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To cite this article: Muhammad Ikman Ishak *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **743** 012009

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# Experimental and computational evaluations of the mechanical stresses of banana trunk fibre-reinforced epoxy resin composite in coffee table application

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**Abstract.** The banana plant including the trunk is normally disposed after it has produced fruits once in its lifetime and becoming unproductive. Herbicide injection and burning using kerosene are the examples of current disposing method. Those methods are unfavourable owing to bad effects to the environment. Therefore, the unproductive banana trunk through its fibre properties, has a high potential to be used as composite in saving the environment. Three tensile test specimens were prepared with two of them have different length of banana fibres – shorter and longer than 0.5 mm, whilst another specimen has no fibres. The elastic modulus, Poisson's ratio, and vertical load of 2 GPa, 0.3, and 981 N, respectively, were applied towards numerical models. The results exhibited that the composite with short banana fibre length promoted encouraging maximum and break stress values. Besides, the properties of the composite are well appropriate to be applied in furniture making as satisfactory stress value recorded in the computational analysis.

## 1. Introduction

Banana plant can be categorised as a gigantic herb which forms trunk with a height of 3 to 6 meters from an underground stem. The plant comprises several main parts such as fruits, leaves, and stem or trunk. The trunk or also recognised as pseudostem, developed by the firmly stuffed overlapping leaf sheaths. The leaves will emerge one after another that allowing the trunk to grow continuously until reaches its maximum height. As the banana fruits can be eaten, the trunk, on the other hand, is usually processed to make natural craft materials and garment [1]. Moreover, the advantages of banana trunk have also been expanded, to date, in medical treatment applications, as instances for blood pressure, digestion, detoxification, healing acidity, weight loss, and gastric problems.

The banana plant is only productive once in its lifetime before it dies. Commonly, the plant takes approximately 13 months to achieve maturity and the plucking process of the fruits is ready. When the banana plants die, they are normally disposed via several ways such as by burning using kerosene, cutting and chopping down using mechanical tools, and injecting herbicide. However, most of the methods are harmful to the environment due to the consequences of air pollution and toxicity. Thus, the unproductive banana plant especially its trunk can otherwise be used for related possible applications in regard to its fibre properties. Up to the present time, natural fibres are widely utilised in numerous appliances owing to less pollution, low density, low cost, light weight, and eco-friendly nature. Natural fibre can be described as substances that produced by animals or plants and it can be



spun into thread, rope, or filament [2]. Banana trunk fibre possesses similar properties with that of natural bamboo, however, it has better spin ability and fineness.

Composite is defined as a material that developed from two or more basic materials (reinforcement and matrix) with different chemical and physical properties, to create a new material with different properties from the individual element. Among the examples of typical engineered composite materials are composite wood, reinforced concrete, reinforced plastics, metal matrix composite, and ceramic matrix composite [3]. The present study emphasises the use of generic organic matrix material which is polymer, to be evaluated.

This study, thus, places a major interest on the evaluation of the mechanical properties of the banana trunk fibre-reinforced polymer composite for furniture making application. To date, there is no study observed that considering the proposed type of composite in the making of furniture. Previous findings reported that the rattan being the typical material used as main parts of furniture since 1970s. The method of weaving reeds or other natural fibres is known as one of the prevalent techniques considered in fabricating related furniture elements. Furthermore, this study is basically an extension of our previous related investigation on the similar composite applied in the fabrication of furniture which focused on the effect of different weights of banana fibre [4]. The present evaluation, however, examined the influence of distinct sizes of the fibre – 0, < 0.5, and > 0.5 mm – on the mechanical stresses generated within the composite under experimental and numerical analyses.

## **2. Materials and methods**

### *2.1. Preparation of banana trunk fibres*

Generally, most of the materials and methods involved in this study were adopted from our past related investigation [4]. A banana trunk of an unproductive matured banana tree was collected from a farm. The trunk was later cleaned and washed with water before cut into some small parts using a cutter, with the thickness of 50 mm for each part. This study only consumes one part of the trunk and it was sliced into tiny fragments. The fibres were then dehydrated under the direct sunlight for 36 hours until they were absolutely dry or all moisture content was removed.

