

# Investigation on mechanical properties of fiber reinforced concrete

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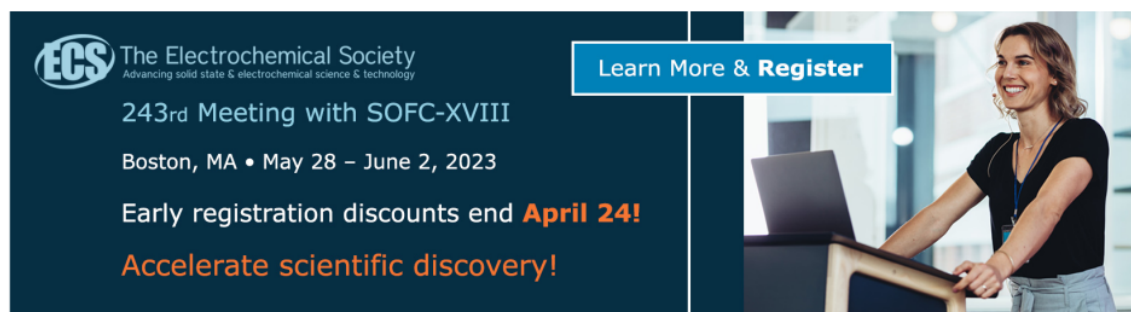
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## Investigation on mechanical properties of fiber reinforced concrete

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**Abstract.** Concrete has high compression strength but low tensile strength. Therefore fibers are added to enhance the tensile strength. South Kalimantan is one of Indonesia's largest wetlands, and the banana tree is common in this area. After harvesting, they are accumulated or be burned, causing pollution. Utilizing banana tree waste as fiber in the concrete minimizes it. This paper investigated the effect of banana fiber length and percentage of fiber by volume fraction on the compressive of mortar, tensile, and compressive concrete strength. The correlation between the compressive and tensile strength was further established. The percentage of fiber used in this research was 0.1%, 0.2%, and 0.3%, and the length of the fiber was 7cm and 15cm. The results showed that the addition of banana fiber significantly improved the mechanical properties of mortar and concrete. The compressive strength of mortar with a fiber length of 7cm was higher than 15cm. The higher percentage of fiber causes the lower compressive strength of mortar. The compressive strength of fiber-reinforced concrete was 27.9 MPa, and the ordinary concrete was only 17.91 MPa. The tensile strength of fiber-reinforced concrete was 6.96 MPa, while the ordinary concrete was just 1.93 MPa.

**Keywords:** Banana Fiber, Natural Fiber, Compressive Strength, Tensile Strength, Strength Effectiveness.

### 1. Introduction

The compressive strength of concrete relatively high but its tensile strength relatively low. Therefore, various fibers are added to fresh concrete. The contribution of fiber reinforcement increases the tensile strength by delaying the first cracks, minimizing cracks number, crack widths, and crack lengths [1]. A mixture of fibers in standard concrete also led to the improvement of the compressive strength. Furthermore, fiber strengthening enhances ductility, impact strength, fatigue and reduces shrinkage [2-3]. There are two types of fiber, natural fibers, and synthetic fibers. Synthetic fibers such as polypropylene, hooked end steel glass, and basalt, for example, are better mechanical properties compare to natural fibers such as coir, rise hay, cotton, jute, and sisal. Although synthetic fibers have excellent mechanical properties, they are expensive, not renewable, not recyclable, high energy consumption, not biodegradable. Contrasts with synthetic fibers, natural fibers were cheaper, renewable, recyclable, low energy consumption, biodegradable [4,5]. However, wax, dried, and dust particulates on the natural fiber surface can be improperly connected to the matrix in concrete. Therefore, preparation or treatment is required to remove wax, dry, and dust particles from the surface of natural fiber [2].

Banana is a frequent fruit in Indonesia. Banana trees are growing and expanding rapidly around them. Just 12% of the planting is taken, and the plant dies once the fruit is harvested. Therefore, an effort is required to use banana waste. Natural fibers were incorporated into the cement mixture in some experiments, but just a few studies used banana fiber. The banana tree trunk is commonly used as a fiber



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in the concrete mix [6,7]. However, the use of banana midrib as an available fiber is not extensive. Therefore, in this research, mixed concrete development considers the mechanical features of the fiber-reinforced concrete by adding banana midrib fibers with a variable composition.

