Investigation of Structure and Tensile Properties of Betel Palm Sheath

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Abstract. Betel palm sheath is a kind of natural material which is increasingly used as a raw material for producing food packaging. To form packaging such as food plates, a raw palm sheath is drawn using drawing dies. Then, the excess edge of the drawn part is cut off with trimming dies. Due to the lack of understanding of the palm sheath structure and its mechanical properties, a lot of defective parts still occur during the production. In this work, the authors aim to investigate the internal structure of the palm sheath. The raw palm sheath was sectioned and subjected to a scanning electron microscope (SEM). In addition, the mechanical properties of the palm sheath were examined by the uni-axial tensile test. Based on the experimental results, the internal structure of the palm sheath was clearly revealed. The tensile properties of the palm sheath were highly anisotropic, namely the maximum load resistance and the elongation at break remarkably varied with the loading direction. Moreover, the deformation of the palm sheath appeared to consist of the elastic and the permanent deformation.

1. Introduction
Betel palm shown in Figure 1 is a kind of plants in the Arecaceae family which is widely found in South east Asia such as India, Myanmar, Thailand etc. Parts such as nut, husk and sheath of the betel palm can be used in different proposed. For example, its wet sheath is used as animal feed, while the dry palm sheath can be used as a fuel for cooking and water heating [1-3].

Figure 1. Betel palm.

According to the plastic packaging waste issue, the production of food packaging from natural material is now intensively considered. The betel palm sheath is a kind of natural materials which has
potential to be used for producing the food packaging because it has sheet form, suitable thickness and sufficiently strength. In Thailand, Veerasa company utilises the palm sheath to produce various packaging such as food plate, banana-cake cup, soap box, etc [4]. The production starts from the preparation of raw palm sheath by washing, drying and cutting into designed size. Then, the palm sheath is drawn using stainless steel drawing dies at elevated temperature. After drawing, the edge of the drawn part is trimmed to obtain finishing products. However, a lot of defective parts still occur during the production. This seems to be caused by the lack of understand of the structure and the mechanical properties of the palm sheath.

There are researchers studying mechanical properties of natural materials-based composites. Srinivasan et al., studied the mechanical and thermal properties of banana-flax based natural fibre composite. They applied the hand layup method for preparing the composite laminates. The results showed that the difference lamination strongly affected the ultimate tensile strength, the tensile elongation, the energy absorption and fire resistance of the composite [5]. Fernandes et al., prepared the natural composite structures between the flax fiber, the agglomerated cork and the bio-resin. They found that the composite had higher load resistance when the density of the fiber in the composite increased [6]. In addition, Chethan et al., prepared the betel palm leaf reinforced resin composite and investigated its tensile properties. Their composite consisted of 70% Epoxy resin and 30% short palm sheath fiber (by volume). They revealed that the ultimate tensile strength and the modulus of the composite was 16.15 MPa and 3345.16 MPa, respectively [7].

From the literature survey, the authors found that there are not any study or report explaining the structure and the mechanical properties of the betel palm sheet. To promote the production of the palm sheath packaging from the household level to the industrial scale, the fundamental knowledge concerning the structure and the mechanical properties of the palm sheet is highly required. Therefore, in this study, the betel palm sheath was collected, sectioned and subjected to the SEM in order to investigate the internal structure of the palm sheath. Also, the palm sheath tensile specimens were prepared from different zones and directions in a palm sheath. Through the experimental results, the structure, the tensile properties and the deformation behavior of the palm sheath were discussed and summarized.

2. Material and experimental conditions
Betel palm sheath used in this study was harvested from Buriram prefecture, Thailand. For all of the investigation, only one palm sheath which had the width and the length of 300 and 400 mm was used. The moisture content of the palm sheath was 16.15%. The entire palm sheath was cut off using a keen knife to prepare the SEM and the uni-axial tensile specimens based on ASTM D828-16.

Figure 2. Layout of tensile specimens.
Before testing, the thickness of the cut samples was measured by a micrometre. At the affix leaf zone, the thickness of the palm sheath varied ranging from 1.972 to 2.526 mm (Avg. = 2.354 mm). For the central zone, the thickness was varied from 1.429 to 2.000 mm (Avg. = 1.718 mm), while at the affix node zone, the thickness was varied between 1.318 mm and 2.255 mm (Avg. = 1.818 mm). Based on the variation of the thickness, the tensile testing samples were formed into three groups for those three zones. In each zone, the tensile specimens were prepared in three directions with respect to the surface lines of the palm sheath. The first direction was parallel to the surface line (They were called “0° specimens”). The second and the third directions were diagonal and perpendicular to the surface lines (They were called “45° and 90° specimens, respectively”). Figure 2 shows the layout of the tensile specimens. For the tensile test, the speed of the moving cross head was fixed as 2 mm/min. The load cell (Capacity: ± 5 kN) was installed to record the load resistance of the palm sheath. After testing, the fracture edges of the specimens were investigated with the SEM.

Apart from the tensile test mentioned above, additional specimens were prepared for studying the deformation behavior of the palm sheath. For this test, the specimens were cut from the affix node zone, prepared to have the dimension based on the same standard as that used for tensile test. Then, small grids were drawn on the surface of the specimens using a small-head permanent pen. After that the specimens were subjected to the uni-axial tensile load. The displacement of the cross head was varied from 0.2 to 1.6 mm. After testing, the displacement-load resistance curve and the geometry of the grids were examined.

