Use of bamboo fiber on the relationship between compressive strength and split tensile strength of high strength concrete

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Abstract. This study was to determine the influence of fiber bamboo on the split tensile strength of concrete and to know the relationship between compressive and tensile strength. In the concrete mixture, fibre bamboo is added with a percentage of 0%, 0.5%, 1% and 1.5% of cement. Concrete strength of the design is 60 MPa with w/c value of 0.25. The coarse aggregate used had a maximum diameter of 12 mm, while the plasticizer used was 2% of cement. Testing was carried out at 28 days. For 0% fiber bamboo, the obtained strength was 62.47 MPa and a split tensile strength was 4.15 MPa. For 0.5% fiber, the obtained strength was 59.83 MPa and a split tensile strength was 5.12 MPa. For 1% fiber, the obtained strength value was 59.07 MPa and a split tensile strength was 5.91 MPa. For 1.5% fiber, the obtained strength value was 54.92 MPa and a split tensile strength was 6.48 MPa. Using fiber bamboo of the test shows a decrease in compressive strength, where the use of 0.5% fiber bamboo in concrete was the most optimal value. The use of the highest-fiber bamboo content of 1.5% achieved the optimum value of split tensile strength of 6.48 MPa.

1. Introduction

One method to improve concrete performance is to add fibers to it to increase the tensile strength of the concrete. Concrete fiber is made from a mixture of cement, fine aggregate, coarse aggregate, and small amounts of fiber. Various types of fiber materials that can be used to improve the mechanical properties of concrete are steel fibers, glass fibers, polypropylene fibers (a variety of high-quality plastic), carbon and natural fibers derived from natural materials (natural fiber), such as palm fiber, coconut fiber, hemp fiber, bamboo fiber, and others. This research used bamboo fiber. Bamboo fiber has an excellent tensile strength, which is expected to increase the elasticity of high-quality concrete and be more resistant to cracking and increases the tensile strength of concrete.

The addition of filler is expected to cover the cavity or pore between the aggregate particles. The filled cavity increases the concrete area so that the concrete ability to withstand the load can be perfect. One of the materials that are used for fillers is palm shell ash because of the high content of silica (SiO2) used as a material pozzolan in concrete mixtures. Palm shell ash must pass sieve no. 200 in order to be used as a filler for the porosity cavity. The results also showed that the optimum compressive strength using palm shell ash was at the content of the additive of 15% [1]. The concrete quality used is f'c = 60 MPa with cylindrical specimens diameter of 150 mm and height of 300 mm. The purpose of this study was to determine the extent of the effect of bamboo fiber on the split tensile strength of high-quality...
concrete and to find out how the relationship between compressive strength and high-strength concrete tensile strength.

2. Methodology

2.1. Bamboo
Bamboo is a plant that grows fast and can be harvested at around three years old. During growth, bamboo can grow vertically 5 cm per hour or 120 cm per day. In bamboo, there is the fiber in bamboo culms, causing the bamboo to have the strength and the ability for building purposes, namely high tensile strength [2]. Some types of bamboo having high tensile strength can be seen in Table 1.

| Type of Bamboo | Tensile Strength (Mpa) Without Nodia | Tensile Strength (Mpa) With Nodia |
|----------------|-------------------------------------|----------------------------------|
| Ori            | 291                                 | 128                              |
| Petung         | 190                                 | 116                              |
| Wulung         | 166                                 | 147                              |
| Tutul          | 216                                 | 74                               |

Bamboo generally has low natural durability, although there are differences regarding the type. Bamboo can be attacked easily by destructive organisms such as dry wood powder, dry wood termites, and subterranean termites. Furthermore, it is stated that anatomically and chemically bamboo and wood have similarities; therefore, the factors that influence wood will also affect the properties of bamboo. These properties include water content and the specific gravity of water [3]. Bamboo skin used as fiber concrete material is based on the consideration that the tensile strength is quite high, making from raw fiber materials is quite easy, and the bamboo population is quite large and scattered so that it is easily obtained [4]. Bamboo has physical properties, as shown in Table 2.

