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Effect of Banana Fiber on Flexural Properties of Fiber Reinforced Concrete for Sustainable Construction †

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Abstract: Currently, banana fiber composites have received wide attention because of their ecofriendly properties. The overall aim of this study is to prove banana fiber as an eco-efficient construction material by checking the behavior of banana fiber-reinforced concrete during flexural loading. The length of fiber is kept 50 mm and a fiber content of 5% by the weight of cement was used for preparing banana fiber reinforced concrete. It is shown from the results that the flexural toughness index (FTI) that has a vital role in sustainable concrete increased while the modulus of rupture (MOR) of banana fiber reinforced concrete decreased as compared to ordinary concrete.

Keywords: ecofriendly construction material; banana fiber reinforced concrete; modulus of rupture; flexural toughness index

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1. Introduction

Natural resources used for the manufacture of concrete can be saved by using agricultural wastes because this waste is present in larger amounts and easily available. By adopting this technique, waste can be disposed of and at the same time, the environment can be saved from being polluted [1]. An estimated 70 million tons of bananas was grown and much of that was lost as waste and causes serious environmental crises [2]. Natural fibers are lightweight, easily available, and have a low impact on the environment than compared to artificial fibers [3]. The manufacture of cement not only depletes natural resources but also increases toxic material to the environment. Therefore, researchers are trying to replace cement with eco-efficient material to some extent [4]. Kevlar and banana fiber increase the life span, strength, and durability of the structure. Moreover, these fibers can be used in earthquake-resistant structures and aquatic structures due to their improved impact resistance, thermal resistance, and corrosion resistance properties [5]. The addition of banana fibers in concrete can mitigate cracking and spalling of concrete to a larger extent and enhances the flexural strength of concrete [6]. Concrete manufacture from fibers is cheap and can be useful for manufacturing earth quake resistance structures [7].

Banana fiber reinforced concrete with 2% banana fibers by volume had increased compression, split, and flexural strength up to 29.6%, 30.7%, and 179%, respectively, as compared to ordinary concrete after 28 days [8]. The addition of 0.2% of banana fiber increases the tensile strength of concrete [9]. Flexural, split tensile, and flexural strengths were enhanced using modified banana fibers (AMBF) [10]. The toughness index of concrete increased when adding fiber in concrete [11].

To the best of the author's knowledge, only research [6] has been conducted on the flexural properties of banana fiber reinforced concrete (BFRC). Sustainability, which should be an important part of any research, has not been linked with flexural properties of fiber-reinforced concrete in any research. In order to achieve the desired properties, a flexural test was performed on beamlets to analyze the behavior of banana fiber-reinforced concrete

during flexural loading. The addition of fibers in concrete decreases the modulus of rupture but enhances the toughness index of concrete because of the good energy absorption properties of natural fibers.

2. Methodology

2.1. Mix Design and Casting Procedure

For manufacturing banana fiber reinforced concrete, ordinary Portland cement (OPC), laranspur sand, coarse aggregates, water, and banana fibers were used. For ordinary concrete, the mix design ratio for cement, sand, and aggregates was 1, 4, and 2, respectively, while a water–cement ratio was kept at 0.6. In the case of BFRC, the mix design ratio is the same as that of PC, except 5 centimeter-long banana fibers of 5% by cement mass were added in concrete, and the same amount of aggregates was deducted from the total mass of aggregates. The water–cement ratio has a great influence on strength of concrete, and the water–cement ratio should be kept carefully in order to gain desired strength [12].

All materials were placed in the mixer drum along with the water for preparing plain concrete, and the mixer was rotated for three minutes. For preparing BFRC, all constituents in the dry state were added in the foam of layers in the mixer machine, and the mixer was rotated for five minutes. In order to make BFRC workable, water was regularly added.

2.2. Specimens

BFRCs were poured into beamlets having dimensions of 100 mm × 100 mm × 450 mm, respectively. Beamlets were lifted up to the height of 200–300 mm and then dropped to the floor for smooth compaction of BFRC, and 20–25 blows of the tamping road were given to remove air voids from concrete. A set of two samples for PC and BFRC was cast. A total of 4 beamlets (2 with PC and 2 with BFRC) were prepared. Labels PC and BFRC were used for ordinary and banana fiber reinforced concrete, respectively.

2.3. Flexural Testing

Flexural testing was performed on beamlets, and a flexural testing machine was used for calculating flexural strength. Beamlets were tested according to ASTM standard C293/C293M-16 using three-point loads for determining the modulus of rupture (MOR). The MOR was calculated using Formula (1).

$$\mathrm{MOR(MPa)} = \mathrm{PL}/\mathrm{bd}^2 \quad (1)$$

3. Results and Analysis

3.1. Flexural Behavior

The load-deformation curves of PC and BFRC are shown in Figure 1a. The flexural behavior of PC and BFRC was noted under the application of load. In PC and BFRC, the first crack occurred at 100% and 62% of their maximum load. PC had a longer and deeper crack than that of BFRC. It may be noted that all specimens of PC broke into two pieces and did not show any resistance after the cracks occur showing a brittle type of failure. On the other hand, the BFRC beamlet showed bridged behavior due to the presence of dispersed fibers. The specimen did not break even at ultimate load; thus, brittle type failure was avoided by adding fibers in concrete. Fibers changed the brittle behavior of PC to the tough behavior of FRC. The cracked section of the PC and BFRC beam is shown in Figure 1b.

Table 1 shows mechanical properties such as percentage weight of fibers (% W), maximum load (P_u), modulus of rupture (MOR), pre-cracked energy (E_α), post-cracked energy (E_β), total energy (E_T), and toughness index (TI) of specimens under flexural loading. Maximum load (P_u) and modulus of rupture (MOR) are less for BFRC than compared to PC, while the total energy and tougness index (TI) of BFRC was higher than compared to PC.

