The effect of reinforcement ratio cantula fiber (*Agave cantula roxb*) on tensile strength of textile reinforced concrete

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Abstract. Cantula Fiber (Roxb Agave Cantula) is a natural fiber that can be developed as a reinforcement material in concrete and can be applied to structural and nonstructural elements of a building. This research aimed to test the direct tensile strength of polymer modified mortar by strengthening cantula fiber in various forms of cantula fiber reinforcement ratios. Test specimens were in the form of polymer modified mortar with reinforced woven fiber and short fiber as textile reinforced concrete (TRC). Specimens used were in the form of plates measuring 12 mm x 80 mm x 400 mm with variations in fiber reinforcement ratios of 1.5%, 2.5%, 3.5%, and 4.5%. Test specimens were tested at age of 3 days and 28 days. The results of the test showed the highest increase in the reinforcement ratio of 4.5% in the PMM specimen with a tensile strength value of 2.41 MPa at 3 days and at 3.41 MPa at 28 days. Meanwhile, the value of the largest tensile strength in TRC was found on the reinforcement ratio of 3.5% with a tensile strength of 2.95 MPa at 3 days and 3.38 MPa at 28 days. Therefore, the effective reinforcement ratio ranged from 3.5% to 4.5%.

1. Introduction

One of the concrete innovations that develops in the civilian world for reinforcement or structural improvement is textile reinforced concrete, showing essential attributes such as thin structural elements, high strength value, high durability, and corrosion resistance [1]. The use of textile reinforced concrete can help bridges, pillars or reinforced concrete to resist vibration, sudden jolt, and torque. Textile reinforced concrete (TRC) is a composite coating material consisting of fine-grained concrete and textile fiber webbing as reinforcement, which is capable of having a concrete blanket with a thickness of less than 2 mm between concrete and textile layers [2]. Strengthening with textiles offers many opportunities, including making very thin composite and concrete components, no risk of corrosion of reinforcing materials, and the ability to produce structural parts with complex shapes and predetermined properties [3]. Another attribute is that it consists of sufficient flexibility from textile manufacturing processes and the possibility of using various other raw materials. In textile reinforcement, it is often used in the form of non-nature materials, which are alkali-resistant glass fiber (AR), aramid, basalt, and carbon fabrics. Therefore, the researchers look for alternative solutions for nature-based reinforcement. Agave Roxb Cantula fiber is a natural fiber that has mechanical ability. The survey results from the Industrial Research and Development Agency of the Ministry of Industry of Yogyakarta indicated the cantula has 64.3% cellulose content so that this fiber has the potential as a composite reinforcing material [4].
attributes possessed by cantula fiber itself are inexpensive, can be deciphered by nature, producible, strong, light and high mechanical ability [5].

2. Theoretical approach

2.1. Characteristics of TRC

Basically, Textile Reinforced Concrete (TRC) is a composite consisting of textiles that functions as reinforcement and fine-grained concrete used as a matrix. Reinforcement in textiles provides support in strengthening the existing concrete structure by providing support for tensile strength, addition of retaining strength, and shear stress. One important step to achieve this goal is to model the mechanical behavior of TRC for numerical applications into real situations.

In the process of loading tensile test, TRC stress-strain can undergo a three-stage model. The stress-strain stages in TRC that occur can include the followings.

- In the first stage (I), TRC experiences a stage where the material holds the tensile strength without experiencing a significant change or known as “free-crack state” or “pre-cracking state”. Under this circumstance, the stiffness of the matrix and fiber determines the magnitude of the slope on the curve. TRC shows almost linear elastic state behavior to the point where the increase in voltage leads to the formation of the first crack.

- The second stage (II) is the position where the material experiences the first crack and leads to a further crack formation process. In this stage, the shape of the crack is relatively good because of the increase in tensile stress. The slope, length, and roughness of this stage depend on the quality of the bond between the textile and the matrix, and the proportion of the fiber volume presents in the composite, where the load undergoes activation for even distribution. This stage, also known as the “further cracking stage” or the “multi-cracking stage”, ends when there are no cracks occur on the matrix.

- The third stage (III) is the expanding of the material or called “crack-widening state” or “post-cracking”, where the material experiences the last state in a stress-strain relation. Under this circumstance, TRC can experience a stable crack expansion pattern or be in the form of the absence of new cracks. The cracks that have been formed will expand and become wider until the TRC experiences a position of failure. This situation can be observed with the naked eye on TRC surface during the test.

For more details, the stages of crack pattern on TRC can be seen in figure 1.

