Dynamic analysis of pineapple leaf fiber reinforced polyester composite pipes

Islahuddin
Dharma Andalas University, Padang, Indonesia

Abstract. This research shows composite pineapple leaf fibers which is made manually to form hollow cylinder with structure variant and fibers orientation of 1 layer 45°, 1 layer 90° and 2 layers 45° and 2 layers 90°. This pipe composite was analyzed through Experimental Modal Analysis (EMA) and Autodesk Inventor in order to identify the crack position. The mechanical properties of pipe composite which gotten from tensile test was used as the input to get natural frequencies mode shapes. The result of this research is pipe composite has low natural frequencies in crack condition and the changing of mode shapes curve can be applied in order to identify pipe composite crack position.

1. Introduction
There are several researches related to dynamic characteristic toward beam. The first research was carried out numerically by applying irregularity mode shape [1]. The second research was carried out numerically by applying finite difference method. The damage of the beam was identified by comparing mode shape of the beam structure with fixed-free no crack and cracks. Finite difference method was used to get the crack position [2]. The third research was using mathematic method. Mathemetic method is different from numerical method, since mathematic method can identify precisely the crack position [3].

The fourth research was carried out numerically and experimentally. This research had low value, efficient time, minim crack sensitiveness, and all mode shapes can be gotten. Crack position can be identified in all mode shapes by analyzing the changes of mode shapes and natural frequencies. This method can identify the position of crack on the beam without needed to compare them. Mode shape curve in every mode shape change constantly, but the existence of the crack has caused changing in mode shape curve and the position of the crack is identified [4]. All the researches discussed about mode shape which is used for material ferro and ceramicic (beam), while this article discusses about mode shape which is used for composite (pipe).

Process of pineapple fiber composite pipe, at first, must pass fibers alkali treatment (NaOH%). The aim of this treatment is to reduce water rate and wax in the fiber. Since the treatment makes the fibers surface rough, the bonding between the fiber and matrix increases [5].

2. Theory
2.1 Pineapple Leaf Fiber
Previously research deals with plantation, such as sugar cane [6] got attention of the researchers, currently the researches tend to go to parts of the plantation, such as the fibers. This natural fibers which are found in nature is not artificial nor human creation. Natural fibers are usually found in plantation
such as bamboo, banana tree, pineapple tree, and others. Before natural fibers are used for composites, alkali treatment using chemistry liquid such as NaOH is carried out on it. Fibers are light, natural process, and environmental friendly, therefore many studies were done on it. Natural natural fibers are renewed material which has high strength, stiffness, and does not cause skin irritation [7].

Pineapple plantation is one of plantations which has high fibers. From all parts of pineapple - which are root, branch, leaf, flower, fruit and bud - , pineapple leaf has the highest fibers. Composites on pineapple leaf are lignin, hemicellulose, and cellulose. The rate of cellulose in pineapple fibers leaf is around 69.5 – 81% which shows that cellulose is the dominant substance. The composition of pineapple leaf fibers cellulose is shown in Table 1.

| Fiber         | Cellulose (wt%) | Hemicellulose (wt%) | Lignin (wt%) | Waxes (wt%) |
|---------------|----------------|---------------------|--------------|-------------|
| Bagasse       | 55.2           | 16.8                | 25.3         | -           |
| Bamboo        | 26-43          | 30                  | 21-31        | -           |
| Flax          | 71             | 18.6-20.6           | 2.2          | 1.5         |
| Ramie         | 68.6-76.2      | 13-16               | 0.6-0.7      | 0.3         |
| Coir          | 32-43          | 0.15-0.25           | 40-45        | -           |
| Oil palm      | 65             | -                   | 29           | -           |
| Pineapple leaf | 81             | -                   | 12.7         | -           |
| Curaua        | 73.6           | 9.9                 | 7.5          | -           |
| Rice straw    | 41-57          | 33                  | 8-19         | 8-38        |

Nature fibers are used in all kinds of human aspects. Natural fibers also can be used in materials which usually used artificial fibers.

