Development of natural fiber tensile test apparatus using cantilever structure loading system

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Abstract Measurement of the mechanical properties of natural fiber is an important role in quality control. One of the most important mechanical properties of fiber is its tensile strength. To carry out tensile test fiber required tensile test apparatus. The tensile test apparatus used today is a foreign-made commercial tensile test imported at an exorbitant price. These conditions cause obstacles in the development of basic natural fiber technology in Indonesia. The purpose of this research is to design a natural fiber tensile test apparatus which is cheap and easy to operate. The result of this research is prototype of fiber tensile test which has been successfully tested with: 5N loading capacity, calibration curve accuracy: N = 1.052 V and loading rate 0.014 N/s. The result of tensile test to one natural fiber that used abaca fiber in range 100 MPa - 900 MPa and the data of tensile test results in existing literatures then there is conformity with the value of tensile strength. The results of this study are expected provide benefits for researchers, academics and industry in supporting the development of Indonesia natural fiber industry as well as enhancing competitiveness at international level.

1. Introduction
In the last decade, the development trend of composite materials shifted on the use of natural fiber back (back to nature) as a substitute for synthetic fibers. This is supported by several advantages possessed by natural fibers, including low density, renewable energy, low energy production, more friendly processes, and good heat and acoustic insulation properties [1]. The use of natural fibers is also triggered by the regulation of automotive component product end-of-life requirements for EU countries and parts of Asia. Since 2006, EU countries have recycled 80% of automotive components, and will increase to 85% in 2015. In Asia, especially Japan, in 2005 around 88% of automotive components were recycled, while in 2015 targeted components recyclables increase to around 95% [2]. Therefore, most automotive manufacturers are evaluating the environmental impact of overall vehicle lifespan from raw materials, manufacturing processes to disposal when old.

Fiber serves as a reinforcement in composite materials. Manufacturing process of composite materials, measurement of fiber mechanical properties (reinforcement) plays an important role in quality control. The tensile strength of fiber is the amount of force needed to pull a single fiber to the breaking point and is one of the mechanical properties that is very important for the analysis and design of composite structured materials [3]. The method of measuring the modulus and strength of fibers by conducting tensile tests on single fiber strands is very popular in the fiber manufacturing industry [4].

From the results of the tensile test we can do material selection for a particular application, we can predict how the material response to various types of force loading systems. The experimental procedure for measuring Young's Modulus and the tensile stress of a single fiber has been proposed in this test detail [5]. The conditions have been determined according to ASTM D3379-75 Standard [6]. Other tensile test methods can be seen in the results of research [7] [8].
Natural fiber composites have very good prospects to be developed in Indonesia. Some reasons include that the majority of natural fiber producing plants can be cultivated in Indonesia, for example abaca, kenaf, ramie, rosella and pineapple fiber [9]. Development of composite technology reinforced by natural fibers is in line with government policy to explore the potential of existing local geniuses. This will increase the empowerment of renewable local natural resources. In fact, the successful development of this natural fiber composite will be able to increase the value of technology and economic value of natural fibers.

In particular to find out the tensile strength of natural fibers required a tensile test apparatus. Tensile testing equipment used today is a foreign-made commercial tensile testing equipment that is imported at very high prices. These conditions cause obstacles in the development of basic industries and natural fiber technology. Most laboratories in higher education institutions and other technology research institutions do not available tensile test apparatus for natural fiber. The purpose of this research is to development tensile test apparatus for natural fiber which is no expensive and easy to operate. The results of this study are expected to provide benefits for researchers, academics and industry to support of development Indonesia natural fiber industry as well as enhancing competitiveness at international level.

2. Method
The method employed to achieve the objectives are divided into two stages. Stage one is design and constructed loading structure and stage two is arrangement of data acquisition system.

2.1. Design concept
Design concept tensile test apparatus for natural fiber was built in the laboratory. The tensile test apparatus specifications are as follows:

1. Load capacity/force: 5N, this is determined from preliminary tensile test results.
2. Total length of single fiber specimen: 20 mm

According to the above specifications, load frame was first constructed. Components of the load frame of the tensile test apparatus equipment consists of several parts, among others:

1. 4 pieces steel profile L, Hot Rolled JIS SS40/A36 (07.2054 ISO1990); Size: width 40 mm x width 40 mm x thickness 4 mm x length 800 mm.
2. 2 pieces of steel profile U; Size: width 65 mm x height 42 mm x thickness 5.5mm x length 600 mm.
3. 2 pieces of steel profile L, Hot Rolled JIS SS40/A36 (07.2054 ISO1990); Size: width 30 mm x width 30 mm x thickness 3 mm x length 150 mm.

