The effect of fishbone fiber and rice husk ash additive on the mechanical properties of normal concrete

S Damayanti¹, T B Aulia² and Y Hayati²

¹Civil Engineering Postgraduate Program, Department of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia
²Department of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia

Corresponding e-mail: sri.d@mhs.unsyiah.ac.id

Abstract. Concrete is a material that strong in holding compression force but weak in holding tension force so reinforcement is needed to prevent cracks in the pull region. Tuna bone fibers work as reinforcement, which is expected to overcome the problem of brittle concrete and produce ductile concrete. To improve concrete performance, fibers and additives are used. Tuna bone fibers and rice husk ash additives were selected to be able to utilize local natural materials. The purpose of this study is to examine the mechanical properties of normal concrete, which include compressive strength and tensile strength, by adding fiber and ash additives. The percentage of fibers added is 0%, 0.5%, 1%, and 1.5% of volume of concrete, and the percentage of additives is 0%, 10%, and 15% of weight of cement. Compression tests were performed to a total of 90 pieces of objects at 7, 28, and 56 days of age. Split tensile tests were performed to a total of 60 pieces of objects at the 28 and 56 days of age. The maximum compressive strength at 7, 28, and 56 days of age are 31.45 MPa, 36.81 MPa, and 41.16 MPa, respectively which were produced by variation BNS1 (BN+fiber 0.5%). The maximum tensile strength at 28 and 56 days of age are 4.08 MPa and 4.12 MPa; respectively which were produced by variation of BNS2 (BN+fiber 1%). All specimens at 7, 28, and 56 days of age produce concrete compressive strength on average 20 MPa of concrete above so that it is categorized into structural concrete.

1. Introduction
Concrete has advantages in strong holding force/compressive stress but also has specific disadvantages that it is not strong holding force/tensile stress. The tensile strength of concrete is only one of twenty of its compressive strength [1]. To improve this performance, fiber concrete is used. The idea of using fiber is to reinforce concrete with fiber that is spread evenly to prevent cracks in the tensile area. The addition of fiber overcomes the problem of brittle concrete (becoming more ductile). Adding fiber to concrete not only increase the concrete’s tensile strength, but it also can improve other concrete’s mechanical properties [2]. Also, fiber concrete has advantages compared to fiber without concrete in several structural properties, among which are ductility, resistance to shock loads (impact resistance), tensile and flexural strength, resistance to fatigue, resistance to shrinkage, and resistance of abrasion.

Tuna bone fiber is a natural fiber derived from animals. Tuna bone is part of the body of fish. It has the highest calcium content compared to other fish species, the calcium content ranges from 12.9% - 39.24% [3]. Bone has relatively hard and light tissue; it is formed from a portion of calcium phosphate. Bone has a relatively high compressive strength of about 170 MPa, a tensile strength of 104-121 MPa, and flexural strength of 51.6 MPa. Bone has a significant level of elasticity contributed by collagen [4].
To improve the performance of concrete, in addition to fiber concrete, the added ingredients is also often used. Rice husk ash is classified as one of the additives. Rice husk ash is the result of burning rice husk which has a dominant silica content of 93%—almost the same as the silica content found in factory-made micro silica [5].

2. Methodology

2.1. Fiber concrete
Fiber concrete is a composite material consisting of ordinary concrete or other material in the form of fiber (in the form of rods with diameters between 5 and 500 μm with a length of about 2.5 mm to 10 mm). The addition of fiber to the intended concrete is to improve the weaknesses of the concrete that has a low tensile strength [6]. Fiber concrete is concrete made from a mixture of cement, aggregate, water, and some fibers that are distributed randomly [2]. The principle of adding fiber into concrete is to give reinforcement to concrete. The fiber is spread evenly into the concrete mix with a random orientation to prevent concrete cracks that are too early in the tensile area due to heat hydration or due to loading.

