



# EXPERIMENTAL STUDIES ON METAKAOLIN BASED BANANA FIBRE REINFORCED CONCRETE

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**Abstract :** Concrete production increasingly incorporates supplementary cementitious materials (SCMs) to reduce cement consumption and mitigate environmental impacts associated with conventional construction practices. SCMs such as fly ash, rice husk ash, silica fume, ground granulated blast furnace slag, and metakaolin exhibit pozzolanic behavior that enhances concrete performance while lowering carbon emissions. This experimental investigation examines the combined effect of Metakaolin and banana fiber on the mechanical properties of concrete. Metakaolin was used as a partial replacement of cement at replacement levels of 0%, 4%, 8%, 12%, 16%, and 20%, while banana fiber was added in proportions of 0%, 0.4%, 0.8%, 1.2%, 1.6%, and 2.0%. Concrete specimens were prepared with and without fiber inclusion. Compressive strength and split tensile strength tests were conducted after curing periods of 7 and 28 days. The experimental results indicate that concrete containing 16% metakaolin and 1.6% banana fiber exhibited the highest compressive and split tensile strengths compared to conventional concrete. Overall, the study demonstrates that the incorporation of metakaolin significantly improves strength characteristics, while banana fiber contributes to enhanced tensile performance. Therefore, the combined use of metakaolin and banana fiber offers a sustainable and effective approach for developing high-performance fiber-reinforced concrete.

**Index Terms - Metakaolin, Banana fiber, Compressive strength, Split tensile strength**

## I. INTRODUCTION

Introduction – Concrete is a composite construction material formed by combining cement, water, fine and coarse aggregates, and, when required, chemical or mineral admixtures. The interaction of these constituents produces a workable mixture that can be molded into desired shapes and subsequently hardens into a rigid and durable mass. Owing to its adaptability, concrete has become one of the most widely used materials in civil engineering applications.

Concrete plays a crucial role in infrastructure development, including the construction of buildings, pavements, bridges, and water-retaining structures. Its high compressive strength, durability, fire resistance, and ability to withstand adverse environmental conditions make it suitable for long-term structural use. Additionally, the thermal mass of concrete contributes to energy efficiency by moderating temperature variations within buildings. From an economic and sustainability perspective, concrete utilizes locally available raw materials and offers long service life with relatively low maintenance requirements.

Despite these advantages, conventional concrete exhibits inherent brittleness and limited tensile strength, which often result in cracking. To overcome these limitations, researchers have focused on modifying concrete through the incorporation of supplementary cementitious materials and fibers. Such modifications aim to enhance mechanical performance, durability, and sustainability while reducing the environmental impact associated with cement production.

The present investigation evaluates the combined effect of metakaolin, a highly reactive pozzolanic material, and banana fiber, a natural reinforcement, on the strength and performance of concrete. The study aims to develop an improved concrete mix capable of meeting modern construction requirements while promoting sustainable material utilization.

## Material and Methods

In this study, the weight of cement is tested by mixing a small amount of sugarcane ash. We will test some amount of sisal fiber in total concrete to increase the strength of concrete. To reduce the chemical quantity in cement, we will test it by adding sugarcane bagasse ash into cement to reduce the cost of cement while keeping the environment in mind.

Materials Used: - Cement, Metakaolin, Banana fiber, Fine Aggregate, Coarse Aggregate, Water.

**Metakaolin:** Metakaolin is a highly reactive aluminosilicate material obtained through the controlled thermal treatment of kaolin clay. The calcination process is typically carried out at temperatures ranging between 600°C and 800°C, resulting in the transformation of crystalline kaolinite into an amorphous and highly pozzolanic material.

The production of metakaolin involves several stages, including the extraction of kaolin clay, purification to remove impurities, drying to eliminate excess moisture, and calcination in a kiln or reactor. The calcined product is then ground into a fine powder suitable for use as a supplementary cementitious material. Due to its fine particle size and high surface area, metakaolin significantly enhances the microstructure of cementitious systems.

When incorporated into concrete, metakaolin reacts with calcium hydroxide released during cement hydration through a pozzolanic reaction. This reaction leads to the formation of additional calcium silicate hydrate (C–S–H) and calcium aluminate hydrate (C–A–H) gels, which contribute to improved strength, reduced permeability, and enhanced durability of concrete. The effectiveness of this reaction is influenced by factors such as curing conditions, water–cement ratio, and the reactivity of metakaolin.