| Physical properties | Bamboo Tali | Bamboo Hitam | Bamboo Kuning | Bamboo Andong | Bamboo Betung | Bamboo Ampel |
|---------------------|-------------|--------------|---------------|---------------|---------------|--------------|
| Results             | 0.54        | 0.69         | 0.72          | 0.53          | 0.51          | 0.75         |
| Quality Classification | Medium    | Low          | Low           | Medium        | Medium        | Low          |
| Value               | 4           | 3            | 2             | 5             | 6             | 1            |

2.2. High strength concrete
Concrete is a function of its constituent material consisting of hydraulic cement (Portland cement), coarse aggregates, fine aggregates, water, and added materials (admixture or additive). Concrete is a set of mechanical and chemical interactions of its constituent element [6]. At present, the concrete is said to be the high-quality concrete if the compressive strength is above 50 MPa [7]. Several properties of high-quality concrete strength are shown in Table 3.

The high-quality concrete is the concrete that has a strength higher than 6000 Psi or 41.4 MPa and is used to reduce the size of columns and beams to be more beneficial in a longer span and can ease the structure. For the nature of concrete itself, it is said that high-quality concrete has a unit weight higher than low-quality concrete [8].
Table 3. Strength properties of various high strength concrete [8].

| Type              | w/c          | Compressive Strength (28 days old) | Remark             |
|-------------------|--------------|-----------------------------------|--------------------|
| Normal Consistency| 0.35 - 0.40  | 35 – 80 Mpa                       | Slump 50 – 100 mm  |
| No – Slump        | 0.30 – 0.45  | 35 – 50 Mpa                       | Slump > 25 mm      |
| w/c low           | 0.20 – 0.35  | 100 – 170 Mpa                     | Use Admixture      |
| Compacted         | 0.05 – 0.30  | 70 – 240 Mpa                      | Strength > 70 Mpa  |

2.3. Fibre concrete

Fibre Concrete is the concrete made from a mixture of cement, fine aggregates, coarse aggregates, and fiber at a small amount. Fibre material that can be used to improve the concrete properties is the fiber from natural materials, hemp, or fiber from other plants [9]. Concrete fiber is one of the developments of concrete technology. This type of concrete is one of the solutions to improve the quality of concrete [9]. Whereas according to [10], fiber concrete can be interpreted as concrete consisting of constituent materials such as water, cement, aggregate, or other additives and added fiber in the mixture. Fibre divided into four types of fiber, namely:

a. Fibre steel, for example, iron fiber and stainless steel.
b. Polymeric fiber, for example, nylon and fiber polypropylene.
c. Fiber mineral, for example, fiberglass.
d. Natural fibers, for example, coconut fiber, sugar cane fiber, banana tree fiber, and bamboo fiber.

Concrete is obtained from mixing fine and coarse aggregate materials, namely sand, stone, broken stone, or other similar material, by adding enough cement, and water as supporting material for chemical reactions during the concrete hardening and maintenance process [11]. Based on [12], concrete is a mixture of cement or other hydraulic cement, fine aggregates, coarse aggregates, and water, with or without additives which form a solid period. Normal concrete has a weight content of 2200 - 2500 kg/m³ using natural aggregates which are broken down or not broken down. The aggregate content in concrete is very high, especially coarse aggregate or gravel, in which almost 78% becomes the main filler of concrete mixtures [8].

The good nature of concrete is if the concrete has a high compressive strength between 20 - 50 MPa, at the age of 28 days. In other words, it can be assumed that the quality of concrete is reviewed only from its compressive strength [13]. The value of compressive and tensile strength of concrete material is not directly proportional; every effort to improve the quality of compressive strength is only accompanied by a small increase in the value of tensile strength. The tensile strength of normal concrete material only ranges from 9% - 15% from its compressive strength [11].

