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Proceeding Paper

A Study on Mechanical Properties of Environmentally friendly Concrete Incorporating Banana Fiber and Banana Leaf Ash †

Minhas Shah * and Majid Ali

Department of Civil Engineering, Capital University of Science and Technology, Islamabad 45320, Pakistan; majid.ali@cust.edu.pk
* Correspondence: minhas.shah@cust.edu.pk
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Abstract: Modern research is increasingly focused on the use of sustainable materials in concrete to increase its mechanical properties in order to enhance its performance for different applications. Banana leaf ash has great potential to increase the compressive strength of concrete, whereas banana fiber has been reported to increase the tensile strength. Therefore, the combined effect of both these materials in concrete needs to be elaborated. This experimental study investigates the influence of a 1.5% proportion of banana fiber and partial replacement of cement with banana leaf ash (10%) on the mechanical properties of concrete. Compressive testing and split tensile testing were employed. The results of this study demonstrate that the inclusion of banana fibers and banana leaf ash results in decreased compressive strength and increased tensile strength. The decrease in compressive strength for FRC is 9.18%. On the other hand, the increase in tensile strength for fiber-reinforced concrete (FRC) against plain concrete (PC) is 12.31%. The study provides valuable insights into the potential of banana-based additives in enhancing the performance of concrete, offering an eco-friendly approach for sustainable construction practices.

Keywords: banana leaf ash; banana fiber; compressive strength; splitting tensile strength

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1. Introduction

Despite limitations such as shrinkage cracks, faulting, and cost concerns, cement concrete is preferred for rigid pavements [1]. Its use in underdeveloped countries is increasing because of improved serviceability, but at a higher cost than flexible options. Concrete curing is susceptible to shrinkage and cracking due to a variety of reasons, endangering pavement durability [2]. Early stage shrinkage cracks exacerbate these issues [3] and can lead to pavement collapse [4]. The poor tensile strength of concrete promotes faulting, with curling as a problem [5], which is compounded by excessive curling and warping from automotive stresses [6]. Thermal stresses cause warping and curling, which leads to pavement faults [7]. To address these difficulties, a sustainable materials approach is required.

In the framework of promoting sustainable concrete technology, the use of waste materials in concrete has received significant attention. Different types of fibers have various qualities that contribute to the mechanical strength of concrete. Affan and Ali [8] investigated the impact of freeze–thaw cycles on concrete containing jute fibers, specifically for pavement applications, in their study. Their research showed that using jute fibers reduced pavement thickness without sacrificing performance. Khan et al. [9] investigated the experimental use of silica fume in conjunction with coconut fibers for rigidity in a separate investigation. Their research found that incorporating these materials could reduce the overall thickness of stiff pavements by up to 8%. Meanwhile, Ali et al. [10] did a comprehensive review concentrating on the use of coir fiber in concrete and comparing it to other natural fiber types. Their detailed investigation found that pineapple fiber outperformed banana fiber in terms of compressive strength. Furthermore, the addition of fibers greatly increased the hardness of the concrete. Natural fibers, such as banana fiber, contributed to higher tensile strength and energy absorption capacity, with banana fiber standing out for its low water absorption and high tensile strength.

Utilizing agricultural waste ashes, particularly from biomass power plants, is a viable way to address cement manufacturing difficulties. These ashes contain cementitious qualities and can be used as a partial substitute for cement [11]. Natural ashes often contain CaO and SiO_2, with SiO_2 being particularly important, combining with calcium hydroxide during cement hydration, generating additional C-S-H, and improving the mechanical properties of concrete. For example, replacing cement with 10% banana leaf ash increases compressive strength. It is finely powdered at 900 °C for higher reactivity [10]. Tests confirm greater performance over normal cement concrete [11], with a compressive strength of 7.9 MPa [12]. This paper aims to develop sustainable concrete by investigating concrete with 10% banana leaf ash as a partial cement replacement and 1.5% banana fiber incorporation.

2. Methodology

2.1. Raw Materials

Portland cement, sand, and coarse aggregates were utilized to make the reference concrete, i.e., PC samples. The cement employed in this study is conventional Portland cement from a local manufacturer, Askari cement, with the following properties: 61.7% Cao, 21% SiO_2, 5.04% Al_2O_3, 3.24% Fe_2O_3, 2.56% MgO, and 1.51% SO_3. The highest fine aggregate size employed was 4.8 mm, and the material was quartz sand with a bulk density of 1527 kg/m^3. The coarse aggregate utilized was 12.5 mm in size and had a bulk density of 1506 kg/m^3. In the case of sustainable concrete, banana ash was utilized as a partial replacement for cement, and banana fiber was used as an addition.