Fiber concrete has the concrete’s mechanical properties which are influenced by several factors, including the type of fiber, fiber aspect ratio, fiber fraction volume, the strength of concrete, geometry, and manufacture of test specimens and aggregates. Adding fiber to the concrete mixture will reduce the elasticity of the affected mixture, including fiber aspect ratio and percentage amount of fiber added to the concrete mix (those will be explained in the following sentences). First, the fiber aspect ratio is the ratio between the length and diameter of the fiber. The maximum limit of fiber aspect ratio that still allows mixing can be easily achieved is \( \frac{lf}{df} < 100 \) (\( lf \) and \( df \) are the length and diameter of the fiber). The high aspect ratio causes the tendency of the fiber to clot (balling effect) and the difficulty to spread evenly. Second, the percentage amount of fiber added to the concrete mix (fiber volume fraction) [7]. The decrease in workability can be overcome by increasing the cement water factor, reducing the maximum aggregate diameter, or using additives. Fibers that are often used in concrete mixtures have a length of 10 - 60 mm [2].

2.2. Tuna bone fiber
Tuna in the Province Aceh Indonesia is often processed into ‘keumamah’ fish. This processed food is closely related to the culture of Aceh, so it is in demand and continues to be produced. ‘Keumamah’ fish production reaches 2.725 tons/year. To utilize the processing of ‘keumamah’ fish, tuna bones are used as fiber.

![Figure 1. Tuna bone.](image-url)
2.2.1. Mechanical characteristics of bones. The main tissue of the bone, the osseous network, is relatively hard and light, formed mostly from Calcium Phosphate in a chemical arrangement called Calcium Hydroxylapatite (this is the tissue which gives rigid properties to the bone). This network has a relatively high compressive strength of about 170 MPa (1800 Kgf / cm) but has a low tensile strength from 104 MPa to 121 MPa and a very low flexural strength of 51.6 MPa, which means it holds the push well, but not good in traction or moment. Bones are brittle but have a significant level of elasticity, which is donated by collagen. All bones are composed of living and dead cells that are in the organic matrix of minerals that make up the tissues [4].

| Mineral content | Percentage |
|-----------------|------------|
| Calcium phosphate | 85%        |
| Calcium carbonate | 14%        |
| Magnesium       | 1%         |

Table 1. Composition of calcium phosphate as a mineral in bone [8].

| Content      | Percentage     |
|--------------|----------------|
| Water content | 5.60 - 8.30%  |
| Ash          | 77.54 - 84.22%|
| Protein      | 0.48 - 1.29%  |
| Fat          | 1.70 - 4.13%  |
| Calcium      | 23.72 - 39.24%|
| Phosphor     | 11.34 - 14.25%|

Table 2. Content of tuna bones in the form of bone flour [9].

Tuna bones have the highest calcium content compared to other fish, which ranges from 12.9% - 39.24%. The main elements that form tuna fish bones are calcium oxide, phosphate, and carbonate [3]. Tuna bones contain calcium oxide (CaO) of 31.36%.

2.3. Rice husk ash
Rice husk ash or RHA has very high pozzolanic activity superior to other SCM, such as fly ash, slag, and silica fume, because they contain silica at 87% - 97%. Rice husk ash has a particle size of 5-10 µm, cellular and irregular particle shape, the specific gravity of 2.0-2.4 kg/m³, the surface area of 20-50 m²/kg and has an amorphous silica content of 85-90%, so that it can act as a potential additive to cement [10].

Rice husk is a cellulosic material like other biomass but contains high silica. The chemical content of rice husk consists of 50% cellulose, 25-30% lignin, and 15-20% silica [11]. Rice husk ash can be classified as pozzolanic because it contains SiO₂ + Al₂O₃ + Fe₂O₃ greater than 70% according to the required pozzolanic quality [12]. The use of rice husk ash in cement composites can provide several benefits such as increasing strength and durability, reducing material costs, reducing the environmental impact of waste materials, and reducing carbon dioxide emissions [13].

2.4. Mechanical properties of concrete

2.4.1. Concrete compressive strength. Compressive strength is one of the main performances of concrete. The compressive strength is the ability of concrete to accept compressive force per unit area [14]. Concrete compressive strength testing refers to the ASTM C 234 standard by using a compression testing machine. The compressive strength of concrete can be calculated by equation (1).

\[ f'_c = \frac{P}{A} \] (1)
Where:
\[ f'_c = \text{compressive strength of concrete cylinders (kg/cm}^2) \]
\[ P = \text{maximum compressed load/ crushed (kg)} \]
\[ A = \text{the cross-sectional area of the test specimen (cm}^2) \]