## 2. Materials

### 2.1. Cement

All the concrete mixes were prepared by using portland composite cement. The cement was manufactured by 3R. The standard consistency of cement was 28%. The specific gravity of cement in this research was 3.15gr/cm<sup>3</sup>, and the bulk density of cement was 1150kg/m<sup>3</sup>.

### 2.2. Banana Fiber

The part of the banana tree that was used in this research was the midrib of banana leaves. The waste of the banana plantation was collected around Tanah Laut Region in South Borneo. The procedure to obtain the banana fibers was as follows. First, removed the banana leaves from the midrib, then washed with tap water and dried for 24 hours at room temperature. After that, the midrib of banana leaves was chopped into 7mm and 15mm in length, as shown in figure 1. The midrib was then immersed in 15% of NaOH for 24 hours. After that, midrib was dried under the sunlight for 7 (seven) days. Finally, it was shredded into a small part, as shown in figure 2.



**Figure 1.** The midrib of banana leaves.



**Figure 2.** Banana fiber.

### 2.3. Fine and coarse aggregates

Local river sand was used as fine aggregate. By using the sieve analysis test, the fine aggregate was categorized as zone II aggregate. Meanwhile, the crushed stone as coarse aggregate was collected from the local quarry. The maximum diameter of the coarse aggregate was 40mm. The characteristic of fine and coarse aggregates are listed in table 1.

**Table 1.** Physical properties of fine and coarse aggregates.

Properties	Fine Aggregate	Coarse Aggregate
Specific gravity	2.84	2.73
Bulk density, kg/m <sup>3</sup>	1500	1440
Fineness modulus	2.62	-
Water absorption, %	0.98	0.62

### 3. Methods

#### 3.1. Mixing Procedure

The composition of banana fiber is based on volume fraction. In this study, 0.1%, 0.2%, and 0.3% of banana fiber were evaluated. The length of the fibers was 7cm and 15cm. The mortar composition was obtained from the composition of the concrete mix design. A concrete compressive strength design was 17MPa, and the w/c ratio was 0.59. The fresh mortar was produced from the fresh concrete to achieve the real composition of fresh mortar from the concrete mix by the following steps, as has been done by Nurwidayati [8]. First, made the concrete mix according to composition in table 2, then remove the coarse aggregate from the fresh concrete. A sieve with an aperture of 4.75mm was used to separate the coarse aggregate from the fresh concrete. The fresh concrete poured into the sieve and stirred using a hand. The coarse aggregate was retained on a sieve, and the mortar passed through the sieve, as shown respectively in figure 3 and figure 4. Then put the banana fiber into the mixing bowl and blend until perfectly mixed. After that, the mortar was molded into 5×5×5 cm<sup>3</sup> cubes. The cubes were unmolded 24 hours after cast, as pictured in figure 5. The treatment process carried out was by immersing them in water. The mortar was tested at 7, 14, and 28 days.

**Table 2.** The mixing composition of concrete.

Specimens ID	Banana Fibers		weight per cubic meter			
	Length (cm)	V <sub>f</sub> (%)	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)
M0	-	-	313.559	717.890	1393.551	185
M07-0.1	7	0.1	313.559	717.890	1393.551	185
M07-0.2	7	0.2	313.559	717.890	1393.551	185
M07-0.3	7	0.3	313.559	717.890	1393.551	185
M15-0.1	15	0.1	313.559	717.890	1393.551	185
M15-0.2	15	0.2	313.559	717.890	1393.551	185
M15-0.3	15	0.3	313.559	717.890	1393.551	185



**Figure 3.** The coarse aggregate was retained on a sieve.



**Figure 4.** The mortar.

After obtained the highest compressive strength of mortar at the ages of 28 days, the next step was to make a concrete that was the same as the optimum mixture. The fresh concrete was poured into a 150mm diameter and height of 300mm cylinder mold (figure 6). Treatment for concrete is the same as for mortar, which is immersed in tap water as shown on figure 7. The concrete cylinder was tested on compressive at the ages of 7, 14 and 28 days and splitting tensile strength only at the ages of 28 days.