2.4. Palm shell ash

Palm shell ash, the waste from the burning of palm oil shells, also contains inorganic cations such as potassium and sodium [14]. In the process of burning shells and fiber fruit at temperatures of 700 - 800 °C in the boiler furnace kitchen. The burning of shells and fiber produces hard white - grey crust due to high-temperature combustion with 61% silica content. This high silica content makes the boiler crust ash can be used as a material pozzolan in concrete mixtures [14]. According to the results of the study [15], fiber and palm kernel shell waste in the form of ash has a useful element to increase mortar strength.

2.5. Concrete tensile strength

The value of compressive and tensile strength of concrete material is not directly proportional; every effort to improve the quality of compressive strength is only accompanied by a small increase in the value of tensile strength. A rough estimate can be used that the tensile strength of normal concrete materials is only between 9% -15% of its compressive strength (11).
The tensile strength of concrete is relatively low, a good approach to calculating the tensile strength of concrete (fct) is by using the formula of \( 0.1 f’c < fct < 0.2 f’c \) [6]. There are a number of methods available to test tensile strength, and the most commonly used is the cylinder division test or the Brazilian test. This experiment is carried out by giving a load perpendicular to the longitudinal axis with the cylinder placed horizontally on the plate of the experimental machine. The tensile strength of concrete can be calculated by equation 1 (12).

\[
f_{ct} = \frac{2P}{\pi ld}
\]

Where:
- \( f_{ct} \) = Split tensile strength (MPa);
- \( P \) = Crushed load (N);
- \( l \) = Length of the test object in the depressed part (mm); and
- \( d \) = Diameter (mm).

2.6. Research method

2.6.1. Material preparation and procurement. Palm shell ash was obtained from one of the palm oil processing factories in Purwodadi Village, Kuala Pesisir District, Nagan Raya Regency, Aceh. Concrete construction starts from the preparation and procurement of materials, the examination of aggregate physical properties, concrete mixing planning, concrete stirring work, concrete mortar inspection, manufacture of specimens, maintenance of test specimens and test specimens carried out in the Construction and Building Materials Department of Unsyiah. Bamboo is obtained from one of the local plantations in the Meulaboh area, West Aceh Regency. The material that will be used to make high-quality concrete is cement material, fine aggregate (sand), coarse aggregate (gravel), and water with added bamboo fiber. Then, as a comparison concrete, high quality 60 MPa concrete is also made without the addition of bamboo fiber (0% fiber bamboo). In this study, the physical and chemical properties of bamboo were not carried out. The physical and chemical properties of bamboo are based on the results of the research [10]. The water that will be used for the concrete mixture and its treatment comes from clean water obtained from the Syiah Kuala University Construction and Building Materials Laboratory. The water in this laboratory has met the standards of clean water that are suitable for use in concrete mixtures.

2.7. Mix design

It is estimated that the compressive strength of the plan is 60 MPa for cylindrical specimens of 15/30 cm using a cement water factor of 0.25. The plasticizer with a percentage of 2% of the weight of cement was used. The crude aggregate used is the broken stone with a maximum aggregate diameter of 12 mm, palm shell ash, and fly ash of 15% of the weight of cement. The percentage of bamboo fibre is 0%, 0.5%, 1%, 1.5%, of the weight of cement.

2.7.1 Work on the concrete mixture. The construction of high-quality concrete begins with mixing concrete forming materials (sand, gravel, cement, and water) and superplasticizer. Then, the material is inserted into a concrete mixer. The next job is to insert the concrete mold for 24 hours. The work on making fiber bamboo concrete is as follows: cement was mixed with coarse sand, fine sand, water, and superplasticizer so that it becomes a mixture of concrete material. Testing the compressive strength and tensile strength of the cylindrical concrete is carried out after the concrete reaches the planned age, i.e. at the age of 28. Concrete is given a vertical direction load or is parallel to the cylinder slowly until the specimen is destroyed. The total number of specimens, which is 24 cylindrical pieces (Ø15 cm, T = 30 cm) with various variations in the aggregate percentage, can be seen in table 4.
Table 4. Number of test object designs.