**Banana Fiber:** banana fiber is a natural lignocellulosic fiber extracted from the pseudostem of the banana plant, which is generally considered agricultural waste after harvesting. In this study, banana fibers were obtained from a local source in Tamil Nadu and prepared in both raw and processed forms. The fibers were cut to uniform lengths using mechanical cutting equipment to ensure consistency in experimental results.

The physical and mechanical properties of the fibers, including length, diameter, density, and specific gravity, were evaluated using standard testing methods. Due to the hygroscopic nature of banana fibers, measurements related to density and water absorption were recorded after a 24-hour immersion period to ensure accuracy.

Banana fibers have gained increasing attention due to their eco-friendly nature, low cost, and satisfactory mechanical properties. They are widely used in textiles, paper manufacturing, and composite materials, including automotive and construction applications. Their biodegradability and renewability make them a sustainable alternative to synthetic fibers.

Fiber Reinforced Concrete (BFRC)

Banana fiber reinforced concrete (BFRC) is a composite material in which discrete banana fibers are uniformly distributed within the concrete matrix to enhance its performance characteristics. The inclusion of banana fibers improves tensile strength, crack resistance, and ductility by providing a bridging mechanism that restricts crack propagation.

BFRC offers several advantages, including improved post-cracking behavior, enhanced durability, and reduced shrinkage-related cracking. The utilization of banana fibers also contributes to sustainability by recycling agricultural waste and reducing dependency on synthetic fiber reinforcement. Additionally, banana fibers are cost-effective and readily available, making them suitable for large-scale construction applications.

## RESULTS AND DISCUSSION

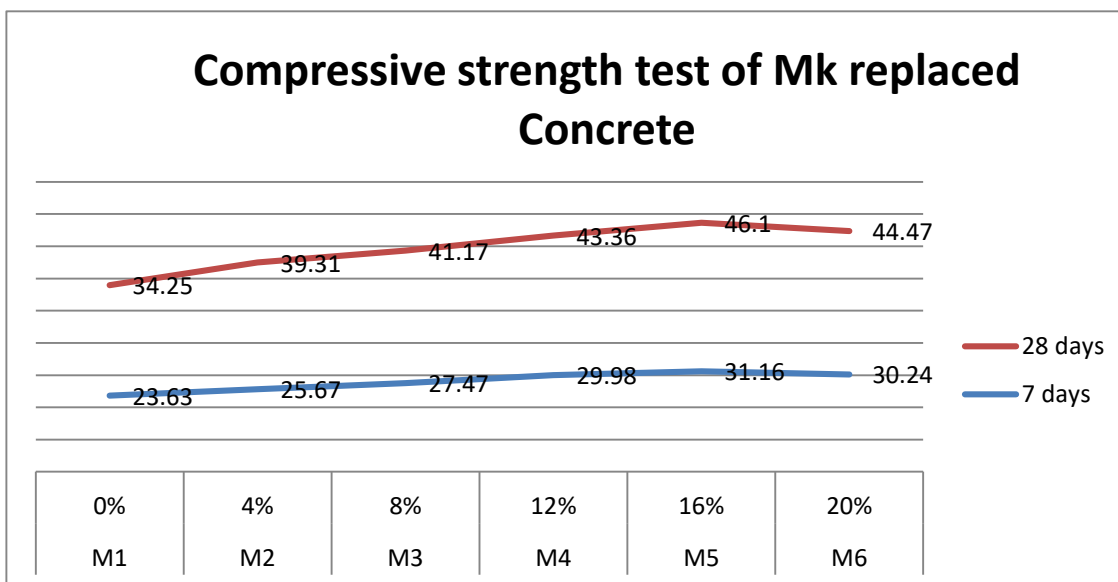
Ordinary Portland Cement (OPC) of 43 grade was used in the present study in accordance with IS 8112:2013 specifications. OPC 43 grade is commonly employed in structural concrete due to its balanced strength development and satisfactory workability. The cement primarily functions as a binding agent that ensures proper cohesion between fine and coarse aggregates, thereby contributing to the overall strength and durability of concrete.