3. Results and discussions

3.1. Structure of betel palm sheath

Figure 3 shows the cross-sectional SEM images of the palm sheath. From this image, six different components of the palm sheath, i.e. spongy mesophyll, phloem, xylem, bundle sheath, upper and lower epidermis were clearly observed. Figure 4 represents the high magnification SEM images at the upper and the lower surface of the palm sheath. These revealed that the upper epidermis was thinner than the lower epidermis. Namely, the upper one had the thickness of about 2.5 µm, while the thickness of the lower one was approximately 20 µm.

![Figure 3. Cross-sectional image of palm sheath.](image)

![Figure 4. High magnification images (a) at upper and (b) at lower surfaces.](image)

3.2. Tensile properties of betel palm sheath

After carrying out the tensile test, the relationship between the load resistance of the palm sheath and the extension was plotted. Figure 5 represents the load resistance curves for all the tensile specimens. The load resistance characteristics were revealed as follows: (i) the highest maximum load resistance ($f_{\text{Max}}$) occurred when loading direction was parallel to the surface line of the palm sheath, 0° direction. Its value was ranging from 309 to 405 N, while the highest $f_{\text{Max}}$ was varied between 62 and 106 for the...
45 and 90° loading directions. (ii) There was a variation of the highest $f_{\text{Max.}}$ when varying the investigation zone of the palm sheath. However, the tendency of this variation could not be observed. (iii) The elongation at break ($\epsilon_{\text{Break}}$) remarkably depended on the loading direction rather than the investigation zone of the betel palm sheath. In the cases of 0 and 90° loading directions, the $\epsilon_{\text{Break}}$ appeared to be low (between 1.0 to 1.9 mm), while the $\epsilon_{\text{Break}}$ was higher in the case of 45° loading direction. From the above tensile testing results, it was revealed that tensile properties of the palm sheath were highly anisotropic.

![Figure 5](image)

**Figure 5.** Relationship between load resistance and extension of palm sheath from tensile test.

### 3.3. Fracture edges of tensile specimens

After tensile testing, the fractured edges of the specimens were investigated with the SEM. Figure 6 shows the SEM images of the fractured edges which were loaded under 0, 45 and 90° at the affix leaf, the central and the affix node zones. This figure revealed that (i) For all zones of the palm sheath, in the case of 0°, the xylem and phloem appeared to be broken. But, they tended to be pulled out from the spongy mesophyll without the breakage in the cases of 45 and 90°. (ii) For all the investigation zones of the palm sheath, there was no crack propagation to the upper surface in the case of 0°, while in the cases of 45 and 90°, the crack propagation was observed. (iv) the fracture of the spongy mesophyll was similar for all specimens. It was indicated that the tensile load response of the spongy mesophyll was similar for all zones of the palm sheath and the loading directions. (v) Applying the tensile load in the 45 and 90°, the fracture of the specimens seemed to be initiated at the surface line. Considering this fracture initiation position and the load resistance curve in Figure 5, the surface line became a
week point for the fracture, especially when the maximum principal tensile stress occurred in 45 and 90° against the surface line. (vi) Seeing the high \( \epsilon_{\text{break}} \) in figure 5(b), although the surface line caused the fracture under the low load resistance, it did not result in the low elongation of the palm sheath.

| Loading direction compared to surface lines of palm sheath |
|----------------------------------------------------------|
| 0 degree | 45 degree | 90 degree |
| Xylem & Phloem | Surface line | Crack propagation |
| Spongy mesophyll | Surface line | Crack propagation |
| Central zone | Surface line | |
| Affix node zone | | |

![Figure 6. Fracture edge of tensile specimens.](image)

3.4. Deformation behavior of betel palm sheath

Apart from the internal structure investigation and the tensile testing, the deformation behavior of the palm sheath was studied. This understanding is crucial, especially for analyzing the deformation of the palm sheath using numerical method such as finite element method (FEM). Typically, when assigning a material model to a simulation software, two types of the deformation modes, i.e. the elastic deformation and the plastic deformation must be assumed, separately [8].

![Figure 7. Relationship between load resistance and extension for extension from 0.2 to 1.6 mm.](image)
Figure 7 shows the load resistance curves after pulling the palm sheath specimens to the specified extension. From this figure, at the small extension, $0 < e < 0.4$, the load resistance tended to be increased without changing the slope of the relationship. When the extension increased, the inflection point of the load resistance ($i_P$) was detected. Here, the $i_P$ occurred at the extension between 0.4 and 0.8 mm. After pulling under the large extension, $e > 0.8$ the slope of the load resistance curve changed, noticeably. This seemed to indicate that the deformation behavior of the palm sheet was changed with increasing the extension.

Figure 8 shows the grids on the palm sheath specimens after pulling. Here, it could be seen that the grids did not deform largely in all extension cases. However, measuring the grid distance ($d_G$) after pulling the samples, the $d_G$ did not change for $0.2 < e \leq 0.4$. But, for $e \geq 0.6$, the $d_G$ tended to be extended, compared to the original $d_G$. This confirmed that, under the tensile loading, the betel palm sheath consisted of the elastic deformation and the permanent deformation.

4. Conclusions
From the experimental investigation of the betel palm sheath, the following conclusions were obtained:
(i) the internal structure of the palm sheath was clearly observed. It consisted of bundle sheath, phloem, xylem, spongy mesophyll, upper and lower epidermis.
(ii) the tensile properties of the palm sheath were highly anisotropic. The highest maximum load resistance occurred when loading direction was perpendicular with the surface line of the palm sheath.
(iii) The fracture initiation seemed to be occurred at the surface line of the palm sheath.
(iv) The load resistance of the palm sheath was very low, when the maximum principal stress occurred in the 45 and 90° against the surface line of the palm sheath.
(v) The palm sheath showed both the elastic deformation and the permanent deformation under the tensile loading.

5. References
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