Experimental investigation on durian thorns

Bundit Phungsara, Ekkarin Phongphinittana, and Petch Jearanaisilawong*

Department of Mechanical and Aerospace Engineering, King Mongkut’s University of Technology North Bangkok, 1518 Pracharat 1 Rd Wongsawang Bangsue, Bangkok, 10800, Thailand

* Corresponding Author: petch.j@eng.kmutnb.ac.th

Abstract

Durian is a fruit that has a round shape with thorny shell. When a durian is ripe and falling down from a tall branch to the ground, its thorn help absorb shock from an impact with the ground and lessen the damage to its soft internal flesh. This research aims to investigate the structure of durian thorn and its mechanical properties. Among varieties of durian cultivars, Monthong durian is selected as a representative variety because of its popularity and availability. Thorns and components of durian peels are harvested from a ripened durian and stored in vacuum refrigerated bags. Modulus of Elasticity of each component is measured by performing uniaxial tensile tests on coupon samples. The results show the gradients of modulus of elasticity at various points on the durian peels. The experimental results can be used as inputs for finite element simulations of durian thorns for further analysis.

1. Introduction

Durian is a fruit native to Indonesia. It is a thorny oblong fruit with aromatic soft yellow flesh, popular among Thai and foreign consumers. While numerous species of durian are found in Thailand, six varieties are grown commercially: Gan-yao, Monthong, Cha-nee, Kra-dum, Long-Lub-Lae, Puangmanee. Among them, Monthong is the most popular variety and commercially available.

Aside from the distinct aroma, durian thorns are the most prominent feature of this fruit. The thorns function as a protective mechanism and a deterrent to natural predators. In addition, when a durian is ripe and falling from the tree, the thorny part of durian sinks into the ground to reduce the effects of impact on the inside flesh. Thus, the structure of its thorns is naturally designed to withstand an impact load.

Durian thorns begin developing from its flower. Once pollinated, the ovary within a flower transforms into a bud of greenish skin with pimples on the surface - as shown in Figure 1a. As the bud grows, the pimples elongate into hardened thorns (Figure 1b). The thorn base is enlarged as the fruit expands in size. The ripened durian is shown in Figure 1c.

A durian thorn has a pyramid-shaped structure with a polygonal base. Thorn sizes depend on the size of the fruit as well as locations on the shell. These thorns are joined at the base. Durian thorns can be divided into several types such as pyramid or cone, with polygonal bases. The tips of these thorns can be hardened and pointy, while others are crooked.
Previous studies on durian thorn structure as impact absorbers are limited due to its exotic nature. Ha et al., [2] studied the structure of durian peels by partitioning into three layers: exocarp, mesocarp and endocarp corresponding to external surface of the thorn, soft flesh inside the thorn, and a thin layer under the thorn, respectively. Compressive tests on individual thorns were performed to measure their strengths. Bulk properties of the thorns were also investigated by compressing rectangular samples of 4, 9, 16 and 25 thorns. Results of the stress tests showed that the stress curves were divided into three phases: the first phase was when the stress-strain curve increased linearly, the second phase when the samples deformed at relatively constant stress, and the third phase when stress increased significantly due to compaction of the thorns. These results show that the deformation energy increases as the number of thorns increases but tapers off after 16 thorns.

A related study was the characterization of jujube branches by Wang et al. [8]. Nanoindentation tests and uniaxial tension tests were performed to measure modulus of elasticity and tensile strength along longitudinal and transverse directions of the branches.

Studies of material structures resembling a thorn of durian under impact loads were performed by Ahmad et al., [3-4]. In these works, thin-walled pyramid- or cone-shaped tubes and those with internal foam inserts were subjected to compressive and impact loads. Effects of taper angles on the strength of tubular cones were investigated. They showed that a tube with a taper angle of 15 degrees had the highest strength. Also, thin-walled cones with foam inserts can absorb impact energy more than hallow thin-walled cones. These studies demonstrate that a composite structure with a hard outer layer and a soft core can be used for absorbing impact energy.

Inspired by previous studies that use structures similar to durian thorns as impact absorbers, this research focuses on characterizing mechanical properties of durian thorns and components of durian peels. The results can lead to an insight into underlying structural design and arrangement of durian thorns that are responsible for the impact absorption capability.

2. Characterization of Durian Peels Structure
Durian is an oblong ellipsoidal fruit covered by thorns on the outer. Inside a durian is divided into several carpels that house arils (flesh) and seeds. A central spine connects all the carpels. For clarification, longitudinal direction of the fruit is defined as the direction along the central spine and transverse direction is perpendicular to the central spine as shown in Figure 2a. A carpel is shown in Figure 2b.