2.1.1. Banana Leaf Ash

Banana leaf ash was bought from the local market, and a similar process, as described in the literature, was employed to produce the banana leaf ash used in this research. The fineness of BLA was determined using the Blaine air-permeability device and the ASTM C204 with a fineness value of 586 m^2/kg. The pozzolanic activity index was calculated using Chapelle's test and yielded a value of 7.6 MPa. According to the vendor, the ASTM 618-12 class of banana leaf ash is F, and the chemical composition of the used banana leaf ash includes aluminum oxide, silicon dioxide, iron oxide, calcium oxide, and sulphur trioxide.

2.1.2. Banana Fiber

Banana fiber, which is produced from the banana plant and is readily available locally, was used, which was acquired from a local vendor. The procedure used in this investigation was to first cut the fibers into 50 mm lengths. Fiber cutting was accomplished by merging the fibers and cutting them together to avoid variance in length. Following that, the fibers were cleaned by soaking them in water and then in a calcium carbonate solution with a concentration of 5% by weight.

2.2. Mix Design and Casting Procedure

The mix design ratio used for the concrete preparation is 1:1.3:2.3 (C:S:A); this mix design is based on trial mixes to reach a compressive strength of 30 MPa. The water–cement ratio used was 0.48. After a 28-day curing period, a water absorption test was performed. The reference concrete, as well as the concrete containing banana fibers and banana leaf ash, employ the same mix design and water–cement ratio. Furthermore, a superplasticizer was utilized to improve the workability of the concrete because the water–cement ratio was kept relatively low. To make conventional concrete and concrete containing banana fiber and banana leaf ash, a motorized concrete mixer was used. Standard concrete was made by mixing raw materials and water in a mixer for three minutes. The components are put to the mixer in three equal parts to form the banana fiber and banana leaf ash concrete, with each part dry mixing before adding water. After setting for 24 h, the samples were placed in a curing tank for 28 days to achieve maximal strength.

2.3. Compressive Testing

This study's methodology follows the rules established by ASTM C39, titled "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens". This standardized method was useful in properly determining the compressive strength of cylindrical concrete specimens, which is an important parameter in structural engineering and construction. Once produced, the specimens were taken from the molds and cured for at least 24 h.

2.4. Splitting Tensile Testing

This study's methodology follows the rules stated in ASTM C496, titled "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens". This standardized approach was crucial for precisely determining the splitting tensile strength of cylindrical concrete specimens, which is a critical parameter for evaluating the behavior of concrete under tensile stresses. A constant-rate compressive load was applied continuously until the specimen failed by splitting along a diametric plane.

3. Results

3.1. Compressive Strength

Figure 1 depicts the stress strain curve for the reference concrete and the concrete containing banana fiber and banana leaf ash under compression load. Table 1 displays the compression strength and strain, as well as the CEP, CEF, CET, and CTI values. As a result, these samples outperformed the PC samples in post-crack energy absorption. The PC sample had a compression strength of 29.45 MPa, while the FRC sample had a compression value of 27.68 MPa. The CS values for FRC have been reduced by 9.18%. The addition of banana leaf ash to concrete simply increases the compressive strength. However, the compressive strength of concrete containing banana fibers and banana leaf ash decreases. The incorporation of low-density fibers results in a decrease in CS values. The strain values for PC and FRC are 0.0019 and 0.0024, respectively.

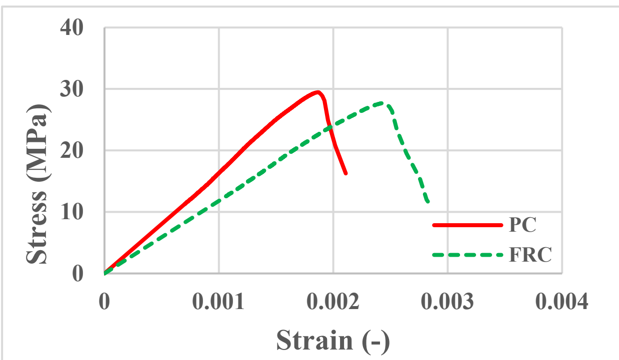

Figure 1. Stress–strain Curves for concrete mixes.

Table 1. Compressive strength properties for concrete mixes.

Sample	CS (MPa)	Strain (-)	CEP (MJ/m^3)	CEF(MJ/m^3)	CET (MJ/m^3)	CTI (-)
PC	29.45	0.0019	0.029	0.006	0.0341	1.19
FRC	27.68	0.0024	0.035	0.008	0.0436	1.23

PC and FRC had CEP values of 0.029 MPa and 0.035 MPa, respectively. When these numbers are compared, the compressive energy at peak load for PC is the lowest, while it increases for FRC. PC has a CEF value of 0.006, but FRC has a CEF value of 0.008, which is more than the PC value. The increase in CEF values is related to the energy absorption after the fracture appears as a result of the availability of banana fibers. The CET values for PC and FRC are 0.0341 MPa and 0.0346, respectively. The increased value is mostly due to post-crack energy absorption and, to a lesser extent, pre-crack energy absorption for FRC. Compressive toughness index values for PC and FRC are 1.19 and 1.23, respectively.

