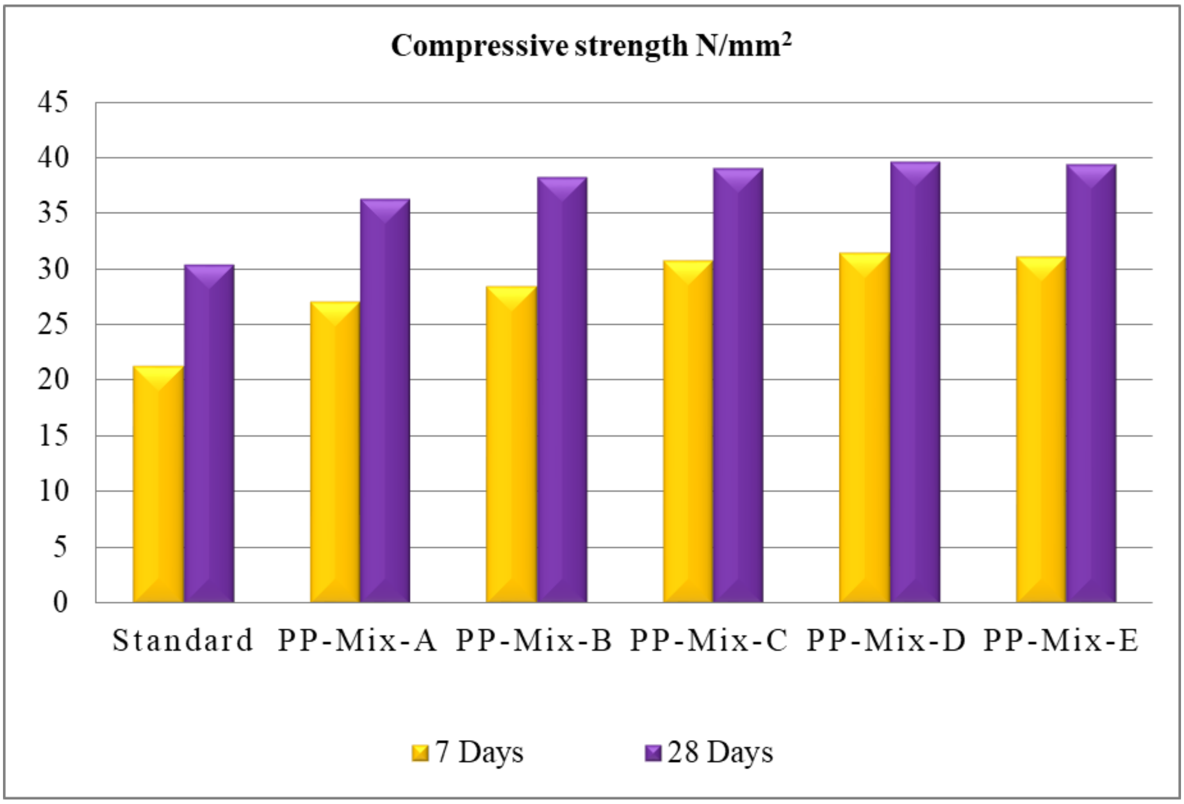

Fig 5: Compressive Strength test with Optimum Bamboo Fiber and Polypropylene Fiber