This research focuses on the structure of durian peels. An inspection on micrographs of the peels shows two distinct layers divided by a thin boundary: an outer layer that consists of hardened thorns and their bases, and an inner layer that represents the soft white locule that houses the durian flesh. The layers of durian peels are shown in Figure 3.
Figure 2. Durian fruit (a) Direction of durian (b) A durian carpel.

Figure 3. (a) Layer of durian peels (b) Cut section of outer and inner layers.

The outer layer is categorized by hardness into three substructures: Thorn tip - a dry hard apex, Thorn skin – its greenish exterior shell, and Thorn core – a white soft material under the skin. In comparison, the inner layer is divided by the texture into two substructures: a soft locule and a stretchy thin membrane attached to the flesh of the durian. Figure 4 shows the substructures of durian peels.

Figure 4. (a) Structure of outer layer (b) Structure of inner layer

3. Mechanical Testing of Durian Peels
Mechanical properties of durian peels’ substructures are investigated. Due to size limitation, the mechanical properties of thorn tip are not covered in this investigation. The properties of four other
substructures were tested using uniaxial tensile tests. A Monthong durian was selected as a test sample because of its availability. This durian had a total mass of 7.5 kg and a shape as close to an oval. Durian peels were cut by a thin knife to rectangular pieces with 60 mm width and 60 mm length. After cutting, the flesh was removed. The durian peels were further cut into outer and inner layers as shown in Figure 3b. The durian thorns on the outer layer were dissected into thorn skin and thorn core.

The thorn skin samples had fibers directed along its length, and they were dryer than other structures. The thorn core had similar structure to the thorn skin but exhibited more porosity. All of the fibers in the thorn core align lengthwise from the thorn tip to the base. Samples of the substructures were harvested from these pieces as shown in Figure 5. The arrows in Figure 5 indicate the directions of fibers within the substructures. The cut samples reveal that a thorn is a composite structure reinforced by fibers along its length. The inner layer is characterized by a composite material with long fibers in the transverse direction as shown in Figure 4b. Samples of the inner layer along both longitudinal and transverse directions were prepared to investigate the effects of anisotropy. Figure 5c-5f show the samples of locule and membrane layers along both longitudinal and transverse directions. Due to the uneven nature of thorns and substructures, the samples were cut into rectangular coupons with varying dimensions as listed in Table 1.

![Figure 5. Samples harvested from a durian peel (a) Thorn skin (b) Thorn core (c) Locule layer along longitudinal direction (d) Locule layer along transverse direction (e) Membrane layer along longitudinal direction and (f) Membrane layer along transverse direction](image)

After preparation, the samples were stored in a controlled environment at 70% humidity and 25°C for 24 hours before being tested. Prior to testing a sample was bonded to a pair of wood panels by epoxy resin to increase gripping area and avoid premature failure at the grips. Figure 6 shows representative samples for tensile test.
Table 1. Dimensions of all samples (unit in millimeter)

| Sample          | W  | t  | Lo  | Sample          | W  | t  | Lo  |
|-----------------|----|----|-----|-----------------|----|----|-----|
| Thorn skin      |    |    |     | Thorn core      |    |    |     |
| No.1            | 3  | 1  | 8.5 | No.1            | 1.9| 1.3| 11  |
| No.2            | 2.8| 1.3| 8.5 | No.2            | 1.9| 1.2| 11.2|
| No.3            | 3  | 0.7| 8.5 | No.3            | 1.9| 1.5| 11.3|
| No.4            | 3.1| 1  | 8.5 | No.4            | 2.2| 1.4| 11.3|
| No.5            | 2.6| 0.8| 8.5 | No.5            | 2  | 1.7| 11.3|
| Locule          |    |    |     | Locule          |    |    |     |
| longitudinal    | No.1| 6.6| 1.3| 15 | No.1| 9.9| 1.5| 20 |
| No.2            | 6.3| 1.5| 14.7| No.2| 9.3| 1.2| 19.8|
| No.3            | 6.7| 1.4| 15 | No.3| 10.3| 1.4| 20 |
| No.4            | 6.7| 1.4| 14.7| No.4| 9.7| 1.8| 20 |
| No.5            | 7.3| 1.5| 14.6| No.5| 10| 1.2| 20 |
| Thin skin       |    |    |     | Thin skin       |    |    |     |
| membrane        | longitudinal| No.1| 7.1| 0.5| 20.5 | No.1| 8.4| 0.6| 20.5 |
| No.2            | 8  | 0.6| 20.5 | No.2| 8.9| 0.5| 19.8|
| No.3            | 8.5| 0.6| 20 | No.3| 9.2| 0.6| 20.5|
| No.4            | 7.6| 0.5| 20.2 | No.4| 10| 0.5| 20 |
| No.5            | 7.9| 0.6| 20.7 | No.5| 9.4| 0.5| 20.5 |

Figure 6. (a) Thorn skin sample (b) Thorn core sample (c) Longitudinal locule layer sample (d) Transverse locule layer sample (e) Longitudinal membrane layer sample and (f) Transverse membrane layer sample

The tensile tests were performed on a standard universal testing machine at a rate of deformation of 1 mm/min. Strain was directly calculated from the crosshead displacement. Tests were conducted until the samples failed.