2.4.2. Concrete tensile strength. The tensile strength is determined by the tensile strength of a concrete cylinder (pressed on its long side) [11]. Of the several methods, the most frequently used is split cylinder testing. According to ASTM C496, the test is carried out by giving load to the side of the cylinder until it breaks or splits. The tensile stress that arises when the test object is split is called the split cylinder strength. The tensile strength is obtained from equation (2).

\[ f_t = \frac{2P}{\pi L D} \]  

Information:
\[ f_t = \text{split tensile strength (kg/cm}^2) \]
\[ P = \text{load time split (kg)} \]
\[ L = \text{the length of the cylindrical test specimen} \]
\[ D = \text{diameter of cylindrical test specimen (cm)} \]

Based on the research of several experts, the value of tensile strength to concrete compressive strength varies. The tensile strength of concrete is around 20% of the compressive strength. The tensile strength of concrete ranges from 10-15% of the compressive strength [7]. The value of the tensile strength approach obtained from the split cylinder test reaches strength \((0.5\sqrt{f'_c} - 0.678\sqrt{f'_c})\) MPa [7].

2.5. Equipment and materials
The equipment used is available at the Construction and Building Materials Laboratory, Department of Civil Engineering, Faculty of Engineering, Syiah Kuala University. The types of equipment are oven, a set of filters, measuring cups, scales, containers, cornering sticks, glass plates, concrete mixer machines with a capacity of 90 liters, slump gauges, rubber hammers, cement spoons, cement spoons, wheelbarrows, shovels and molds cylindrical specimens of 15 cm diameter, 30 cm height and 30 cm x 10 cm x 30 cm of mold prism specimens dimensions. The planned material used can be seen in table 3 below.

| No | Material       | Goals to Be Achieved               | Requirements                  | Size Plan Used                      |
|----|----------------|------------------------------------|--------------------------------|------------------------------------|
| 1  | Aggregate      | Fiber can be spread evenly         | Aggregate diameter < 19 mm    | ≤ 4.75 mm (fine sand)              |
|    |                |                                    |                                | 4.76 - 9.5 mm (rough sand)         |
|    |                |                                    |                                | < 19 mm (gravel)                   |
| 2  | Tuna Fish Fiber| A measure often used               | Long 10 mm - 60 mm            | Diameter 1 mm, length of 20 - 60 mm|
|    |                | Easy stirring/ workability         | Aspect ratio If/df < 100       | 20 - 60 mm                         |
|    |                | Good speediness                    | Fiber content < 2%             | Percentage                          |
|    |                |                                    |                                | 0%, 0.5%, 1%, 1.5%                 |
| 3  | Rice Husk Abu  | As a partial substitution          | Percentage of fiber (10-15%)   | Percentage                          |
|    |                |                                    |                                | 0%, 10%, 15%                       |
| 4  | Cement         | Slump limits fiber concrete        | Slump value; 25 - 100 mm (tolerance ± 20 mm) | The weight of cement is adjusted accordingly water used |
| No | Material | Goals to Be Achieved | Requirements | Size Plan Used |
|----|----------|----------------------|--------------|----------------|
|    | Water    | WCR of normal concrete | WCR (0.4 - 0.65) | WCR 0.4 |
| *  | Concrete | Medium quality concrete | f'c; 20 - < 35 MPa | f'c Plans: 30 MPa |

Material inspection carried out includes checking specific gravity (ASTM C.127-93), absorption (ASTM C.128-93), bulk volume (ASTM C.127-88), and sieve analyzer (ASTM C.136-93).

3. Results and discussion

3.1. Aggregate physical examination results

Table 4. Results of calculation of physical properties of aggregates.

| Material Check Type | Aggregate Type | Volume Weight (kg/l) | Permit Limits Orchard (1979) |
|---------------------|----------------|----------------------|-------------------------------|
| I                   | Aggregate Type |                      |                               |
|                     | Gravel         | 1.829                |                               |
|                     | Rough sands    | 1.778                | > 1.445                       |
|                     | Fine sands     | 1.632                |                               |
| II                  | Aggregate Type | Specific Gravity    | Limit on Specific Gravity Permit (SNI 03-1970-1990) | Absorption (%) | Absorption Permit Limit (%) (SNI) |
|                     | Gravel Ø19 mm  | 2.757 2.730          | > 2.5                        | 0.988          | < 3                        |
|                     | Rough sand Ø9.52 mm  | 2.660 2.597          |                               | 2.421          |                             |
|                     | Fine sand Ø4.76 mm  | 2.548 2.502          |                               | 1.837          |                             |
| III                 | Aggregate Type | Fineness Modulus    | Permit Limits (SNI 03 1970 1990) |
|                     | Gravel         | 6.222                | 6.0 - 8.0                    |
|                     | Rough sands    | 2.788                | 1.5 - 3.8                    |
|                     | Fine Sand      | 2.646                |                               |