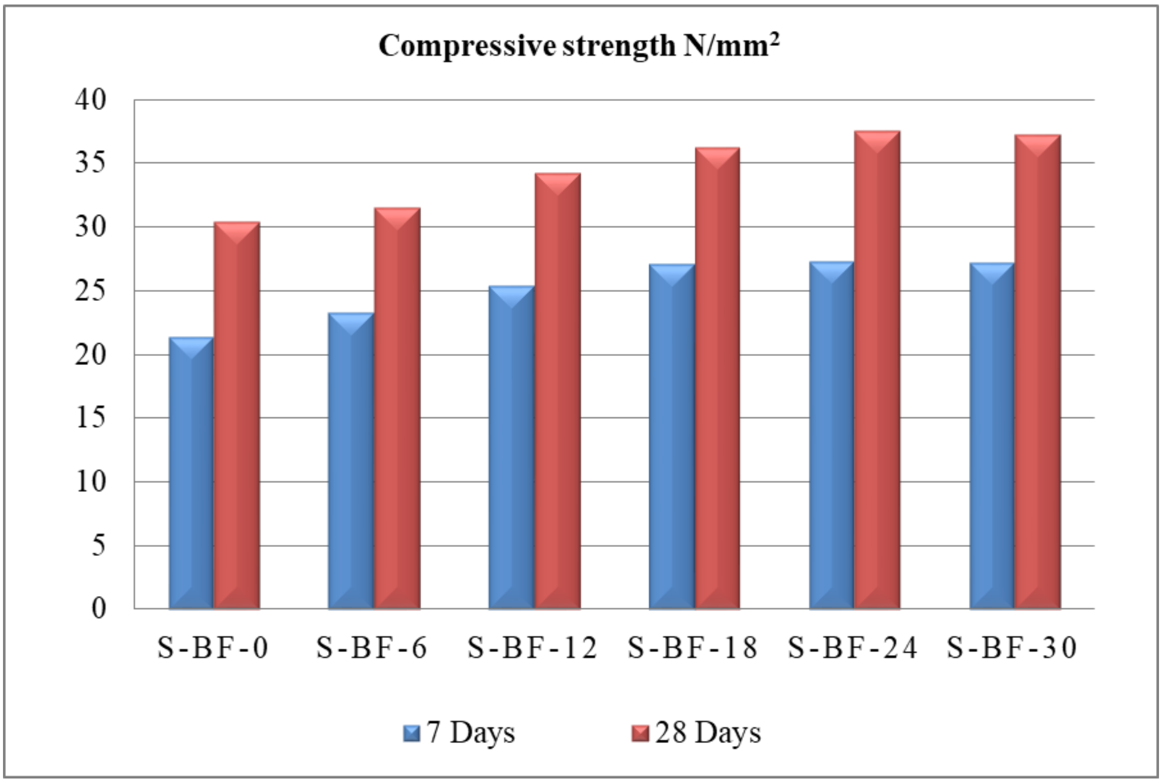

Fig 6: Compressive strength of Concrete with PBF at varying Percentage

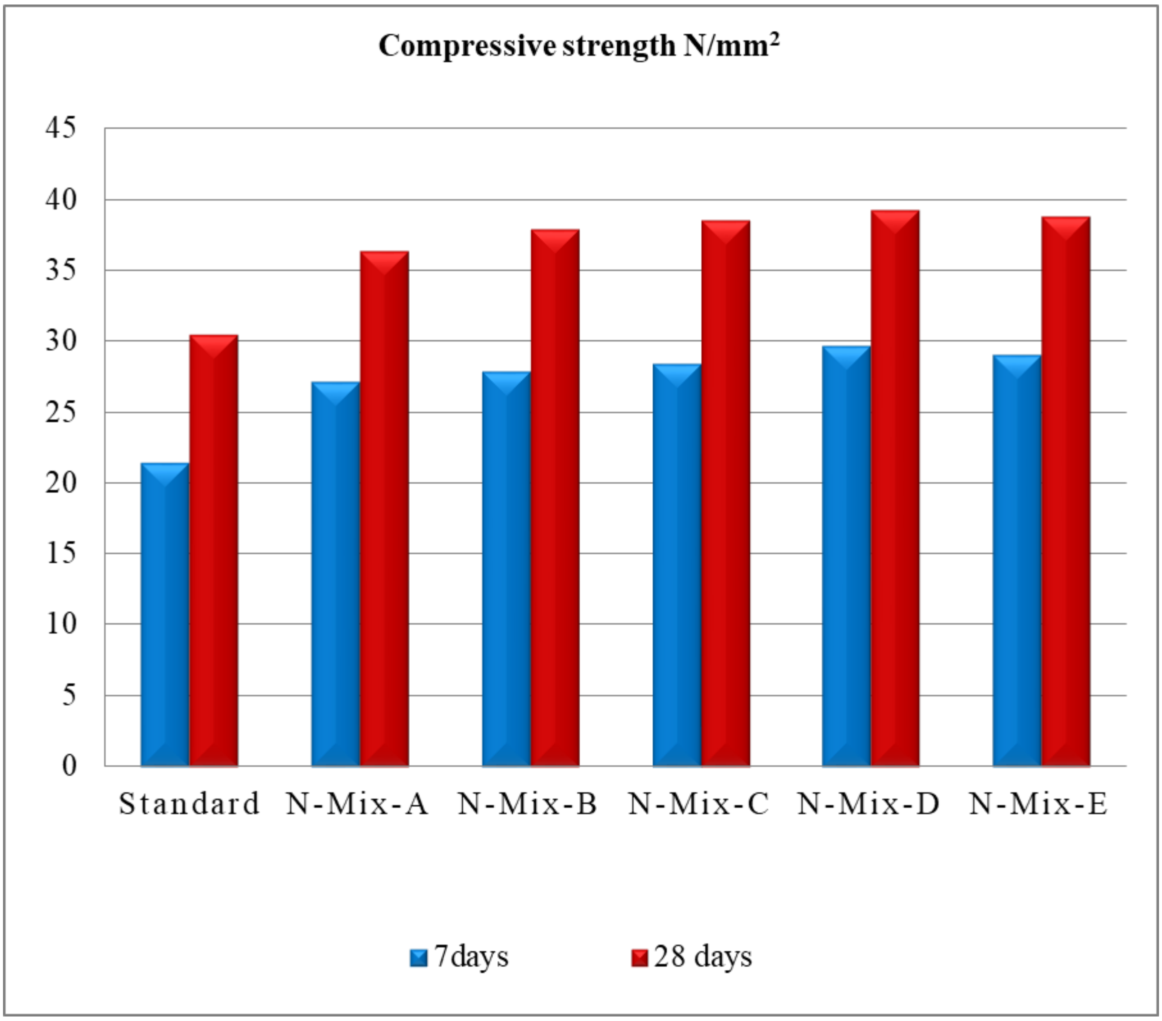

Fig 7: Compressive Strength test with Optimum Bamboo Fiber and Nylon-66 Fiber

IV. CONCLUSIONS

The study emphasizes the benefits of incorporating fibers into concrete, transforming it into fiber-reinforced concrete (FRC) with enhanced mechanical properties. Key findings include:

Enhanced Mechanical Properties: Natural bamboo fibers and synthetic fibers like polypropylene and nylon-66 improved tensile strength, ductility, crack resistance, and durability by acting as micro-reinforcements.

Optimized Fiber Content: Testing various proportions of bamboo fiber (0% to 30%) in M-30 concrete showed significant improvements in compressive strength and overall performance, especially when combined with synthetic fibers.

Improved Performance Metrics: Concrete samples with natural and synthetic fiber blends exhibited superior compressive strength, flexural strength, and impact resistance, making FRC suitable for heavy-load and dynamic-force infrastructure projects.

Practical Implications: Using a mix of natural and synthetic fibers offers a cost-effective method to enhance concrete properties in applications such as pavements, industrial floors, high-rises, and seismic-resistant structures.

Environmental and Economic Benefits: Incorporating natural waste fibers like bamboo not only enhances mechanical properties but also reduces waste and promotes sustainability in construction practices.

Future Research: Further research is crucial to optimize fiber types, proportions, and distributions for enhanced FRC performance. Advances in material science will likely lead to broader applications and improved sustainability in construction.

In conclusion, integrating natural and synthetic fibers into concrete significantly enhances its mechanical properties, positioning fiber-reinforced concrete as a versatile and robust material for modern construction, meeting demands for durability, safety, and high performance in infrastructure.

REFERENCES

[1] Ali Jahami, Nour Zeaiter, Mounir Cheaib, "Reviewing the potential: a comprehensive review of natural fibers (NFs) in structural concrete and their multifaceted

influences", Innovative Infrastructure Solutions 9(4), 2024.

[2] Manoj Kumar Singh, Renu Tewari, Sunny Zafar, Sanjay Mavinkere Rangappa, Suchart Siengchin, "A comprehensive review of various factors for application feasibility of natural fiber-reinforced polymer composites", Results in Materials, Vol. 17, 2023.