![Figure 1. Crack behavior.](image)
2.2. Tensile test
The value of tensile strength (ultimate tensile strength) is the maximum stress that the material can hold when stretched or pulled, before the material breaks. Meanwhile, the value of yield strength is the starting point of a material or metal begins to deform physically. The yield stress equation \( (f_y) \) is in equation 1 and the ultimate tensile strength \( (f_{ct}) \) in equation 2 is shown as follows.

\[
f_y = \frac{P_y}{A} \tag{1}
\]

\[
f_{ct} = \frac{P_{max}}{A} \tag{2}
\]

\( P_y \) is the load when the test object has reached a yield point, \( P_{max} \) is the maximum load that can be received by the test object, and \( A \) is the area of the test object. One of the tests for tensile testing includes a tensile testing machine. The results obtained will record the behaviour of a connection phenomenon between strain stresses that occur during the tensile test process.

2.3. Ductility
Ductility is the ability of a material to maintain stiffness and strength when experiencing post elasticity. The value of the material ductility factor is the ratio between the ultimate deviation area of \( \Delta_u \) and the area of deviation during the first yield of \( \Delta_y \). Ductility factor values can be seen in equation 3.

\[
\mu = \frac{\Delta_u}{\Delta_y} \tag{3}
\]

2.4. Reinforcement ratio
The amount of reinforcement in a matrix should be limited and not exceed the limit. Over-reinforcement will cause the matrix to fail and break before the reinforcement gives support to the matrix or when reinforcement hasn't experienced a period of melting point. In general, the reinforcement ratio on the matrix can be calculated by equation 4 below.

\[
\rho = \frac{A_s}{b \times d} \tag{4}
\]

\( \rho \) is a reinforcement ratio, \( A_s \) is the area of reinforcement, \( b \) is the cross-sectional width of the matrix, and \( d \) is the cross-sectional height of the matrix. The matrix with the addition of reinforcement can experience three collapse scenarios, which can be caused by several factors, namely under-reinforced, a balanced state, and over-reinforced.

3. Materials and methods

3.1. Materials
The main material in textile reinforced concrete is a composite consisting of textiles that function as reinforcement and fine-grained concrete used as a matrix. Materials that were needed to be prepared for the matrix in this research included the followings.

- The fine aggregate used is sand which meets the requirements of passing the filter 1.18 mm.
- Cement with Portland Pozzolan (PPC) type.
- Short fiber cantula, with a fraction volume of 3% and a length of 2 cm.
- The superplasticizer used is the Glenium® ACE 8595 Master produced by PT. BASF Indonesia. This superplasticizer is to increase flowability and add ductile properties to the mortar.
- The SIKACIM® Accelerator Accelerator is 50% of the amount of water used to make the test object. Accelerator is useful for accelerating the hardening of the mortar and increasing the strength of the mortar at an early age.
CYCIM® Bonding Adhesive Polymers. Polymers are useful as adhesives between mortars and cantula fiber.

3.2. Test object
The test object used in this research was a rectangular prism with dimensions of 400 mm x 80 mm x 12 mm. Direct tensile testing of the test object was carried out at the ages of 3 days and 28 days. The specimens made were three pieces per variation of the test object. Variations of the test object to be examined were matrix variations, variations in reinforcement ratios, and comparative reinforcement. The matrix variance was tested in the form of polymer modified mortar (PMM) and textile reinforced concrete (TRC). Variations in reinforcement ratios of Cantula have a length of 398 mm and dimensions of 2.7 mm. Reinforcement was placed in the middle of the matrix transversely. The detail of the object can be seen in figure 2 and table 1 below.

![Figure 2](image)

**Figure 2.** The cross-sectional image of PMM and TRC specimens with (a) appearance of the test object, (b) location of reinforcement on the matrix.

| No | Test Object | Mortar | Short Fiber (3 %, l = 2 cm) | RR | RT | Total Samples | Total Samples |
|----|-------------|--------|-----------------------------|----|----|---------------|---------------|
| 1. | PMM N       | ✓      | -                           | -  | -  | 3             | 3             | 6             |
| 2. | PMM 1.5%    | ✓      | -                           | 1.5%| Cantula | 3             | 3             | 6             |
| 3. | PMM 2.6%    | ✓      | -                           | 2.6%| Cantula | 3             | 3             | 6             |
| 4. | PMM 3.6%    | ✓      | -                           | 3.6%| Cantula | 3             | 3             | 6             |
| 5. | PMM 4.6%    | ✓      | -                           | 4.6%| Cantula | 3             | 3             | 6             |
| 6. | TRC N       | ✓      | ✓                           | -  | -  | 3             | 3             | 6             |
| 7. | TRC 1.5%    | ✓      | ✓                           | 1.5%| Cantula | 3             | 3             | 6             |
| 8. | TRC 2.6%    | ✓      | ✓                           | 2.6%| Cantula | 3             | 3             | 6             |
| 9. | TRC 3.6%    | ✓      | ✓                           | 3.6%| Cantula | 3             | 3             | 6             |
| 10.| TRC 4.6%    | ✓      | ✓                           | 4.6%| Cantula | 3             | 3             | 6             |