From table 4, it can be concluded that the material used in the study as a concrete forming material has fulfilled the requirements.

3.1.1. Physical properties of other materials. Other physical properties data include fishbone fibers. The result of the calculation of fishbone volume weight is 0.813 kg/l, and the specific gravity is 0.639 g/ml.

3.2. Aggregate physical examination results

The calculation of a concrete mix design uses the ACI method. The results of the calculation of concrete mix designs for each variation with a composition of 1 m³ concrete can be seen in the table below:
Table 5. 1 m³ Concrete mixture design for all fiber variations and additives.

| Variations | Composition per m³ of concrete (kg) |
|------------|-----------------------------------|
|            | Material                          | Total | Unit |
| 1          | BN (Normal Concrete)              |       |      |
|            | Water                             | 205.00| Kg   |
|            | Cement                            | 512.50| Kg   |
|            | Rough Aggregate                   | 1220.63| Kg |
|            | Fine Aggregate                    | 406.88| Kg   |
| 2          | BNS1 (BN + 0.5% ST)               |       |      |
|            | 0.5% Bone Fiber                   | 3.20  | Kg   |
| 3          | BNS2 (BN + 1% ST)                 |       |      |
|            | 1% Bone Fiber                     | 6.40  | Kg   |
| 4          | BNS3 (BN + 1.5% ST)               |       |      |
|            | 1.5% Bone Fiber                   | 9.60  | Kg   |
| 5          | BS1A1 (BN + 0.5% ST + 10% AS)     |       |      |
|            | 0.5% Bone Fiber                   | 3.20  | Kg   |
|            | 10% Rice Husk Ash                 | 51.25 | Kg   |
| 6          | BS1A2 (BN + 0.5% ST + 15% AS)     |       |      |
|            | 0.5% Bone Fiber                   | 3.20  | Kg   |
|            | 15% Rice Husk Ash                 | 76.88 | Kg   |
| 7          | BS2A1 (BN + 1% ST + 10% AS)       |       |      |
|            | 1% Bone Fiber                     | 6.40  | Kg   |
|            | 10% Rice Husk Ash                 | 51.25 | Kg   |
| 8          | BS2A2 (BN + 1% ST + 15% AS)       |       |      |
|            | 1% Bone Fiber                     | 6.40  | Kg   |
|            | 15% Rice Husk Ash                 | 76.88 | Kg   |
| 9          | BS3A1 (BN + 1.5% ST + 10% US)     |       |      |
|            | 1.5% Bone Fiber                   | 9.60  | Kg   |
|            | Rice Husk Ash 10%                 | 51.25 | Kg   |
| 10         | BS3A2 (BN + 1.5% ST + 15% US)     |       |      |
|            | 1.5% Bone Fiber                   | 9.60  | Kg   |
|            | Rice Husk Ash 15%                 | 76.88 | Kg   |

3.3. Concrete mechanical properties test results

3.3.1. Compressive strength. The compressive strength of the concrete with 0.5% fiber addition on all variations of age tests which were 7, 28, and 56 days increased 16.78% (31.45 MPa), 7.57% (36.81 MPa), and 18.00% (41.16 MPa) compared to normal concrete, respectively. The average compressive strength of concrete with 0.5%, 1%, and 1.5% fiber addition at 7, 28, and 56 days of age is higher than normal concrete (see figure 2). This shows that 31.36% of calcium oxide (CaO) found in the bones of tuna fish which CaO is also found in cement as the main constituent component (60-67%) affects to increase the hardening speed and the strength of concrete.
The compressive strength of concrete with 0.5% and 1% fiber addition and 10% additives at 28 days of age is below normal concrete however at 56 days of age the strength is above normal concrete (see figure 2). This shows that the decomposition of rice husk ash particles with carbon above 45 μm affects the rate of hydration to increase the strength of the concrete. The silica SiO2 in the rice husk ash that reacts to decompose Ca(OH)2 produces calcium silicate hydrate (CSH) and the silica also affects the rate of strength increment.