Through this study, the influence of banana trunk size (length) embedded in the polymer matrix on the mechanical properties was a major focus. Hence, it is important to note that the quantity of the fibre (weight) was set to be identical (0.9 g) in all specimens. Whilst, epoxy resin was selected as the material of the matrix which used to bind all the fibres together. In overall, there were three specimens made; 1) Specimen 1: Without fibre (pure epoxy resin matrix), 2) Specimen 2: 0.9 g fibre with the fibre size of less than 0.5 mm (14.6 ml epoxy resin matrix), and 3) Specimen 3: 0.9 g fibre with the fibre size of more than 0.5 mm (14.6 ml epoxy resin matrix). Two different manual sifters with the hole size of smaller and greater than 0.5 mm were utilised to strain out all the needed fibre size.

### *2.2. Preparation of specimen mould*

Prior to the experimental testing of the specimens, there is a need to fabricate the specimen moulds first. Therefore, a three-dimensional (3-D) model of dog bone shape signifying the design and dimension of the specimen, was created using SolidWorks software. The 3-D model was then printed using a rapid prototyping machine and it has a length, width, and thickness of 150, 20, and 4 mm, respectively. The printed dog bone-shaped model was casted to produce the specimen mould by combining two types of material – silicon rubber and hardener. The ratio of silicon rubber to hardener considered is 25:1. Among the advantages of silicon rubber are good heat resistance and elasticity. After the mixture of both materials had been prepared, it was directly poured into a container. The specimen models were later put into the mixture solution and the mould was let harden. Figure 1 exhibits the hardened silicon rubber mould and the dried banana trunk fibres.

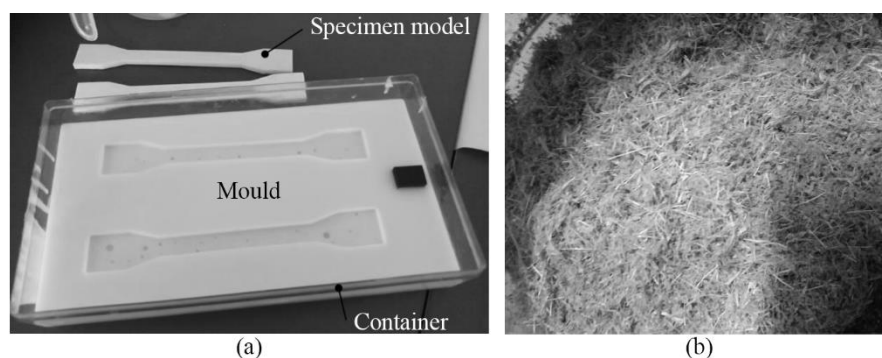
### *2.3. Preparation of tensile testing specimens*

The testing specimens had been produced by mixing epoxy resin and hardener at a ratio of 2:1 to be as the composite matrix, and the mixture was poured into three separated containers. Two of the containers were inserted with different sizes of banana trunk fibre – smaller and greater than 0.5 mm,

respectively, and stirred evenly, while another container was left unmixed with any fibres. Afterward, the composite mixture was ran into the mould and dried at room temperature for approximately 24 hours. The mechanical properties of the composite namely maximum and break stresses (MPa) were determined through a tensile test. The tensile test machine was firstly calibrated to prevent any errors which may affect the result data. The speed of the stroke was fixed at 30 mm/min.

#### 2.4. Computational analysis of furniture

A numerical examination on a furniture model was conducted to evaluate its performance in regard to the properties of the composite attained in the experimental analysis. Thus, a 3-D model of coffee table was developed using SolidWorks software and then transferred into Abaqus software for the finite element analysis (FEA). Finite element technique shows a vital role in solving mathematical modelling difficulties in numerous fields of technology, science, and industry [5-20].