Caption: RR is Reinforcement Ratio and RT is Reinforcement Type
3.3. Test setup
Direct tensile testing on textile reinforced concrete basically is the same with tensile testing of polymer matrix composites which is based on ASTM D3039. This testing was carried out on test objects of 3 days and 28 days of ages. Tensile testing was directly carried out using the Universal Testing Machine (UTM) test. The loading speed of direct tensile testing was set at a speed of 5 mm/minute. Test object and setup can be seen in figure 3 below.

![Test setup diagram](image)

**Figure 3.** Setting the testing tool with (a) the front view of the test and (b) universal testing machine.

4. Results and analysis

4.1. Results direct tensile of test objects
The results of testing the direct tensile strength of polymer modified mortar (PMM) with the addition of reinforcement cantula fiber are shown in table 2. The value of direct tensile strength (MPa) in PMM was obtained from the results of calculations from equation 2.

| Test Objects | Average Tensile Strength (MPa) | % Toward PMM N |
|--------------|--------------------------------|-----------------|
|              | 3 Days                        | 28 Days         | 3 Days | 28 Days |
| PMM N        | 0.88                          | 1.67            | -      | -       |
| PMM 1.5%     | 1.04                          | 1.37            | 18.43% | -18.33% |
| PMM 2.6%     | 1.18                          | 1.45            | 36.45% | -13.60% |
| PMM 3.6%     | 2.16                          | 3.30            | 146.13%| 96.92%  |
| PMM 4.6%     | 2.41                          | 3.41            | 173.69%| 103.80% |

The results from table 2 data, specimens with additional reinforcement experienced an increase in tensile strength compared to PMM N at the age of 3 days, with the highest percentage increase in test specimens was found in PMM 4.6% which was 173.69% and the smallest increase was in PMM 1.5% at 18.43%. The decrease in the percentage of tensile strength compared to PMM N occurred on 28 days, which was found on PMM 1.5% and PMM 2.6%. This is because the PMM 1.5% and PMM 2.6% experienced a slip process. Slips occurred because the specimen was fractured on the clamping part, so that the process of direct tensile testing gave a low tensile strength value.
From the polynomial regression equation in figure 4 above, the optimum value of PMM tensile strength is on the reinforcement ratio of 8.53% at the age of 3 days with a value of 2.684 MPa and the optimum tensile strength at 28 days which is in the reinforcement ratio 7.25% with a value of 3.560 MPa.

From the results of testing the TRC tensile strength, a graph in the form of a relationship between tensile and deformation loads was obtained. The results of the calculation of the tensile strength of the test object were compared to the tensile strength with the TRC matrix without reinforcement. The results of the calculation were displayed in the following table.

Table 3. The results of TRC tensile strength and percentage increase against TRC N.

| Test Objects | Average Tensile Strength (MPa) | % Toward TRC N | 3 Days | 28 Days | 3 Days | 28 Days |
|--------------|-------------------------------|----------------|--------|--------|--------|--------|
| TRC N        | 1.62                          | -              | 1.81   | -      |        |        |
| TRC 1.5%     | 1.94                          | 19.68 %        | 2.34   | 29.50 %|        |        |
| TRC 2.6%     | 2.02                          | 24.60 %        | 2.38   | 31.87 %|        |        |
| TRC 3.6%     | 2.95                          | 81.36 %        | 3.38   | 86.99 %|        |        |
| TRC 4.6%     | 2.54                          | 56.24 %        | 2.82   | 56.10 %|        |        |

Table 3 indicates that the matrix with fiber reinforcement is superior compared to the reference TRC (TRC N) with the lowest percentage increase in TRC 2% with 19.68% at 3 days and 29.50% at 28 days. The highest percentage increase value lies in TRC 4% specimens with a value of 81.36% aged 3 days and 86.99% aged 28 days.
Figure 5 indicates that the optimum tensile strength of the TRC regression polynomial equation produced at the age of 3 days is 2.950 MPa which is found in the reinforcement ratio of 3.44% and the optimum tensile strength at 28 days is 3.405 MPa which is on the reinforcement ratio 3.40%. Figure 6 shows a decrease in tensile strength in the test object with a reinforcement ratio of 4.6%. This is due to the addition of short fiber to the matrix which causes a decrease in interfacial bonds between reinforcement and the matrix. If the test object is withdrawn, the test object will experience a faster collapse. In order to obtain optimum tensile strength results, the interfacial bond between reinforcement with the matrix must be considered and therefore the distribution and displacement of the load becomes more effective.