The average compressive strength of concrete with 15% additives is below the strength of normal concrete. This demonstrates that the addition of fiber and additives in the concrete mixture reduces the workability which results in decreasing the concrete strength.

The test results of BNS1, BNS2, and BNS3 variations at 7 days achieved the minimum compressive strength target which was 30 MPa. For 28 days test, almost all variations reached the minimum compressive strength target (30 MPa) except BS3A1 and BS3A2 variations. For 56 days test, only BS3A2 variation did not reach the strength target. Concerning the structural quality of concrete, all specimens produce the average compressive strength above 20 MPa, so that they can be categorized as structural concrete.

**Figure 2.** Concrete Compressive Strength Graph for All Variations of Fiber and Additives.

Note: S1 (0.5% Fiber), S2 (1% Fiber), S3 (1.5% Fiber), A1 (Additive 10%), A2 (Additive 15%)

**3.3.2. Split tensile strength.** The average split tensile strength of all sample variations at 28 and 56 days of age is higher than the split tensile strength of normal concrete (see figure 3). The average split tensile strength of concrete with 1% fiber addition at 28 and 56 days of age increase 7.33% (4.08 MPa) and 6.06% (4.12 MPa) from normal concrete, respectively.

The split tensile strength of concrete with addition of fiber and 10% additives at 28 days of age is lower than the split tensile strength of normal concrete however at 56 days of age the strength is higher than the strength of normal concrete. This shows that the decomposition of rice husk ash particles containing carbon above 45 μm is believed to affect the hydration rate which increases the strength of the concrete. The silica SiO2 in the rice husk ash decomposes Ca(OH)2 to produce calcium silicate hydrate (CSH) and also affects to increase the rate of strength.

The average tensile strength of all variations of concrete with fiber addition and 15% of additives is lower than the tensile strength of normal concrete. This shows that the effect of fiber and additives in the concrete mixture reduces workability and clarity and decreases the strength of concrete produced.
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4. Conclusion

From the results of the study, the addition of tuna bone fibers and rice husk ash as additives to the normal concrete obtained several conclusions regarding mechanical properties as follows:

- The compressive strength of concrete with 0.5% fiber addition at 7, 28, and 56 days of age is higher than other variations. The compressive strength of concrete with 0.5%, 1%, and 1.5% addition of the fiber is higher than the strength of normal concrete. The concretes with fiber addition and 10% of additives at 28 days of age have compressive strength lower than normal concrete however at 56 days of age, the concretes have the strength higher than normal concrete. All variations of concrete with fiber addition and 15% of additives have the average compressive strength lower than normal concrete.

- The tensile strength of concrete with 1% of fiber addition at 28 and 56 days of age is higher than other variations. The concrete using 0.5% and 1% of fiber addition can increase the tensile strength. Concrete with fiber addition and 10% of additives at 28 days of age has the tensile strength lower than the normal concrete however at 56 days of age this concrete has the tensile strength higher than the normal concrete. Concrete with fiber addition and 15% of additives, all variations produce lower average tensile strength than the normal concrete.

- Regarding the structural quality of concrete, all specimens produce concrete compressive strength values above 20 MPa, so they can be categorized as structural concrete.

The results of this study are expected to be useful in the development of science, especially materials technology, and it can be taken into consideration that the local natural materials should be used as an alternative material to substitute synthetic fibers and factory-made additives.

Research on the addition of tuna fishbone fibers and rice husk ash additives in normal concrete mixes is expected to be continued by other researchers; therefore, it is suggested as follows:

- In further studies, it can be done by adding the percentage of tuna bone fibers with another percentage to see its effect on the tensile strength of concrete and other mechanical properties.

- In subsequent studies, the addition of rice husk ash additives can be done with other percentages to see the effect on the compressive strength of fiber concrete along with other mechanical properties.

- In subsequent studies, variations in the addition of tuna fishbone fibers with other types of additives at different percentages can be done.
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