Compressive strength, split tensile strength, and flexural strength tests were conducted on concrete specimens cured for periods of 7 and 28 days. The experimental results obtained from these tests are presented in the form of tables and graphical representations for clarity and comparison.

The compressive strength of concrete specimens was evaluated at 7 and 28 days of curing. For plain cement concrete, the compressive strength values obtained were 23.63 N/mm<sup>2</sup> at 7 days and 34.25 N/mm<sup>2</sup> at 28 days. These values serve as the reference for comparison with metakaolin- and banana fiber-modified concrete.

**Table 1: Compressive strength test of Metakaolin replaced Concrete.**

S. No.	Types of Specimens	Mix	Curing Period	Average Strength (N/mm <sup>2</sup> )
1	Plain cement concrete	M1	7 days	23.63
			28 days	34.25
2	Concrete and Metakaolin 4%	M2	7 days	25.67
			28 days	39.31
3	Concrete and Metakaolin 8%	M3	7 days	27.47
			28 days	41.17
4	Concrete and Metakaolin 12%	M4	7 days	29.98
			28 days	43.36
5	Concrete and Metakaolin 16%	M5	7 days	<b>31.16</b>
			28 days	<b>46.10</b>
6	Concrete and Metakaolin 20%	M6	7 days	30.24
			28 days	44.47

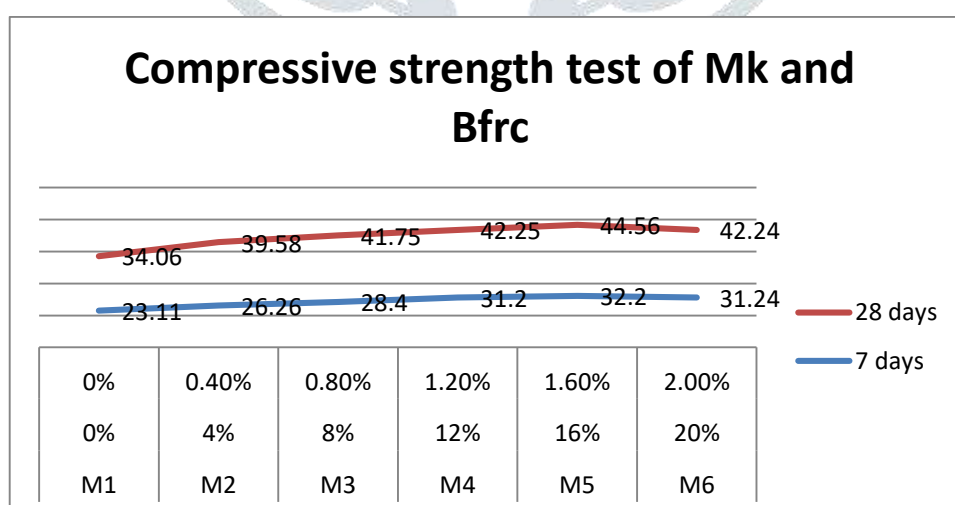


**Figure 1: Compressive strength test of Metakaolin replaced concrete.**

When banana fiber was incorporated along with metakaolin, a further enhancement in compressive strength was observed up to an optimum fiber content. The maximum compressive strength was achieved for the mix containing 16% metakaolin and 1.6% banana fiber, with values of 32.20 N/mm<sup>2</sup> at 7 days and 44.56 N/mm<sup>2</sup> at 28 days. Beyond this level, a slight reduction in strength was noticed, which may be due to fiber clustering and reduced workability.

**Table 1.1: Compressive strength test of Metakaolin and Banana fiber Reinforced Concrete.**

Mix	% Replacement of Mk in Cement	% Addition of banana fiber in concrete	Compressive strength at 7 days (N/mm <sup>2</sup> )	Compressive strength at 28 days (N/mm <sup>2</sup> )
M1	0%	0%	23.11	34.06
M2	4%	0.4%	26.26	39.58
M3	8%	0.8%	28.40	41.75
M4	12%	1.2%	31.20	42.25
M5	16%	1.6%	<b>32.20</b>	<b>44.56</b>
M6	20%	2.0%	31.24	42.24



**Figure 1.1: Flexural strength test of Metakaolin and Banana fiber reinforced concrete.**

**Split Tensile Strength**

Split tensile strength tests were performed at 7 and 28 days to assess the tensile behavior of concrete. Plain cement concrete exhibited split tensile strengths of 2.57 N/mm<sup>2</sup> and 3.88 N/mm<sup>2</sup> at 7 and 28 days, respectively.