2.2 Experimental Modal Analysis

Presently, composite materials using Experimental Modal Analysis (EMA) is an essential tool in new design structural analysis [9]. EMA is the determination of natural frequencies, mode shapes, and ratio dumper from vibration measurement experiment. The basic theory is creating relations between system vibrate responds on a location as the function of its excitation frequencies. These relations are called as Frequencies Response Function (FRF). The measurement of vibrate in EMA is known as modal testing with ASTM E756 standardize. Modal analysis is essential in analysing and controlling the vibration.

2.3 Frequencies Response Function

Frequencies Respons Function (FRF) is a curve of a measurement which separated dynamic parameter from a structure. FRF describes relation of input-output between two points on the structure as the frequencies function. As an example, the impulse force and displacement respond are caused by the excitation load of the measurement system in producing FRF. The formula can be seen as

\[ X(w) = H(w) \times F(w) \text{ atau } H(w) = \frac{X(w)}{F(w)} \tag{1} \]

The formula shows H(w) is FRF matrix, X (w)is vector discrete Fourier Transform respond displacement, and F(W) is external load vector discrete transform. FRF of a system is a function with
a complex value from independent variable with a real value. Therefore, it has real and imaginier components.

From imaginier FRF, it can be used to form mode shapes, while FRF magnitude only natural frequencies can be gotten. Technique used was combining peak value of FRF imaginier of each element with the same point. Therefore, the first point to the last point is in mode shape sequence, which starts from the smallest to the highest.

2.4 Measuring Crack Position

This measurement is carried out in order to get the crack position through the changing of mode shapes curve. The formula can be seen as

$$\text{mm} = \frac{|y_2 - y_1|}{(x_2 - x_1)^2}$$

(2)

Where
- x is composite pipe element length
- y is displacement in y axis
- mm is mode shape curve changing

The result of mode shape curve changing gotten from the formula is shown in a graph, between the composite crack position and mode shapes changing.

3. Method

In this research, Experimental Modal Analysis (EMA) and Autodesk Investor Program on composite pipe model for layers variation and fiber orientation of 1 layer 45°, 1 layer 90°, 2 layers 45°, and 2 layers 90° were carried out. The testing of dynamic characteristic was done to composite pipe one crack and two cracks in order to get FRF. The peak value of every imaginier FRF is on the same natural frequencies ($\phi_{eksp}$). if it is related to each beat, mode shapes curve is gotten ($\phi_{eksp}$). The results from those two analyses were compared on the natural frequencies and on the mode shapes in order to get precisely the crack position on composite pipe. The flow chart is shown in Figure 1.

4. Result and Discussion

The results of this research were based on EMA and Autodesk Program. EMA was used to identify the crack through an experiment. In the experiment, the composite pipe was bent in order to get curve FRF which shows the crack position. While in Autodesk program, the analysis was through numerical.
4.1 Crack Identification through Autodesk Inventor Modelling 2017 and Experimental Mode Shapes Study

4.1.1 Natural Frequencies Analysis

From natural frequencies analysis, it shows that composite pipe of 1 layer 45° is low comparing to natural frequencies 2 layers 45°. It is because the number of layers influence the result of natural frequencies. The higher number of the fiber layer, the higher natural frequency will be. Crack which was given also influences the result of natural frequencies. Natural frequencies no crack give higher value comparing to 1 or 2 cracks treatment. The result of composite pipe natural frequencies and autodesk inventor 2017 with the treatment is shown in Table 2.

|                | 1 layer 45° (Hz) | 1 layer 90° (Hz) | 2 layers 45° (Hz) | 2 layers 90° (Hz) |
|----------------|-----------------|-----------------|-----------------|-----------------|
| No Crack       | 115.4           | 111.8           | 125.7           | 129.2           |
| One crack      | 118             | 113.37          | 121             | 118.2           |
| Two cracks     | 121             | 125.5           | 125.5           | 119.2           |
| 2 layers 45°   | 655.7           | 652             | 714.7           | 734.6           |
| No crack       | 111.8           | 118             | 121             | 125.5           |
| One crack      | 661             | 673.8           | 688.8           | 698.5           |
| Two cracks     | 714.7           | 734.6           | 688.8           | 698.5           |
| 2 layers 90°   | 1629            | 1615            | 1775.5          | 1824            |
| No crack       | 1615            | 1615            | 1615            | 1615            |
| One crack      | 1615            | 1615            | 1615            | 1615            |
| Two cracks     | 1615            | 1615            | 1615            | 1615            |