### 3.2. Testing Procedure

The entire tests were carried out at the Structure and Materials Laboratory of the Faculty of Engineering, Lambung Mangkurat University, Banjarmasin, Indonesia. A total of sixty-three mortar cubes were tested for compressive strength with different fiber lengths, and the percentages of fiber are presented in table 2. The compressive strength of mortar and concrete were tested according to ASTM C109/C109M - 20b [9] and ASTM C39/C39M – 20 [10], respectively. Meanwhile, the splitting tensile strength of concrete was tested using C496/C496M – 17 [11].



**Figure 5.** Mortar.



**Figure 6.** Concrete.



**Figure 7.** Concrete curing

The compressive strength of mortar and concrete was determined using an equation as follows.

$$f'_c = \frac{P}{A} \quad (1)$$

Where  $f'_c$  is the compressive strength (MPa), P is the total maximum load (kN), A is the area of loaded surface (mm<sup>2</sup>). The splitting tensile strength was determined using the following equation.

$$f_t = \frac{2P}{\pi LD} \quad (2)$$

Where  $f_t$  is the splitting tensile strength (MPa), P is the total maximum load (kN), L is the length of cylinder specimen (mm), and D is the diameter of the cylinder specimen (mm).

## 4. Result and Discussion

The average compressive strength of three mortar specimens on 7, 14, and 28 days is shown in table 3. SE stands for strength effectiveness, which is the additional strength of fiber-reinforced mortar compared with the ordinary mortar as follow [12]:

$$SE (\%) = \frac{S_{FRM} - S_{OM}}{S_{OM}} \times 100\% \quad (3)$$

Where SE is strength effectiveness (%),  $S_{FRM}$  is the strength of fiber-reinforced mortar (MPa),  $S_{OM}$  is the strength of the original mortar (MPa).

### 4.1. Effect of the percentage of banana fiber on Mortar compressive strength

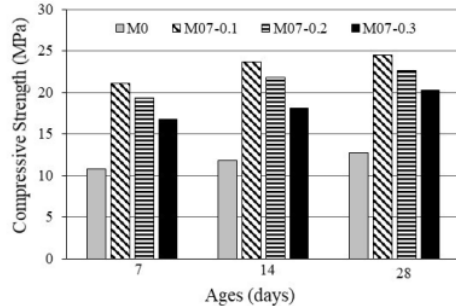
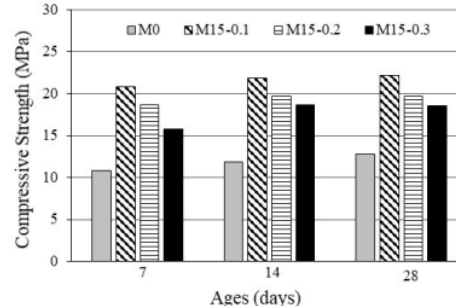
Figure 8 and figure 9 illustrated the effect of a percentage of banana fiber used in the mortar compressive strength, respectively, on fiber length of 7cm and 15cm. It can be pointed out that additional fiber in mortar increased the compressive strength at 7, 14, and 28 days significantly. For such a longer cured duration, the compressive strength developed. As the percentage of fiber increased, the compressive strength decreased at the same fiber length. The same results occurred in research conducted by Lertwattanak and Suntijitto [13].

**Table 3.** Compressive strength of banana fiber-reinforced mortar.

Specimens ID	7day compressive strength			14day compressive strength			28day compressive strength		
	Average strength (MPa)	Standard deviation (MPa)	SE (%)	Average strength (MPa)	Standard deviation (MPa)	SE (%)	Average strength (MPa)	Standard deviation (MPa)	SE (%)
M0	10.80	1.2	-	11.87	0.6	-	12.80	0.7	-
M07-0.1	21.07	1.2	95.1	23.73	0.5	100	24.53	0.9	91.7
M07-0.2	19.33	0.6	79.0	21.87	1.7	84.3	22.67	1.7	77.1
M07-0.3	16.80	2.4	55.6	18.13	2.4	52.8	20.27	1.2	58.3
M15-0.1	20.80	0.8	92.6	21.87	0.9	84.3	22.13	1.7	72.9
M15-0.2	18.67	0.5	72.8	19.73	0.5	66.3	19.73	0.5	54.2
M15-0.3	15.73	0.5	45.7	18.67	2.0	57.3	18.53	1.0	44.8