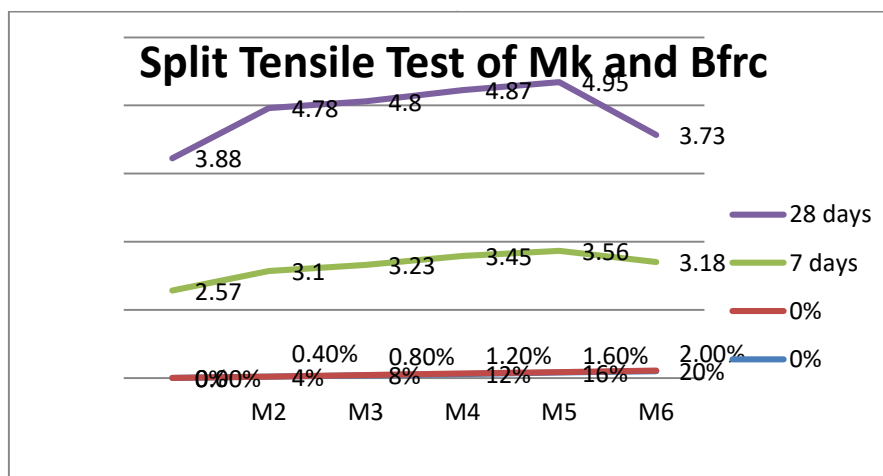
The inclusion of metakaolin and banana fiber significantly improved the tensile performance of concrete. The mix containing 16% metakaolin and 1.6% banana fiber recorded the highest split tensile strength values of 3.56 N/mm<sup>2</sup> at 7 days and 4.95 N/mm<sup>2</sup>

at 28 days. The enhancement in tensile strength can be attributed to the crack-bridging action of banana fibers, which restricts crack propagation and improves post-cracking resistance.

However, at higher fiber contents, a marginal decrease in tensile strength was observed, possibly due to non-uniform fiber distribution within the concrete matrix.

**Table 1.2: Split Tensile Test of Metakaolin and Banana Fiber Reinforced Concrete.**

Mix	% Replacement of Mk in Cement	% Addition of banana fiber in concrete	Tensile strength at 7 days (N/mm <sup>2</sup> )	tensile strength at 28 days (N/mm <sup>2</sup> )
M1	0%	0%	2.57	3.88
M2	4%	0.4%	3.1	4.78
M3	8%	0.8%	3.23	4.8
M4	12%	1.2%	3.45	4.87
M5	16%	1.6%	<b>3.56</b>	<b>4.95</b>
M6	20%	2.0%	3.18	3.73



**Figure : Flexural strength test of Metakaolin and Banana fiber reinforced concrete.**

**Flexural Strength**

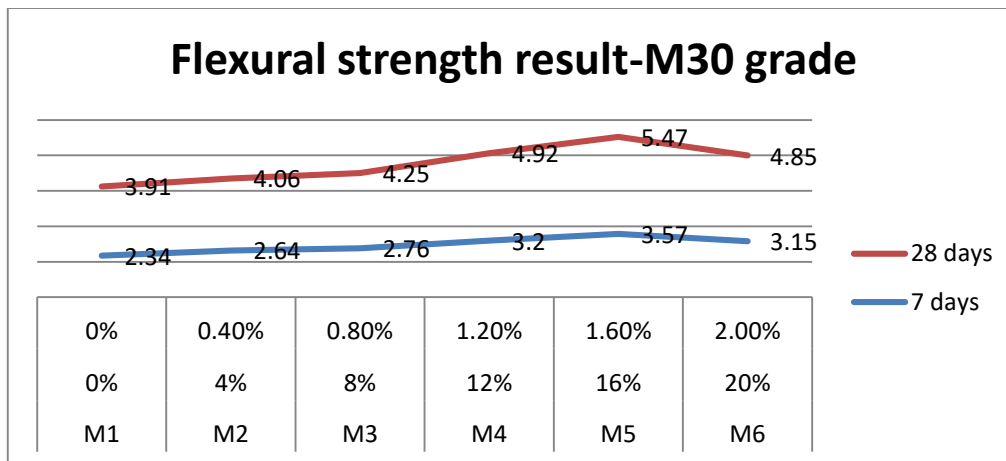
Flexural strength tests were conducted to evaluate the bending performance of the concrete mixes. Plain cement concrete achieved flexural strength values of 2.34 N/mm<sup>2</sup> at 7 days and 3.91 N/mm<sup>2</sup> at 28 days.