**Figure 1.** Show assembly of loading frame for tensile test.

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These steel profile L pieces are used for fixture of a cantilever beam to measure load applied to a fiber specimen.

Total assembly of the loading frame is shown in Figure 1. One end of a specimen is fixed at the end of a cantilever as a load cell by a very light nylon line, fishing line, and the other end is also fixed to one end of the nylon line, of which the other end is connected to a gear box. The gear box is driven by a motor and a rotation rate of the motor is reduced to 2.4 rpm by the gear box, its reduction ratio of 5402:1. The winding shaft is of 3.0 mm in a diameter. Therefore, the winding rate is around 0.4 mm/sec, but this does not correspond to a loading rate of a specimen, because the cantilever used for a load cell is bent.

2.2. Loaded models

A cantilever (Copper plate) made of phosphor bronze is utilized for load measurement system. Phosphor bronze is used for spring, and its chemical compositions are 5% Sn, 0.2% P, 94.8% Cu. Young Modulus is 110 GPa, tensile strength is 570 - 665 MPa, and Poison ratio is 0.33 [9]. Consider a cantilever, 1 mm long, 2 mm thick and 4 mm wide. This plate is fixed at load frame column by small steel angle pieces as shown in figure 2.

Two strain gauges are mounted 10 mm distant from the fixture end on front and back surfaces. At the free end of the cantilever, one specimen grip is fixed as shown in Figure 2. Fishing line in length of 400 mm, 40 pound strength, is used to pulling an abaca fiber specimen. One end of fishing line is connected to one grip of a specimen and the other end is fixed at winch barrel. This winch is a mini electrical motor with a reduction gear box, rotation speed is 1 rotation/2 minute. When mini motor is powered on, a fiber specimen is pulled up and the cantilever end is also lifted dependent on the applied force to the specimen. Then, output from the two strain gages is proportional to the applied force. Before starting tensile test of fiber specimens, the output of the strain gages is calibrated against applied force. Using the calibration curve, we can measure the force at fiber fracture precisely.

A simple model calculation can provide the calibration curve. When this cantilever is loaded by \( P \) at the end, bending moment \( M \), is calculated as [10],

\[
M = Px \tag{1}
\]

where \( x \) is distance from loading point. Bending stress at this point is given as,

\[
\sigma = \frac{M}{Z} = \frac{Px}{bh^2/6} \tag{2}
\]

where \( Z \) is section modulus, \( b \) and \( h \) are width and thickness of the cantilever of course, in elastic regime, Hooke’s law is held, then strain is given as,
\[
\varepsilon = \frac{\sigma}{E} = \frac{6Px}{bh^2E}
\]

where \(E\) is Young’s Modulus. Next, we consider output from two strain gauges. When we try to measure stress, we usually use strain gage. This strain gauge measures strain at the position where the strain gage is mounted. The principle of strain gage measurement is explained as follows.

As shown in Figure 4, a strain gauge is a thin foil of resistance. If the resistance is \(L\) mm long, and the resistance foil is stretched by \(\Delta L\), the resistance change from \(R\) to \(R + \Delta L\). This resistance change is calculated as follows,

\[
R = \frac{L}{A}
\]

where \(A\) is cross section area of the resistance. \(\rho\) is specific electrical resistance. If we take legalistic differentiation of both sides,

\[
\frac{dR}{R} = \frac{dL}{L} = \frac{dA}{A}
\]

where Hooke’s law is used to calculate \(\frac{dA}{A}\)

We consider a round bar of which diameter is \(d\), and the bar is strained by \(\varepsilon\) in the longitudinal direction. The diameter reduces by Poisson effect. This reduction in \(d\) is calculated as,

\[
\frac{\Delta d}{d} = -\nu\varepsilon
\]

Therefore, cross section area reduces as,

\[
\Delta A = \frac{\pi(d - \Delta d)^2}{4} - \frac{\pi d^2}{4} = \frac{\pi d^2}{4} \left(1 - \frac{\Delta d}{d}\right)^2 - 1 = -A \frac{2\Delta d}{d} = -2\Lambda \varepsilon
\]

Substituting Eq. 6 and Eq. 7 into Eq. 5, we obtain,

\[
\frac{dR}{R} = (1 + 2\nu)\varepsilon = K_S \varepsilon
\]

where \(K_S\) is called a gage factor, around 2 for most common gauges.