Strength effectiveness was in the range of 44.8% to 91.7% at 28days. The strength effectiveness of mortar compressive strength on the 7cm fiber length for 0.1%, 0.2%, and 0.3% was 91.7%, 77.1%, and 58.3%, respectively. Similar results were noticed on the 15cm fiber length. Comparing with ordinary mortar, compressive strength of fiber-reinforced mortar (strength effectiveness) increased 72.9%, 54.2%, and 44.8%, respectively as the percentage of fiber 0.1%, 0.2%, and 0.3%. On both fiber lengths, the higher percentage of fiber causes lower strength effectiveness. Compressive strength dropped at a higher percentage of the fiber mainly because more water is absorbed and a lower bonding between paste and the aggregate [14].

According to the 28day results, the optimum of fiber-reinforced mortar compressive strength was determined as 24.53MPa. That was the variation on the concrete mix with a 0.1 percentage of fiber dan 7cm the fiber length. It increased by 91.67% when compared to mortar without fiber. This proportion is taken for further research on the concrete phase in this study.

**Figure 8.** The mortar compressive strength on fiber length of 7cm.**Figure 9.** The mortar compressive strength on fiber length of 15cm.

#### 4.2. Effect of the length of banana fiber on Mortar compressive strength

It was observed from figure 8 and figure 9 that the longer fiber length caused the compressive strength decreased at the same percentage of fiber. However, the effect of fiber length to compressive strength of mortar was not as significant as the percentage of fiber in this study.

#### 4.3. Compressive and tensile strength of fiber-reinforced concrete

As mention above, only the mix composition of the highest mortar compressive strength was considered for further analysis into the concrete. M07-0.1 was the highest compressive strength of the mortar; therefore, the fiber-reinforced concrete was named S07-0.1. A total of 18 concrete specimens were

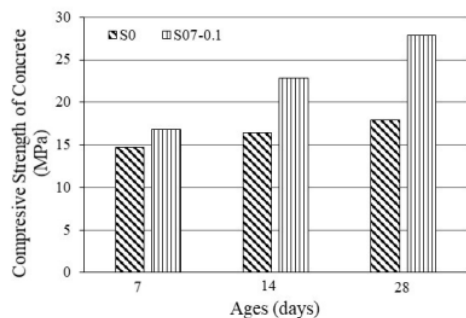
conducted in this research. The compressive strength results for fiber-reinforced concrete in various days were displayed in table 4. It was three cylinders on average. Also, as a control, standard concrete was made. The results show clearly that the required strength was achieved in 28th curing by all the different proportions of the fiber applied to the concrete. The effect of banana fibers on the compressive strength of concrete was demonstrated in figure 10.

Fiber-reinforced concrete strength effectiveness improved as a more extended concrete curing. At 7, 14 and 28 days, strength effectiveness amounted to 14.6%, 39.3%, and 55.8%, respectively. Fiber applied to the concrete mix raised the compressive strength of the concrete significantly.

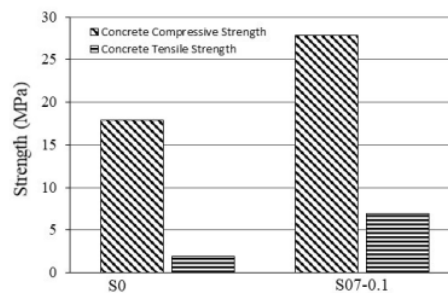
**Table 4.** Compressive strength of original concrete and banana fiber-reinforced concrete.

Specimens ID	7day compressive strength			14day compressive strength			28day compressive strength		
	Average strength (MPa)	Standard deviation (MPa)	SE. (%)	Average strength (MPa)	Standard deviation (MPa)	SE. (%)	Average strength (MPa)	Standard deviation (MPa)	SE. (%)
S0	14.71	1.14	-	16.40	1.13	-	17.91	0.87	-
S07-0.1	16.86	0.97	14.6	22.85	0.30	39.3	27.90	0.69	55.8

Compression strength ( $f'_c$ ) and splitting tensile strength ( $f_t$ ) of concrete are two main parameters on the structural design [15]. This study's experimental results on the split tensile test stated the standard concrete tensile strength at 28 days was 1.93MPa, and the fiber-reinforced concrete tensile strength was up to 6.96MPa, as shown in figure 11. The addition of banana fiber to concrete increased the splitting tensile strength by approximately three times as high as standard concrete. The increase in tensile strength by inserting fibers is caused by fibers working through cracks in the concrete matrix [16].