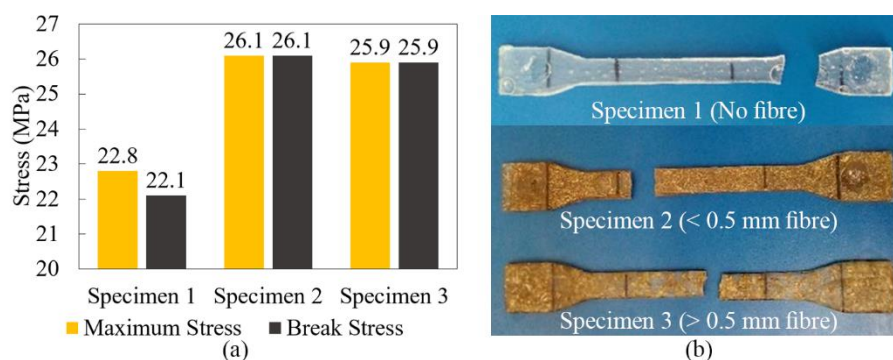


**Figure 1.** (a) The hardened silicon rubber mould. (b) The dried banana trunk fibres [4].

### 3. Results and discussions

#### 3.1. Maximum and break stress magnitudes

Figure 2 illustrates the comparison of maximum and break stress magnitudes recorded among the specimens and the condition of the specimens after the tensile test conducted. It was found that the maximum stresses were considerably increased as the size of fibre decreased. The value of maximum stress was significantly lower in both Specimen 1 (no fibre) and Specimen 3 ( $> 0.5$  mm fibre) than the one in Specimen 2 ( $< 0.5$  mm fibre) with discrepancies of 12.64 and 11.97%, respectively. Similar situations were observed for the break stress outcomes in which Specimen 2 (26.1 MPa) still superior with about 1.18- and 1.01-times higher break stress magnitude as compared to Specimen 1 (22.1 MPa) and Specimen 3 (25.9 MPa), respectively. The specimens with fibre content irrespective of its size exhibited brittle-like fracture surface compared to the one without.

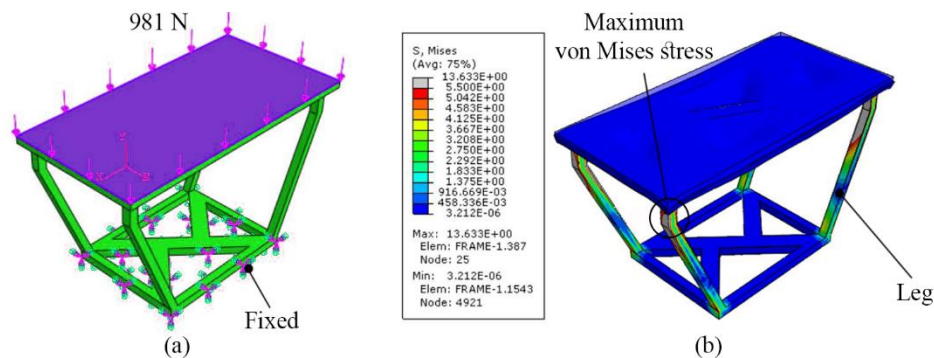


**Figure 2.** (a) The comparison of maximum and break stress values among all specimens. (b) The condition of specimens after the tensile test.

One of the promising clarifications for the greater stress values recorded in the specimen with decreased size of fibres is due to the high contact area of fibre-to-matrix. The decrease in fibre size has increased the total contact area of all fibres, accordingly. In comparison, it was important to note that the maximum and break stress values were similar for Specimen 2 and Specimen 3. Meanwhile, for Specimen 1, the break stress was slightly smaller than the maximum stress magnitude by nearly 3%. This could be due to the brittleness of the composite which has generated less strain hardening phase or plastic deformation before fracture. These were in accordance to the type of specimen fracture depicted by Specimen 2 and Specimen 3 wherein no necking or constriction seen to reveal the elasticity elongation under the application of tensile force.

### 3.2. Maximum von Mises stress dispersion in furniture model

The outcomes of FEA in terms of von Mises stress value and distribution within the coffee table model are exhibited in figure 3. From the tensile test results, it was reported that the Young's modulus,  $E$  of the tested composite is about 2 GPa, with the Poisson's ratio,  $\nu$  of 0.3 assumed. These material properties had been assigned for the table legs in the pre-processing settings of analysis. A vertical load of 981 N was onto the top surface of the table and all FEA models were meshed with four nodes solid tetrahedral elements.



**Figure 3.** (a) The boundary conditions and applied loading on the FEA model [4].  
(b) Von Mises stress plot for the table model that assigned with the composite properties.

The findings revealed that the load was uniformly dispersed all over the legs with excessive stress intensity found at the top regions. The highest von Mises stress level produced in the table was 13.6 MPa illustrated in grey colour spectrum scale. The magnitude appears significantly way lower than the normal range of ultimate tensile stress value of the natural fibre-reinforced polymer composite. It could thus be agreed that the properties of banana trunk fibre-reinforced epoxy resin composite are satisfactory in yielding promising stress value within the furniture.

## 4. Conclusions

The findings of the present study support the following conclusions. The mechanical properties of banana trunk fibre-reinforced epoxy resin composite was observed to be favourable in the application of furniture making owing to encouraging mechanical stress value obtained via numerical analysis. Also, the decrease in the size of fibre embedded within the polymer matrix was evident to have considerably improved the properties of the composite.

## Acknowledgements

Appreciation is given to Faculty of Engineering Technology, Universiti Malaysia Perlis. The authors reported no conflicts of interest related to this study.

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