[3] Muhammad Nasir Amin, Kaffayatullah Khan, Sohaib Nazar and Ahmed Farouk Deifalla, "Application of waste recycle tire steel fibers as a construction material in concrete", Reviews on Advanced Materials Science, Vol. 7, 2023.

[4] Manoj Kumar Singh a, Renu Tewari, Sunny Zafar, Sanjay Mavinkere Rangappa, Suchart Siengchin, "A comprehensive review of various factors for application feasibility of natural fiber-reinforced polymer composites", Results in Materials, Vol. 17, 2023.

[5] Jawad Ahmad, Mohamed Moafak Arbili, Ali Majdi, Fadi Althoey, Ahmed Farouk Deifalla, Cut Rahmawati, " Performance of concrete reinforced with jute fibers (natural fibers): A review", Journal of Engineered Fibers and Fabrics, Vol. 17, pp. 1-17, 2022.

[6] Dr. I.C.Sharma Mr Kshitij Gupta, "Structure Health Monitoring Using Vibration-Based Technique", International Journal for research in applied Science& Engineering Technology, Vol. 7, 2019.

[7] Ms Geetanajali Ganguly, Dr. I.C.Sharma, "Sustainable Solid Waste Management, Smart Cities and Swatch Bharat Initiative", Institute of Technology & Engineering Jaipur, 2017.

[8] Dr.PBL Chaursia, Er.Raj P Sekhwat, Dr. I.C.Sharma, "Utalization of Marble Slurry in Concrete Replacing Fine Aggrigate", American journal of engineering research, Vol. 4, Issue. 1, 2015.

[9] Ishwar Chand Sharma & Dr. N.C. Saxena, "Engineering Utilization Of Marble Slurry", International journal of civil engineering and technology(IJCIET), Vol. 3, Issue. 2, pp. 1-6, 2012.

[10] Hemant Kumar Sain, Krishana wadhwani, Rohit Vashishth, Vikash Siddh, "Experimental Study of Floating Concrete With Light Weight Aggregate", Third International Conference on Advances in Physical Sciences and Materials 2022, AIP Conference Proceedings, 2023.

[11] Sneha Mathew, Hemant Kumar Sain, "An Innovative Study on Utilisation of Pareva Dust and Quartz Sand in Concrete", Key Engineering Materials, Vol. 961, pp. 135-140, 2023.

[12] Manoj Kumar Sharma, Hemant Kumar Sain, "A Review on Seismic Analysis of Connected and High Rise Buildings", International Journal of Engineering Trends and Applications (IJETA), Vol. 11, Issue. 1, pp. 18-21, 2024.

[13] Dr I .C.Sharma, Gori Shankar Soni, "Assessment of Limestone Dust and Chips as Eco-friendly Alternatives in Concrete Production", International Journal of Engineering Trends and Applications (IJETA), 2024.

[14] Mukesh Yadav, Hemant Sain, Anil Sharma, "Strength Of Concrete Grade M30 & M35 by Partial Replacement Of Cement With Paper Ash And Fly Ash", International Journal of Management, Technology And Engineering, Vol. 8, Issue. 5, pp. 496-509, 2018.

[15] Hament Sain, Sitender Chhillar, Sarjeet Singh Yadav, "Utilization of Sugarcane Bagasse ash in Concrete as Partial Replacement of Cement", Journal of Emerging Technologies and Innovative Research (JETIR), Vol. , Issue. , pp. 126-129, 2019.

[16] Nikhil Goyal, Hemant Kumar Sain, Mohsin Khan Agwan, "Analytical Study on Fiber Reinforced Concrete Using Different Types of Virgin Polypropylene Fiber in Preparation of Concrete Sample", International Advanced Research Journal in Science, Engineering and Technology, Vol. 9, Issue. 9, pp. 59-64, 2022.

[17] Hemant Kumar Sain, Basant Kumar Meena, "An experimental analysis on concrete containing GGBFS and meta kaolin with CCR", AIP Conference Proceedings 2901(1), 050008, pp. 1-13, 2023.

[18] Hemant Kumar Sain, Vishakha Sharma, Bazila Nisar, "Effect of Rock Cracks on RC Structures", AIP Conference Proceedings 2901(1), 050005, pp. 1-5, 2023.