Concrete containing metakaolin and banana fiber showed a notable increase in flexural strength. The highest flexural strength was obtained for the mix with 16% metakaolin and 1.6% banana fiber, recording values of 3.57 N/mm<sup>2</sup> at 7 days and 5.47 N/mm<sup>2</sup> at 28 days. The improvement in flexural performance is mainly due to fiber reinforcement, which enhances energy absorption capacity and delays crack formation under bending loads.

A reduction in flexural strength was observed when the fiber content exceeded the optimum level, indicating that excessive fiber addition adversely affects workability and compaction.

**Table 1.3: Flexural strength result-M30 grade at normal water**

Mix	% Replacement of Mk in Cement	% Addition of banana fiber in concrete	Flexural strength at 7 days (N/mm <sup>2</sup> )	Flexural strength at 28 days (N/mm <sup>2</sup> )
M1	0%	0%	2.34	3.91
M2	4%	0.4%	2.64	4.06
M3	8%	0.8%	2.76	4.25
M4	12%	1.2%	3.20	4.92
M5	16%	1.6%	<b>3.57</b>	<b>5.47</b>
M6	20%	2.0%	3.15	4.85



**Figure : Flexural strength test of Metakaolin and Banana fiber reinforced concrete**

### Discussion

The experimental results demonstrate that the partial replacement of cement with metakaolin significantly enhances the strength characteristics of concrete. The improvement is primarily due to the pozzolanic activity of metakaolin, which refines the pore structure and improves the interfacial transition zone.

The addition of banana fiber further improves tensile and flexural performance by providing effective crack control and improved ductility. An optimum combination of 16% metakaolin and 1.6% banana fiber was identified as the most effective mix proportion in terms of mechanical performance.

Overall, the combined use of metakaolin and banana fiber produces a sustainable, high-performance concrete suitable for structural applications

### Conclusions

Based on the experimental investigation carried out on M30 grade metakaolin concrete reinforced with banana fibre, the following conclusions are drawn:

- 1.The experimental results indicate that the incorporation of banana fibre into metakaolin-based concrete leads to a noticeable improvement in its strength characteristics.
- 2.The addition of banana fibre significantly enhanced the mechanical properties of metakaolin concrete, particularly compressive strength and split tensile strength and Flexural strength test due to effective crack-bridging and improved load transfer mechanisms.
- 3.The cracking resistance of concrete improved considerably with the inclusion of banana fibres, resulting in reduced brittleness and better post-cracking behavior.
- 4.When compared to conventional concrete, banana fibre reinforced metakaolin concrete of M30 grade exhibited superior compressive strength performance.
- 5.The compressive strength of concrete increased progressively up to an optimum combination of 16% metakaolin and 1.6% banana fibre, beyond which a gradual reduction in strength was observed. This reduction may be attributed to reduced workability and non-uniform fibre dispersion at higher replacement levels.
- 6.The maximum increase in compressive strength at the optimum mix proportion (16% metakaolin + 1.6% banana fibre) was 32.20 % at 7 days and 44.56% at 28 days when compared to control concrete.
- 7.The maximum improvement in split tensile strength at the optimum mix proportion (16% metakaolin + 1.6% banana fibre) was found to be 3.56% at 7 days and 4.95% at 28 days.
- 8.The maximum improvement in Flexural strength at the optimum mix proportion (16% metakaolin + 1.6% banana fibre) was found to be 3.57% at 7 days and 5.47% at 28 days.
- 9.Overall, the study confirms that the combined use of metakaolin and banana fibre at optimum proportions can produce a high-strength, crack-resistant, and sustainable concrete suitable for structural applications.

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