| Type of Object Designs | Dimension       | Number of Object Designs | Number of Object Designs Compressive Strength (28 days) | Number of Object Designs Split Tensile Strength (28 days) |
|------------------------|-----------------|--------------------------|-------------------------------------------------------|--------------------------------------------------------|
| Cylinder (0% bamboo fibre) | Ø 15 x 30 cm    | 3                        | 3                                                      | 3                                                      |
| Cylinder (0.5% bamboo fibre) | Ø 15 x 30 cm    | 3                        | 3                                                      | 3                                                      |
| Cylinder (1% bamboo fibre)  | Ø 15 x 30 cm    | 3                        | 3                                                      | 3                                                      |
| Cylinder (1.5% bamboo fibre) | Ø 15 x 30 cm    | 3                        | 3                                                      | 3                                                      |

3. Results and discussion

The results obtained from the study began from examining the aggregate physical properties, planning the proportion of concrete mixtures, testing the tensile strength of concrete, and comparing the results of the test results of concrete compressive strength associated with the results of testing of split tensile strength. The results of the analysis are presented in the form of tables and graphs so that they are easy to understand. Table 5 shows the proportion of one cylindrical specimen.

Table 5. Concrete mixtures for 1 test object.

| Materials                     | Weight Based on Percentage of Bamboo Fibre |
|-------------------------------|--------------------------------------------|
|                              | 0%  | 0.5% | 1%  | 1.5% |
| Portland cement (kg)          | 3.18| 3.18 | 3.18| 3.18 |
| Bamboo fibre (kg)             | 0   | 0.02 | 0.03| 0.05 |
| Palm shell ash 15% (kg)       | 0.48| 0.48 | 0.48| 0.48 |
| Fine sand 0 – 2 mm (kg)       | 2.34| 2.32 | 2.30| 2.28 |
| Coarse sand 2 – 5 mm (kg)     | 0.78| 0.77 | 0.77| 0.76 |
| Coarse aggregate 5 – 8 mm (kg)| 1.56| 1.55 | 1.53| 1.52 |
| Coarse aggregate 8 – 12 mm (kg)| 3.12| 3.10 | 3.07| 3.04 |
| Water (kg)                    | 0.80| 0.80 | 0.80| 0.80 |
| Super plasticizer 2% (kg)     | 0.06| 0.06 | 0.06| 0.06 |

The testing of the concrete tensile strength aims to obtain load data that can be carried by concrete cylindrical specimens until destruction occurs. The size of the split tensile strength is obtained from a ratio of twice the maximum load with the multiplication area between the diameter and height of the cylinder. Based on the results of testing the concrete tensile strength at the age of 28 days, the split tensile strength values are shown in table 6.

Table 6. Results of 28 days concrete split tensile strength.

| Percentage Bamboo Fibre | w/c | Weight of Specimen (kg) | Πx L x D (mm²) | P (KN) | 2P (N) | (f_c) (N/mm²) |
|-------------------------|-----|-------------------------|----------------|--------|--------|--------------|
| 0% (1)                  | 0.25| 12.77                   | 141300         | 240    | 480000 | 4.09         |
| 0% (2)                  | 0.25| 12.92                   | 141300         | 220    | 440000 | 3.75         |
| 0% (3)                  | 0.25| 12.93                   | 141300         | 270    | 540000 | 4.60         |
| Average                 |     |                         |                |        | 486667 | 4.15         |
| 0.5% (1)                | 0.25| 12.80                   | 141300         | 220    | 440000 | 3.75         |
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Based on figure 1 of the graph of the concrete tensile strength at the age of 28 days, the average concrete tensile strength of concrete with the use of bamboo fiber of 0%, 0.5%, 1%, and 1.5% is 4.15 MPa, 5 MPa, 12 MPa, 5.91 MPa, and 6.48 MPa, respectively. The testing of concrete compressive strength aims to obtain load data that can be carried by concrete cylindrical specimens until destruction occurs. The compressive strength is obtained from the ratio of the maximum load to the cylinder cross-sectional area. Based on the results of testing the concrete compressive strength at the age of 28 days, the compressive strength values are shown in table 7.