Therefore, we can measure strain using resistance change rate of strain gauge. To measure the change of resistance in strain gauge, we use a bridge circuit to change the resistance into voltage [11]. The principle of bridge circuit can be explained using the cantilever model mentioned above.

In figure 3, a bridge circuit used for this research is shown. At side A-B, lead wires from strain gauge mounted on the back surface of cantilever is connected, at side A-D, lead wires from strain gauge mounted on the front surface is connected. At sides B-C, and C-D, fixed resistances of 120 \(\Omega\) are connected. When the cantilever is subjected to bending moment \(M\), and bent, resistances of two strain gages change by the same amount, but the sign is different. This condition is shown in fig. 4. In this case, the current flowing along sides A-B-C is different from one along A-D-C, but the difference is very small.
Therefore, for simplicity, the current is approximately \( i = \frac{V_0}{R} \). Therefore, the potential difference \( \Delta V \) between points B and D is calculated as,

\[
\Delta V = (R + \Delta R)i - (R - \Delta R)i = 2R \frac{V_0}{R} \Delta R = 2V_0 \frac{\Delta R}{R} = 2V_0 K_s \epsilon = \frac{12K_s V_0 x}{bh^2E} \quad (9)
\]

The factor before P gives slope of the calibration curve.

3. Results and discussions

The results will be discussed in 3 subsections, they are: calibration curve of cantilever load cell, data acquisition system, and tensile test result.

3.1. Calibration curve of cantilever load cell

In order to measure a load applied to a specimen, voltage output from the strain gages mounted on the cantilever must be converted to the load applied to the specimen. The constructed calibration curve is shown in fig. 3, shown in the below figure, all the measured data fall almost on the calibration curve.
A calibration curve of the voltage output vs the applied load is constructed. For this end, a known load is applied to the cantilever end and the voltage output of the strain gauge through a signal conditioner is recorded. It means that the load cell manufactured by the author can precisely indicate a load applied to a specimen. The straight calibration curve is expressed by,

\[ N = 1.052V \]  \hspace{1cm} (10)

where, N is a load applied to a specimen, and V is voltage output from the signal conditioner. In the figure, the coefficient of determination is 0.9973. This emphasizes that two variables, N and V are straightly correlated with each other.

3.2. Data acquisition system

Data acquisition system used in this research is shown in figure 5. Output from the strain gauges through bridge circuit is input into a signal conditioner of which frequency response is 500 kHz. The signal from the strain gauges is amplified up to voltage level, voltage level and output of the signal conditioner enter the data logger. The data logger used in this research is National Instruments, NI USB-609 is shown in Figure 5, this has 14 bit resolution and 48 k signals/sec data sampling speed. Converted to 14 bit digital data is stored as a function of time in PC. Therefore, we can easily measure fracture force of fiber specimen when the data stored in PC is archived.

![Image of data acquisition system](image)

**Figure 5.** Data acquisition system.

Data acquisition system is used to convert analog data obtained during a tensile test in to digital data and to store the digital data in a computer. The digital data is output on excel data sheet as a function of time to determine the fracture load of abaca fiber. Operations are as follows:

1. The first step is to click on software Measurement & Automation on the desktop computer.
2. The second step is to click on the software
3. The third step is to click on the LabVIEW Signal Express 2010 and Right Click on Launch LabVIEW Signal Express 2010.
4. The fourth step is to click on the Acquire Signal
5. Step five is to click on Voltage
6. Next on the sixth step will be display Add Channels to Task and click on ai0, then click OK
7. Then the seventh step is the settings on the input signal range, the sample period (s) of "500m" and condition mode "1 sample (on demand)".
8. The eighth step is to click Add Display and click Chart, then right-click on the screen and click Signals “click Add Signal”.

9. Next will perform the following Chart below.

10. Last recording test data during tensile testing machine was working tool, click "RUN" on the application, it will look like on a graph line number 9 (nine) above.

![Figure 6](image.png)

**Figure 6.** An example of load-time history measure by the loading.

Recorded data exported to an excel work sheet as shown in figure 6. The left coordinate axis, output voltage from the signal conditioner is shown while on the right coordinate axis, load applied to a specimen is shown. In the figure, the applied load linearly increases with the time, from this figure, loading rate is 0.014 N/sec.