### 4.2. Ductility

The graph of the direct tensile test results can be processed to find the value of the ductility factor by calculating the result of the division between the ultimate curvature curve area and the area of the curvature curve in the first crack. The results of the calculation of PMM ductility are shown in table 4 and the results of the calculation of TRC ductility are shown in table 5.

#### Table 4. Ductility value of polymer modified mortar (PMM).

| Test Objects | Average Ductility | % Toward PMM N |
|--------------|-------------------|----------------|
|              | 3 Days | 28 Days | 3 Days | 28 Days |
| PMM N        | 1.09   | 3.53    | -      | -       |
| PMM 1.5%     | 32.25  | 8.58    | 2,868.8 % | 142.9 % |
| PMM 2.6%     | 47.61  | 15.12   | 4,300.5 % | 328.1 % |
| PMM 3.6%     | 38.61  | 36.20   | 3,453.7 % | 925.0 % |
| PMM 4.6%     | 67.59  | 39.27   | 6,121.1 % | 1,012.0 % |

#### Table 5. Ductility value of textile reinforced concrete (TRC).

| Test Objects | Average Ductility | % Toward TRC N |
|--------------|-------------------|----------------|
|              | 3 Days | 28 Days | 3 Days | 28 Days |
| TRC N        | 2.11   | 3.38    | -      | -       |
| TRC 1.5%     | 5.92   | 11.21   | 179.9 % | 232.0 % |
| TRC 2.6%     | 14.57  | 5.58    | 589.3 % | 65.4 % |
| TRC 3.6%     | 8.55   | 13.40   | 304.5 % | 296.9 % |
| TRC 4.6%     | 14.71  | 13.10   | 595.9 % | 288.0 % |
From table 4 above, it can be seen that the addition of reinforcement percentage will increase the ductility value, while from table 5 the ductility value experiences irregularity in value, it also shows that the ductility of PMM specimens has a higher value than TRC specimens because the addition of short fibers reduces the bond between the matrix and reinforcement so reinforcement becomes ineffective.

5. Conclusions

Based on the results of testing data and data analysis, the effect of reinforcement ratio on the tensile strength of textile reinforced concrete which using cantula as reinforcement, conclusions can be drawn as follows.

- The addition of short fiber pieces of cantula on polymer modified mortar could increase the ability to withstand the maximum tensile load (Pmax) from 0.88 MPa to 1.62 MPa or increase by 84.87% at the age of 3 days and an increase from 1.67 MPa to 1.81 MPa or increase by 7.94% at the age of 28 days.
- The effect of the cantula fiber addition as reinforcement in polymer modified mortar compared to PMM N obtained the highest tensile strength at 4.6% with a value of 2.41 MPa or in a percentage increase 173.69% at the age of 3 days and a tensile strength 3.41 MPa or in percentage increase 103.80% at the age of 28 days. The value of ductility factor is 67.59 or in percentage increase 6,121% at the age of 3 days, and at the age of 28 days the value 39.27 or in percentage increased to1012%. The results of extrapolation, the optimum value of PMM tensile strength was found in the reinforcement ratio of 8.53% which has a tensile strength of 2.68 MPa at the age of 3 days while at 28 days the optimum value was found in the reinforcement ratio 7.25% with a tensile strength of 3.56 MPa.
- The effect of the cantula fiber addition as a reinforcement in polymer modified mortar compared to TRC N obtained the highest tensile strength at 3.6% with a value of 2.95 MPa or in a percentage increase 81.36% at the age of 3 days and a tensile strength 2.82 MPa or in percentage increase 86.99% at the age of 28 days. The value of ductility factor is 8.55 or in percentage increase 304.5% at the age of 3 days, and at the age of 28 days the value 13.40 or in percentage increase of 296.9%. The results of interpolation, the optimum value of TRC tensile strength was found in the reinforcement ratio of 3.44% which has a tensile strength of 2.95 MPa at the age of 3 days while at 28 days the optimum value was found in the reinforcement ratio 3.40% with a tensile strength of 3.405 MPa.
- Based on direct tensile testing, TRC test specimens with the addition of cantula fiber as reinforcement indicated a higher tensile strength than wire mesh reinforcement.

References

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