Mechanical Behavior of 3D-Printed Banana Pseudostem-Like Structure

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Abstract. Studying nature-inspired structure is important to know how nature can adapt with environmental loading and how to emulate this structure for engineering applications. In this work, banana Pseudostem-like structure were fabricated using Fused Filament Fabrication (FFF) type of 3D Printer using thermoplastic polyurethane (TPU) material. Specimens for tensile test with angle variation of 0°, 15° and 30° were produced and tensile tested. Results show that the specimen with 0° is able withstand higher load because no lateral strain at the outer walls of the specimen due to the absence of the reorientation of the secondary walls. It can be inferred that the natural design of pseudostem structure that has low angle of longitudinal walls are useful to hold the tensile load. The current results on tensile behavior of pseudostem-like structure could open up new engineering applications such as architected microstructures for mechanical energy absorber.

Keywords: 3D printing, banana pseudostem, cellular structures, tensile properties, lightweight structures

1. Introduction

Cellular structures have been popularly used in many engineering applications due their superior properties. Cellular materials that comprise solid and void phases with certain density and architecture offer lightweight, high specific stiffness and strength, high permeability, excellent impact-absorption, thermal and acoustic insulation [1]. As a result, they are successfully implemented in applications such as biomedical implants, scaffolds for tissue engineering, vibration damping, filters, electrodes, catalysts, heat exchangers, insulation, and lightweight structures [2]. Due to the complex internal geometry, manufacturing these structures is impossible with traditional machining. Thanks to the advancement of additive manufacturing (AM) technology, currently complex material architecture at various length scales can be manufactured easily. AM fabricates the 3D object layer by layer using various feedstocks, usually in powder, liquid, or solid filament. The most popular type of AM is FFF because the machine and the filament feedstock are affordable and the machine is easy to operate [3].

Cellular structure design could be inspired from nature. Geometrical microstructures in nature has unique mechanical behavior that can provide insight for the materials design. The unique structures designed by nature such as the human bone, bamboo, wood, cuttlefish bone, silk, honeycomb, etc are usually very strong, very tough, and very light in weight [4].

Banana is amongs the largest agriculture business in the world. The banana tree (pseudostem) is usually disposed after the fruit harvesting, which causes huge amount of banana biomass waste [5]. To utilize its by-
product, banana tree can be exploited by extracting its fibers and utilize it for fabrics and composites [6]. Only few works investigate the mechanical behavior of the naturally designed of the cellular structure of the banana trees and emulate the structure for engineering application. Ennos reported that the design of banana petiole is extremely efficient and very lightweight [7]. This structure can efficiently support huge leave and withstand hurricanes. In this work, we investigated one layer of banana pseudostem structure and emulate the microstructure with help of 3D printer. Thermoplastic Polyurethane (TPU) were chosen as the material. Tensile testing were employed to study the mechanical response of the structure.

2. Materials and Methods
A section of fresh banana pseudostem was cut and its photograph was taken. As seen from Figure 1, the banana pseudostem structure is composed of primary cell walls with ± 1.2 mm thickness reinforced with lower thickness (± 0.3 mm) of longitudinally oriented walls. In the real structure, many pseudostem layers are stacked together to build a round cross-sectional shape of the banana tree. We designed the CAD model to emulate one layer of pseudostem structure and fabricate the specimens for tensile tests with a FFF 3D Printer using TPU as the feedstock filament. The CAD model and the specimens are shown in Figure 2. The angle between primary and secondary walls of the real structure is around 15° and thus specimens with angle variation of 0°, 15°, and 30° were chosen. TPU is used because the flexibility is close to that of the pseudostem structure. Tensile tests were performed at a constant crosshead speed of 10 mm/min in Zwick-Roell Z250 at ambient temperature (~25 °C). The Poisson’s ratio is evaluated from the ratio of strain between lateral and axial direction.

3. Results and Discussion
The banana pseudostem-like structure response under tensile loading are shown in Figure 3. The load-displacement curve and its corresponding deformation mechanisms are presented. It can be seen from the figure that the primary walls are responsible to hold the tensile load. The secondary, longitudinally-aligned walls change the orientation approaching to the load direction as the load increases. This event influences the Poisson’s ratio as the specimen with 30° angle orients to the load direction faster, and thus higher Poisson’s ratio than other specimens, as seen from Figure 3. The average Poisson’s ratio for specimens with 30°, 15° and 0° are 0.13, 0.08 and 0.02, respectively. Cellular structure [8], nano-cellular buckypaper and their composites [9,10] commonly have almost zero Poisson’s ratio since this structure can easily deform uniaxially with negligible or low lateral or longitudinal deformation.
Figure 3. a) Load-displacement curve of 0°, 15°, and 30° specimens, and b) the corresponding deformation mechanisms.

The re-alignment of the specimen with 15° and 30° angle induces higher strain at the outer primary walls. Meanwhile, it doesn’t happen to specimen with 0° since the longitudinal walls have zero load and thus no secondary walls’ re-alignment. This results in ability of specimen with 0° to withstand higher load because no additional strain at the outer primary walls of the specimen. It can be inferred that the natural design of pseudostem structure that has low angle of longitudinal walls are useful to hold the tensile load. Similar to the structure of petiole, eventhough there is no woody tissue, the pseudostem structure have ability to support the whole tree structure, can withstand winds, and able to transport nutrients and water.

Figure 3. a) Poisson’s ratio of specimens with angle of 0°, 15°, and 30°, and b) the corresponding deformation mechanisms.

4. Conclusion

The pseudostem is a hierarchically cellular structure. Many pseudostem layers are stacked together to build a round cross-sectional shape of the banana tree. The macroscopic mechanical behavior is the cumulative result of the properties of one layer of pseudostem and its pseudostem stack. In this work, one layer of banana Pseudostem-like structures were fabricated using FFF 3D Printer using TPU material. Tensile specimens with angle variation of 0°, 15° and 30° were produced and tested. Results showed that the specimen with 0° is able to withstand higher tensile load because no lateral strain at the outer walls of the specimen. The absence of the lateral strain as indicated by the almost zero Poisson’s ratio is due to the absence of the reorientation of the secondary walls to the axial direction. It can be inferred that the natural design of pseudostem structure that has low angle of longitudinal walls is useful to hold the tensile load. The study of natural structures is important to the development of biomimetic structures. The current results on tensile behavior of Pseudostem-like structure could open up new engineering
applications such as for lightweight mechanical energy absorber. Further works such as mechanical behavior of pseudostem layer and pseudostem stack under compression, torsion and bending could be performed.

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