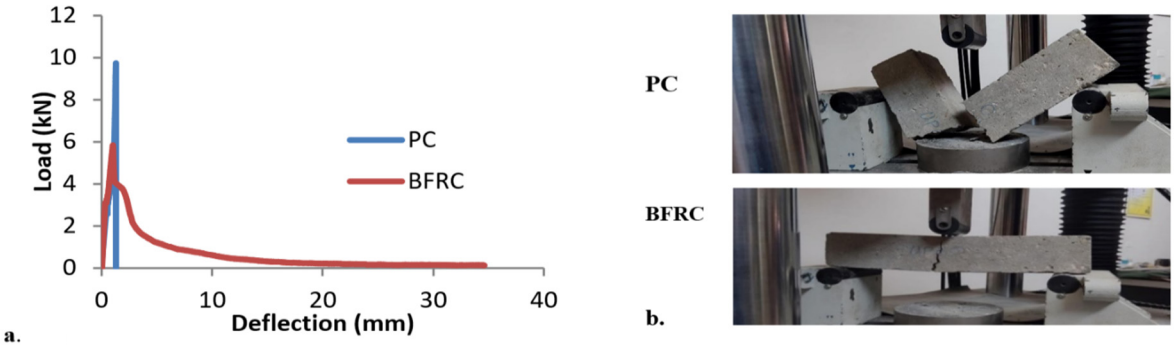


Figure 1. Flexural behavior; (**a**) load-deflection graph; (**b**) specimen cracking behavior.

Table 1. Mechanical Properties of PC and BFRC.

Sample	Fiber (% W)	W (kg)	P_u (kN)	MOR (MPa)	E_α MJ/m^3	E_β MJ/m^3	E_T MJ/m^3	TI
PC	0	11.87 ± 1.31	9.72 ± 0.64	4.37 ± 0.08	4.53 ± 1.27	0	4.53 ± 1.27	1 ± 0
BFRC	5	9.48 ± 0.87	5.84 ± 0.30	2.62 ± 0.14	3.36 ± 2.09	19.50 ± 1.75	22.87 ± 3.84	6.8 ± 0.49

3.2. Banana Fiber Reinforced Concrete as a Sustainable Material

The modulus of rupture of BFRC is lower than PC. Here, we take the advantage of energy absorption and toughness index of BFRC because, in most of the structures, a higher value of strength is not necessary but a higher value of toughness index is beneficial. Thus, instead of making expensive concrete, it is better to make concrete that has a minimum required flexural strength possessing improved toughness index. This method will also be very beneficial for the environment because replacing cement with fibers lessens the emission of CO_2 and saves non-renewable resources used for manufacturing cement. The maximum load value of BFRC is 5.84 kN, which is 39% less than 9.72 kN of PC. The modulus of rupture of BFRC is also 39% less than that of PC. The total energy absorption and toughness index of BFRC is 404% and 580% more than that of PC. The presence of less dense and lightweight fibers decreases the strength of fiber-reinforced concrete due to the increased bridging effect and bond strength between concrete matrix and fibers; the total energy absorption and toughness index of fiber reinforced concrete increased, as shown in Figure 2.

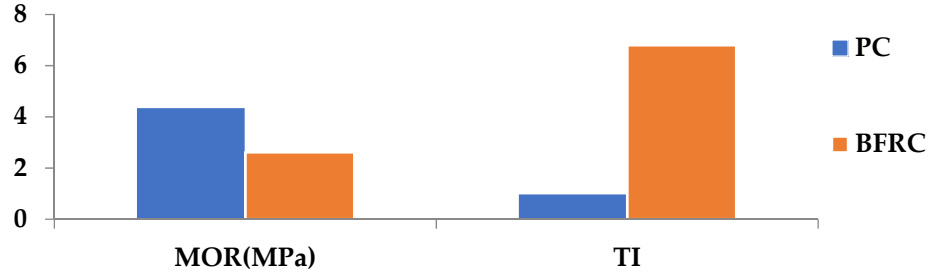


Figure 2. Relative comparison of modulus of rupture (MOR) and toughness index (TI) of PC and BFRC.

4. Conclusions

Natural reinforced materials, i.e., banana fiber, have the potential to improve the mechanical properties of concrete. Banana fibers are added at 5% (by mass of cement) with 5-centimeter length for preparing concrete. Experiments have been carried out to find the mechanical properties of banana fiber-reinforced concrete (BFRC). These mechanical properties include slump, density, flexural behavior, modulus of rupture, total flexural energy, and flexural toughness index. A slump test was performed on fresh concrete

while flexural properties of concrete were determined by casting beamlets. Flexural testing is performed on two beamlets of each combination (i.e., PC and BFRC). Based on the experimental results, the following conclusions were drawn:

- The flexural toughness index of banana fiber-reinforced concrete (BFRC) increased while the modulus of rupture of BFRC decreased when compared to PC.
- The improved energy absorption and flexural toughness index of Banana fiber reinforced concrete can provide better resistance against impact loading to resist cracking failure in the structure than compared to ordinary concrete.
- Effective utilization of agriculture fibers i.e., banana fibers, in concrete can minimize land pollution that occurs due to the dumping of bananas waste in open fields.
- The addition of banana fibers by mass of cement reduces the consumption of cement step towards cheap and sustainable concrete.

From the above-mentioned results, it is concluded that BFRC has improved properties favoring its demand to be used globally. BFRC should be optimized with different mix design ratios (i.e., fibers length, content mix design ratio, water-cement ratio, etc.) for its application in construction projects.

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Conflicts of Interest: The authors declare no conflict of interest.

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