From the comparison between natural frequencies of different treatments, it shows that treatment 2 layers 45° no crack has the highest natural frequencies in a row, which are 129.2, 734.6, 1824 Hz. The lowest natural frequencies is on 1 layer 45° one crack. The result of natural frequencies using experimental mode shapes analysis can be seen in Table 3.

|                | 1 layer 45° (Hz) | 1 layer 90° (Hz) | 2 layer 45° (Hz) | 2 layer 90° (Hz) |
|----------------|-----------------|-----------------|-----------------|-----------------|
| No crack       | 108             | 110             | 118             | 119             |
| One crack      | 106             | 110             | 118             | 119             |
| Two cracks     | 110             | 118             | 118             | 119             |
| 2 layers 45°   | 652.2           | 640.2           | 673.2           | 718.3           |
| No crack       | 110             | 118             | 118             | 119             |
| One crack      | 667.2           | 675.3           | 690.3           | 616.2           |
| Two cracks     | 633.2           | 675.3           | 690.3           | 616.2           |
| 2 layers 90°   | 1698            | 1632            | 1731            | 1734            |
| No crack       | 1642            | 1646            | 1645            | 1684            |
| One crack      | 1646            | 1649            | 1684            | 1675            |
| Two cracks     | 1645            | 1684            | 1675            | 1572            |

From the frequencies results, there is a tendency of natural frequencies value decreases in variation of one crack 1 and two cracks. The highest natural frequencies is on 2 layers 45° no crack with value 119, 718.3, and 173 Hz on the mode shapes. This shows that comparison between natural frequencies using EMA and Autodesk Inventor is nearly the same.

4.2 Identifying the Crack through Autodesk Inventor Modelling 2017 and Experimental Mode Shape Study

EMA was firstly carried out with no crack, and continued to one crack, two cracks to each layer variation and fiber orientation. From the result, FRF is gotten. This curve was analyzed by using mathematic formula in order to get natural frequencies and mode shape. Next, Autodesk Inventor by modelling the pipe no crack, one crack, and two cracks was carried out. The first crack position of EMA is similar to the modelling of Autodesk Inventor. The test result of EMA was compared to Autodesk Inventor.
4.2.1 Shapes Analysis
The analysis of mode shape with Autodesk Inventor was done by dividing the composite pipe into 18 same part. Mode shapes curve and Autodesk Inventor with treatment of 1 layer 45° one crack shows changes mode shapes on the first, second, and the third. Pipe composite mode shapes for 1 layer 45° can be seen in Figure 2.

![Figure 2](image)

**Figure 2.** Mode Shape Curve of the three composite pipes 1 curve 45° one crack with Autodesk Inventor 2017.

In general, the gotten mode shape for any variation of fiber orientation and fiber layers tends to have the same crack position. From treatment toward 1 layer 45° with 1 crack, the position is between 100.68-100.77 mm, while in the EMA is 99.5-100.5 mm. This shows that crack position of mode shape curve is relatively the same. Moreover, from the EMA, it is known that the crack position does not have differences with the crack position of Autodesk Inventor since the value result is the same. From EMA test, the coherence result is quite good. This is shown in Figure 3.

![Figure 3](image)

**Figure 3.** Crack Position with EMA 1 Layer 45° One Crack

From Figure 3, it can be seen that the crack position in number 100.5 mm. This shows that EMA crack position and Autodesk Inventor is nearly having the same value.

5. Conclusion
It can be concluded that mode shapes analysis can be implemented to pineapple leaf fibers composite pipe in order to identify the composite pipe crack position. The natural frequencies pineapple leaf is influenced by the layers and fibers orientation, and also by composite elasticity modulus. From EMA and Auto desk program, the lowest natural frequencies is on the 2 layers 90°. Overall, mode shapes in these two ways give relatively the same result.
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