4. Results and Discussions
Stress-strain plots of thorn skin, thorn core, locule along longitudinal direction, locule along transverse direction, membrane along longitudinal direction and membrane along transverse direction are shown in Figure 7 to 12, respectively. Modulus of elasticity, ultimate tensile strength and elongation at break of each substructure are listed in Table 2. The thorn skins show a linear stress-strain response to failure. In comparison, the thorn cores exhibit an initially linear followed by a softening response. The thorn cores have lower modulus but higher elongation at break compared to the thorn skin. This is because the thorn cores have a porous structure whereas the thorn skins are homogeneous.
The stress-strain response of durian locule along both directions exhibit a linear behavior similar to the thorn skin. Comparisons among the responses of the two directions show that the transverse direction is stiffer than then longitudinal direction because the reinforcing fibers align along the transverse direction. This confirms material anisotropy of the locule.
Figure 9. Stress strain curve of locules along longitudinal direction

Figure 10. Stress strain curve of locules along transverse direction
The responses of durian membranes are also similar to the locules. However, the modulus and tensile strength of the membranes are higher despite being thinner layers than those of the locules. The average ultimate tensile strength of the membrane along the longitudinal direction is lower than that along the transverse direction because the reinforcing fibers in the membrane layers appear to be along the transverse direction as well.
Figure 13. Averaged stress and strain of components of durian peels

Table 2. Mechanical properties of components of durian peels

| Sample            | Modulus (MPa)     | Tensile Strength (MPa) | Maximum elongation (mm/mm) |
|-------------------|-------------------|------------------------|---------------------------|
| Thorn skin        | 307.188±39.5      | 20.070±3.109           | 0.085±0.010               |
| Thorn core        | 216.714±23.611    | 8.527±1.818            | 0.098±0.020               |
| Locule Longitudinal | 58.864±18.693   | 3.610±0.426            | 0.193±0.013               |
| Locule Transverse | 121.521±29.304    | 6.019±1.323            | 0.100±0.030               |
| Membrane Longitudinal | 62.133±17.037 | 4.876±0.534            | 0.232±0.034               |
| Membrane Transverse | 221.908±70.523  | 11.249±1.876           | 0.070±0.011               |

Figure 13 shows the averaged stress-strain relation of all six substructures of a durian peel. Among these components, the thorn has the highest modulus and the locule along longitudinal direction has the lowest because thorn skin is the least porous structure whereas the inner parts of the peels are less dense as shown in Figure 14. Fiber directions also influence the mechanical responses of the locule and the membrane layers. The average modulus of the thin membrane is higher than the locule because the locule layer appears to be less dense than the membrane.
5. Conclusion

In this study, the mechanical properties of components of a durian peel were investigated through tensile tests. The modulus of components of a durian peel ranks, from the highest to the lowest, and from the outer to inner layers. Factors that affect the mechanical properties of durian peel are alignment of underlying fibers and porosity. The locule and the membrane layers exhibit stiffer responses along the transverse direction of durian fruit. The substructure with a higher porosity has less modulus than a denser one.

References

[1] Manshor M R Anuar H Aimi M N N Fitrie M I A Nazri W B W Sapuan S M El-Shekeil Y A and Wahit M U 2014 J. Materials and Design 59 279-286
[2] Ha N S Lu G Shu D W and Yu T X 2020 Journal of the mechanical behavior of biomedical materials 104 103603
[3] Ahmad Z 2009 Impact and energy absorption of empty and foam-filled conical tubes (Queensland University)
[4] Ahmad Z Thambiratnam D P and Tan A C C 2010 International Journal of Impact Engineering 37 475-488
[5] Li Z Chen W and Hao H 2019 International Journal of Impact Engineering 133 103341
[6] Wisutiamonkul A Dwamena C A Allan A C and Ketsa S 2017 Scientia Horticulturae 220 233-242
[7] Zhao X Zhu G Zhou C and Yu Q 2019 Composite Structure 222 110920
[8] Wang B He M Li C Wang L and Meng H 2020 Biosystem