3.2. Splitting Tensile Testing

Figure 2 depicts the load-deformation curve of the specimens, namely reference concrete and PC and FRC, under the split tensile load. The addition of fiber reduces the brittle behavior of the concrete by lowering the fracture width, and the samples are not broken into two pieces once the first crack appears due to the bridging effect. As a result, the addition of fibers to concrete can help to improve the post-crack behavior of the concrete, particularly in split tensile loading.

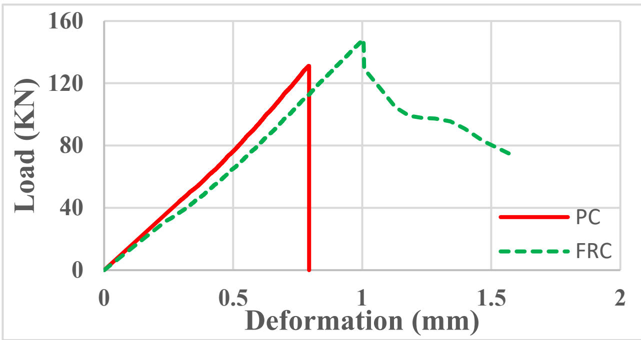

Figure 2. Load-deformation curves for concrete mixes.

The maximum value of load is used to calculate the strength in splitting tension (STS). The energy absorbed before the peak load is referred to as the pre-crack absorbed splitting tensile energy (STEP), whereas the energy absorbed after the peak load is referred to as the energy absorbed post crack splitting tensile energy (STEF). It is crucial to note that the STEP and TSTE values for the PC samples are the same since the entire energy absorbed by the PC occurred before to peak load, and the sample was split into two pieces at peak load. The Splitting Toughness Index (STI) is calculated by dividing the TSTE by the STEP value.

Table 2 shows the data acquired from the load deformation curve. STS, STEP, STEF, TSTE, and STI values have been provided for PC and FRC samples. STS values for PC and FRC are 4.05 and 4.56 MPa, respectively. It can be seen that the STS values grow in descending order as the content of banana fibers in concrete increases. The STS value for FRC specimens has improved up to 12.59 percent. This demonstrates that the addition of banana fibers increases the splitting tensile strength of the concrete.

Table 2. Splitting tensile strength properties for concrete mixes.

Sample	STS (MPa)	STEP (N.m)	STEF (N.m)	TSTE (N.m)	STI (-)
PC	4.05	49.24	-	49.24	1
FRC	4.56	69.51	55.6	125.12	1.79

STEP values for PC and FRC are 49.24 N.m and 125.12 N.m, respectively. STEP is becoming increasingly important for FRC. The increased STEP value is attributable to the energy absorption capability of natural fibers, specifically banana fibers. The STEF results for the PC are 0, since no energy was absorbed after the peak load. The STEF values of FRC exist due to the bridging action of fibers. The TSTE values found for PC and FRC are

49.24 N.m and 125.12 N.m, respectively. When the results of PC and FRC are compared, 154% of the total splitting tensile energy has increased. PC and FRC have hardness indices of 1 and 1.79, respectively.

4. Practical Implementation

The use of banana fiber as an additive and banana leaf ash as a partial replacement for cement in the construction of rigid pavements offers an environmentally responsible and sustainable method of infrastructure development. Banana fiber increases the tensile strength and crack resistance of concrete, increasing the pavement's durability and ability to sustain severe loads. Additionally, using banana leaf ash as a partial cement replacement lessens the environmental impact of cement manufacturing while simultaneously enhancing the pozzolanic characteristics of the concrete, which boosts its long-term performance.

Concrete fiber and banana leaf ash have been used to reduce the rigid pavement's thickness, which is a novel sustainable method of pavement design. While the compressive strength of this environmentally friendly concrete mix may be reduced, its observable improvement in tensile strength might be strategically utilized. Engineers may design thinner pavement sections while maintaining structural integrity thanks to the increased tensile strength, which enables empirical measurements of the rupture modulus. This not only preserves precious resources, but also supports sustainability goals by using less material and spending less money on construction while maintaining the performance and longevity of the pavement. In the context of contemporary building and transportation, such innovative solutions support the promotion of environmentally sound infrastructure practices.

5. Conclusions

The addition of fibers of banana and the partial replacement of cement with banana leaf ash shows the following effect on the mechanical properties of concrete:

1. The compressive strength decreases 9.18% for FRC as compared to PC.
2. An increase of compressive toughness is seen with the use of 1.5% content of banana fiber with 10% content of banana leaf ash.
3. The increase in strength in splitting tensile, as compared to conventional concrete, is 12.31% for FRC.
4. The total tensile toughness energy increases as the content of banana fibers increases.

Based on the above conclusions, it can be said that concrete containing banana fiber and banana leaf ash has great potential to be used for rigid pavement applications. Hence, it is required to assess the performance of the concrete using modern tools.

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