3.3. Carry out the tensile test
Natural fibers used as tensile test specimens for carry out the tensile test apparatus are Abaca Banana Fiber (Abaca Musatexilis Nee). All the measured data are summarized in tables 1. To this end, tensile strength was measured for 70 abaca single fiber from East Aceh, Aceh Province, Indonesia.

| No. | d (mm) | σB (MPa) | d (mm) | σB (MPa) | d (mm) | σB (MPa) | d (mm) | σB (MPa) |
|-----|--------|----------|--------|----------|--------|----------|--------|----------|
| 1   | 0.060  | 821.3    | 0.073  | 575.3    | 0.089  | 470.8    | 0.106  | 339.4    | 0.118  | 325.5   |
| 2   | 0.060  | 900.2    | 0.073  | 530.2    | 0.090  | 465.1    | 0.106  | 350.3    | 0.119  | 287.1   |
| 3   | 0.063  | 690.4    | 0.075  | 537.5    | 0.092  | 464.5    | 0.106  | 333.3    | 0.119  | 298.9   |
| 4   | 0.065  | 671.2    | 0.078  | 534.1    | 0.093  | 463.4    | 0.107  | 347.6    | 0.120  | 281.5   |
| 5   | 0.067  | 800.3    | 0.078  | 510.8    | 0.095  | 462.3    | 0.107  | 370.8    | 0.120  | 282.6   |
| 6   | 0.067  | 632.1    | 0.080  | 502.5    | 0.095  | 355.3    | 0.107  | 340.1    | 0.120  | 270.1   |
| 7   | 0.068  | 601.0    | 0.080  | 501.4    | 0.098  | 421.9    | 0.107  | 345.8    | 0.126  | 271.2   |
| 8   | 0.069  | 707.5    | 0.081  | 522.5    | 0.099  | 410.8    | 0.107  | 319.4    | 0.130  | 254.2   |
| 9   | 0.069  | 770.2    | 0.081  | 500.6    | 0.099  | 399.4    | 0.108  | 369.2    | 0.132  | 253.3   |
| 10  | 0.069  | 580.0    | 0.082  | 510.7    | 0.102  | 400.5    | 0.109  | 340.6    | 0.135  | 281.1   |
| 11  | 0.070  | 547.3    | 0.084  | 490.2    | 0.102  | 378.3    | 0.112  | 360.8    | 0.137  | 280.3   |
| 12  | 0.070  | 640.1    | 0.085  | 483.1    | 0.104  | 394.4    | 0.115  | 357.3    | 0.139  | 275.2   |
| 13  | 0.071  | 539.1    | 0.087  | 477.8    | 0.105  | 382.3    | 0.117  | 335.4    | 0.140  | 220.2   |
| 14  | 0.071  | 601.1    | 0.088  | 480.9    | 0.106  | 359.1    | 0.118  | 309.1    | 0.140  | 229.4   |
Diameters of abaca fiber specimen are measured using a digital microscope, because an abaca fiber is rather soft and micrometer or caliper with physical contact edges likely indents the fiber surface. Measurement of fiber diameter is done at three positions of specimen gauge length, the center and two ends, and average value of three measurements is taken as the specimen diameter [12]. In addition, a fiber cross section is not perfect circle and at each position, diameter measurement was done twice by turning 90 degrees. One sample population consists of 70 abaca fiber specimens [13].

Furthermore, the fibers specimens are made according to standard ASTM D3379-75 for tensile testing [6]. In this study, 100 cm long abaca fibers were supplied from the district of East Aceh, Aceh Province, Indonesia [14]. 90 mm long sample fiber is cut from top part of the received abaca fiber. Specimen gauge length is 30 mm and 30 mm both ends are mounted between two paper sheets with glue.

Tensile strength is shown in the descending order from the maximum to the minimum. Dependence of tensile strength on fiber diameter is shown in Figures 7. It should be noted that when the tensile strength increases as the fiber diameter decreases and reaches around 900 MPa. However, the lowest strength is around 100 MPa. The results of this tensile test are obtained compared with the results of the tensile test data in the existing literature, there is a similarity with the value of tested [15] [16].

![Figure 7. Diameter vs tensile strength.](image)

4. Conclusion
This paper has focused on developing a prototype of a natural fiber tensile test apparatus and a trial has been successfully made. Virtual instrumentation software was adopted to enable direct manipulation of the load cell through series of hardware communication devices. The results of tensile tests on abaca fibers obtained the range of tensile strength 100 MPa - 900 MPa. The tensile test results are obtained compared with the results of the tensile test data in the existing literature, there is a similarity with the value of tested. The results of this study are expected provide benefits for researchers, academics and industry in supporting the development of Indonesia natural fiber industry as well as enhancing competitiveness at international level.

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