Table 7. Results of 28 days concrete compressive strength.

| Percentage Bamboo Fibre | w/c | Weight Content of Specimen (kg/m³) | Cross Section Area (mm²) | P (KN) | P (N) | (f’c) (N/mm²) |
|-------------------------|-----|----------------------------------|--------------------------|--------|-------|--------------|
| 0% (1)                  | 0.25| 2477.36                          | 17662.50                 | 1080   | 108000| 61.15        |
| 0% (2)                  | 0.25| 2545.28                          | 17662.50                 | 1120   | 112000| 63.41        |
| 0% (3)                  | 0.25| 2512.09                          | 17662.50                 | 1110   | 111000| 62.85        |
| Average                 |     | 1103.33                          | 1103333                  |        |       | 62.47        |
| 0.5% (1)                | 0.25| 2513.21                          | 17662.50                 | 1000   | 100000| 56.62        |
| 0.5% (2)                | 0.25| 2515.09                          | 17662.50                 | 1050   | 105000| 59.45        |
| 0.5% (3)                | 0.25| 2456.60                          | 17662.50                 | 1120   | 112000| 63.41        |

Figure 1. The graph of the concrete tensile strength at the age of 28 days.
The value of compressive and tensile strength of concrete material is not directly proportional; every effort to improve the quality of compressive strength is only accompanied by a small increase in the value of tensile strength. A rough estimate can be used that the tensile strength of normal concrete materials only ranges between 9% - 15% of the compressive strength. Therefore, the writer wants to compare how the influence of the team's concrete compressive strength with the same proportion of mixture on the concrete tensile strength in theory. Figure 6 shows the graph of compressive strength and 28-day-old concrete tensile strength with the same mixed proposition and show a graph of the concrete tensile strength based on theoretical compressive strength of 0.1 f'c <fct <0.2 f'c [3].

Based on Graph 3, it can be seen that in testing the average compressive strength of 0% cylindrical concrete bamboo fiber is 62.47 MPa. Whereas concrete with bamboo fibre of 0.5%, 1%, 75% and 1.5% is 59.83 MPa, 59.07 MPa, and 54.92 MPa, respectively. The results of the study show a decrease in high-quality concrete compressive strength with the addition of bamboo fiber. The optimum concrete compressive strength, which is obtained with the addition of bamboo fiber at 0.5% and 1%, is 59.83 MPa and 59.07 MPa, respectively.

Based on the results of the tests, the value of the compressive strength for the split tensile strength equal to the theory cannot be obtained. Only the concrete with 1.5% bamboo fiber is equal to the theory. Based on [3], a good approach to calculating concrete tensile strength (fct) is the formula of 0.1 f'c <fct <0.2 f'c. Table 8 shows the relationship of compressive strength to the tensile strength of concrete.
Table 8. Relationship of compressive strength to concrete tensile strength.