**Figure 10.** Effect banana fiber on compressive strength of concrete at 28 days.



**Figure 11.** Effect banana fiber on the relationship between compressive strength and tensile strength of concrete at 28 days.

The tensile strength of concrete can be computed through equations based on the compressive strength of concrete [15]. Researchers have strength acknowledged the 0.5 power relationship between tensile strength and the compressive concrete [16-20]. Hence, based on the evaluation in figure 11, the correlation between the splitting tensile strength and the compressive strength for original concrete and fiber-reinforced concrete at 28 days developed in this research as the following equation (4) and equation (5), respectively.

$$f_t = 0.46 \sqrt{f'_c}, \text{ for original concrete, and} \quad (4)$$

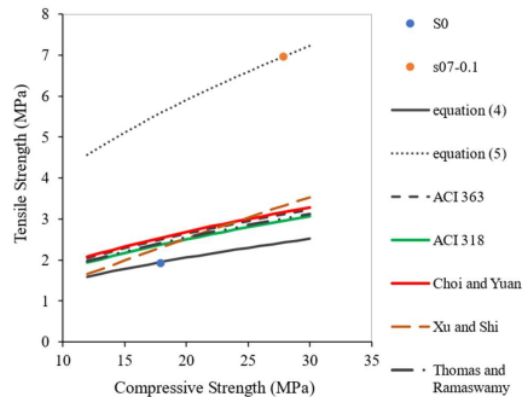
$$f_t = 1.32 \sqrt{f'_c}, \text{ for fiber-reinforced concrete} \quad (5)$$



Meanwhile, researchers developed the formulas in order to predict the tensile strength of concrete. They are founded on a specific type of concrete, such as steel fiber reinforced concrete [15, 16], conventional concrete [18, 19], and glass fiber reinforced and polypropylene fiber reinforced concrete [20], as listed in table 5. Figure 12 illustrates the tensile strength of fiber-reinforced concrete based on those models. The model that was developed in the current study was superior to those other prediction models. The coefficient on the equation (5) was more than one that was high. Hence, the current model requires more evaluation for the next research.

**Table 5.** Prediction models for splitting tensile strength

code	Equation (SI Unit)	Concrete type	Equations
Xu and Shi [15]	$f_t = 0.21f_c^{0.83}$	SFRC	(6)
Thomas and Ramaswamy [16]	$f_t = 0.57\sqrt{f'_c}$	SFRC ( $30 < f'_c < 75$ )	(7)
ACI 363R-92 [18]	$f_t = 0.59\sqrt{f_c}$	Conventional concrete ( $21 < f'_c < 83$ )	(8)
ACI 318-99 [19]	$f_t = 0.56\sqrt{f_c}$	Conventional concrete	(9)
Choi and Yuan [20]	$f_t = 0.60\sqrt{f'_c}$	GFRC	(10)
	$f_t = 0.55\sqrt{f'_c}$	PFRC	(11)



**Figure 12.** Tensile strength predictions model.

## 5. Conclusions

It can be inferred as follows based on the discussion above:

1. Banana fibers increased the mortar compressive strength, the concrete compressive strength, and the concrete tensile strength.
2. The compressive strength of the mortar and the compressive strength of the concrete increased with age.
3. The higher percentage of fiber caused the lower the compressive strength of the mortar.
4. The lower the compressive strength as the longer length of the fiber on all-fiber percentages.

5. The highest mortar compressive strength was on 0.1% fiber, and the fiber length of 7cm. That is 24.53MPa. This value increased by 91.7% compared to mortar without fiber.
6. The addition of fibers to concrete significantly increases the relationship between tensile strength and compressive strength of concrete.
7. In ordinary concrete, the tensile strength was 11% of the compressive strength of concrete, while in fiber-reinforced concrete, the tensile strength was 25% of the compressive strength of concrete.

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