| Percentage of Bamboo Fibre | w/c | Compressive Strength ($f'_c$) (N/mm$^2$) | Split Tensile Strength ($f_{ct}$) (N/mm$^2$) | Tensile Strength (0.1 x $f_{ct}$) (Nawi, 1998) (N/mm$^2$) | Tensile Strength (0.2 x $f_{ct}$) (Nawi, 1998) (N/mm$^2$) |
|----------------------------|-----|-----------------------------------------|---------------------------------------------|------------------------------------------------------------|------------------------------------------------------------|
| 0% (1)                     | 0.25| 61.15                                   | 4.09                                        | 6.12                                                       | 12.23                                                      |
| 0% (2)                     | 0.25| 63.41                                   | 3.75                                        | 6.34                                                       | 12.68                                                      |
| 0% (3)                     | 0.25| 62.85                                   | 4.60                                        | 6.29                                                       | 12.57                                                      |
| **Average**                |     | **62.47**                               | **4.15**                                    | **6.25**                                                   | **12.49**                                                  |
| 0.5% (1)                   | 0.25| 56.62                                   | 3.75                                        | 5.66                                                       | 11.32                                                      |
| 0.5% (2)                   | 0.25| 59.45                                   | 4.77                                        | 5.95                                                       | 11.89                                                      |
| 0.5% (3)                   | 0.25| 63.41                                   | 6.82                                        | 6.34                                                       | 12.68                                                      |
| **Average**                |     | **59.83**                               | **5.12**                                    | **5.98**                                                   | **11.97**                                                  |
| 1% (1)                     | 0.25| 63.41                                   | 5.97                                        | 6.34                                                       | 12.68                                                      |
| 1% (2)                     | 0.25| 56.62                                   | 5.80                                        | 5.66                                                       | 11.32                                                      |
| 1% (3)                     | 0.25| 57.18                                   | 5.97                                        | 5.72                                                       | 11.44                                                      |
| **Average**                |     | **59.07**                               | **5.91**                                    | **5.91**                                                   | **11.81**                                                  |
| 1.5% (1)                   | 0.25| 57.18                                   | 7.33                                        | 5.72                                                       | 11.44                                                      |
| 1.5% (2)                   | 0.25| 52.65                                   | 6.31                                        | 5.27                                                       | 10.53                                                      |
| 1.5% (3)                   | 0.25| 54.92                                   | 5.80                                        | 5.49                                                       | 10.98                                                      |
| **Average**                |     | **54.92**                               | **6.48**                                    | **5.49**                                                   | **10.98**                                                  |

Based on Table 8, it can be seen that the value of the split tensile strength obtained from the calculation does not fit into the theoretical range. The tensile strength of normal concrete without fiber is 4.15 MPa which is under the range of 6.25 – 12.49 MPa. The split tensile strength of concrete with the addition of bamboo fiber at the percentage of 0.5% is 5.12 MPa which is below the range of 5.98 – 11.97 MPa. The

Figure 3. The graph of the relationship between compressive strength and split tensile strength.
tensile strength of concrete with the addition of bamboo fiber at a percentage of 1% is 5.91 MPa which fits the range of 5.91 – 11.81 MPa. Also, the tensile strength of concrete with the addition of bamboo fiber at a percentage of 1.5% is 6.48 MPa which fits the range of 5.49 – 10.98 MPa.

The addition of bamboo fiber into high-quality concrete caused a decrease in the value of concrete compressive strength, but not too significant. On the contrary, the value of high-quality concrete tensile strength causes an increase in split tensile strength, even though the results of each variation have entered into the theoretical concrete tensile for 1% and 1.5% additional bamboo fiber.

4. Conclusion
Based on the results of research and data processing that has been done, several conclusions can be taken as the final results of this study:

a. From the results of the study, the use of bamboo fiber in the concrete mixture caused a decrease in the compressive strength of high-strength concrete, on the contrary, there was an increase in the quality of the concrete tensile strength due to the addition of bamboo fiber.
b. Overall, based on the testing of the concrete tensile strength at 28 days, the optimum concrete split tensile strength is recycled by substitution at 0.5%, which is equal to 6.48 Mpa.
c. Concrete with variations in the addition of bamboo fiber is still classified as high-quality concrete because it has a compressive strength greater than 50 Mpa [16].

Based on this research, the authors sincerely hope that further research on high strength concrete can be developed by adding other fiber naturals that are rattan or fiber abaca banana which are known to have high tensile strength. Then, this study should also be continued with the investigation of beam flexural capacity so that we can get how much the tensile strength of bamboo fiber contributes to the tensile strength of high-strength concrete beams.

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