Effects of Culm Height Levels and Node Presence on Mechanical Properties and Fracture Modes of *Gigantochloa scortechinii* Strips Loaded in Shear Parallel to Grain

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Effect of culm height levels and node presence on mechanical properties and fracture modes of *Gigantochloa scortechinii* strips loaded in shear parallel to grain were investigated at macroscopic and microscopic level. The specimens were taken from bottom, middle and top portions of bamboo culm. In each portion, specimens were taken from internodes and node parts. From the results, there was a significant increment of Maximum Shear Stress \( \tau_{\text{max}} \) value in bottom to top portions. Presence of node greatly reduced the \( \tau_{\text{max}} \) value of bamboo strips. From macroscopic observation, fracture modes of *G. scortechinii* loaded in shear parallel to grain were classified as Even Splitting (Mode I) and Uneven Splitting (Mode II). Mode I occurred in internodes, while Mode II in all parts with nodes. Microscopic observation showed that Mode I exhibited even splitting in parenchyma without any fracture in vascular bundles regions, while Mode II exhibited uneven splitting fracture in both regions. Generally, anatomical behaviour of *G. scortechinii* at different portions and parts of culms influence the different mechanical properties and fracture modes of this bamboo species loaded in shear parallel to grain.

Bamboo is probably the most useful raw material. Its versatility can be developed to overcome the problems of timber shortages and inadequate raw materials. The uses of bamboo are traditionally well established by peoples in the rural areas of many tropical countries. The bamboo used in such traditional ways frequently lack proper production techniques due to a lack of understanding of its characteristics.

Increased knowledge of its characteristics could further develop the uses of bamboo. Understanding of mechanical properties and fracture modes will enable reliable, durable and safe bamboo products especially for structural purposes. Therefore this study was carried out with the following objectives: (1) to determine the effects of culm height levels and node presence on mechanical properties of *G. scortechinii* strips loaded in shear parallel to grain, (2) to determine the effects of culm height levels and node presence on fracture modes of *G. scortechinii* strips loaded in shear parallel to grain at macroscopic level, (3) to determine the effects of culm height levels and node presence on fracture modes of *G. scortechinii* strips loaded in shear parallel to grain at microscopic level.

**MATERIALS AND METHODS**

**Specimen preparation**

Eight (8) culms of *G. scortechinii*, locally known as Semantan bamboo, were harvested from managed clumps in Felda Mempa at Bentong, Pahang. The present study was confined to bamboo culms of three years old since the bamboos were found to be matured at this age (Kassim et al. 1992; Wahab et al. 1997). The bamboo culms were cut at about 30 cm above the ground based on previous study (Kassim 1999; Mohmod & Pham 2001). All culms are almost straight and homogeneous in term of physical appearance. Each culm was cut into three equal portions of 2 m length, representing the bottom, middle and top portions. The culms were then soaked in 4% aqueous emulsion of boron for 24 hours for protection against borers and fungi. These culms were then air-dried for several weeks and moisture content MC was monitored until equilibrium. After the completion of the drying process, each portion was split into eight pieces by using a
splitting machine. Each piece is approximately 20 mm in width. The split bamboos were planed by using a planer machine to remove the skin and to produce the rectangular shape of bamboo strips for each portion with approximately 5 mm in thickness. Specimens were taken from internodes and node parts at the middle section of bamboo strips for each portion. Specimens were also taken adjacent to each other to avoid bias. The specimens with presence of node were cut in such a way that the node was located in the middle section of the specimens. Figure 1 illustrates the experimental design for this study. It indicates the different portions, parts and tests carried out in the research.

Classification and analysis of fracture modes at macroscopic level

Fracture modes at macroscopic level of Semantan bamboo strips loaded in shear were investigated by observing the pattern of failure by naked eyes and low magnification microscope for each specimen tested. Failure modes were classified according to the appearance of fractured surface and manner in which the failure develops (Anonymous 2003). Actual views of each classified failure mode were captured at radial and tangential surface by using ordinary digital camera. A schematic model for each classified failure mode was sketched. Distribution of classified failure modes at different portions and parts was recorded. The discussions were based on the behaviour of the grains and cells structures in the different failure modes for each portion and part of Semantan bamboo culm.

Observation of fracture modes at microscopic level

Fracture modes at microscopic level of Semantan bamboo strips loaded in shear were further observed at cross section view in the extension of fracture modes at macroscopic level. The methods described by Ahmad (2000) and Hoadley (1990) were used as general guide in microscopic slide preparation. Specimens were cut into smaller pieces at middle section with failure zone left intact. Failure zones were submersed in water and placed under vacuum for 60 minutes. Water-saturated failure zones were sliced at cross section, radial and tangential view on microtome to produce sections with thickness of 60 μm. Each section was rinsed in distilled water, mounted on glass slide and covered with glass slip with a drop of glycerine. Slides were observed on light microscope for microscopic failures observation using Leica DMLS microscope and 4x objective lens. Images were captured using Leica DC300 digital camera and processed using Video Test Master Morphology software. The difference of microscopic failures behaviour between classified failure modes in Semantan bamboo was discussed. Special attention was given for failure behaviour in parenchyma and vascular bundles regions of Semantan bamboo strips loaded in shear parallel to grain.
RESULTS AND DISCUSSION

**Determination of mechanical properties**

Figure 2 shows the mean Maximum Shear Stress $\tau_{\text{max}}$ values of Semantan bamboo strips in bottom to top portions for specimens with absence of node. The $\tau_{\text{max}}$ value in bottom portion was 4.49 N/mm$^2$, middle was 6.52 N/mm$^2$ and top was 6.80 N/mm$^2$ and these values were significantly different from each other.

Figure 3 shows the mean $\tau_{\text{max}}$ values of Semantan bamboo strips in bottom to top portions for specimens with presence of node. $\tau_{\text{max}}$ value in bottom portion was 4.07 N/mm$^2$, middle was 4.08 N/mm$^2$ and top was 6.74 N/mm$^2$. $\tau_{\text{max}}$ values for specimens with presence of node in bottom and middle portions were not significantly different. However, $\tau_{\text{max}}$ values for internodes in top and other portions were significantly different.

The result was similar to Bahari et al. (2006), Lee et al. (1994) and Mohmod & Pham (2001). There was an increment of $\tau_{\text{max}}$ value for bamboo strips from lower to higher portions of bamboo culm due to the increasing amount of fibro-vascular bundles in the respective portions (Mohmod & Pham 2001). Fibres are important for the determination of strength behaviour (Espiloy 1985; Ho 1993; Liese 1998).

Figure 4 shows the comparison of mean $\tau_{\text{max}}$ values of Semantan bamboo strips with absence and presence of node. $\tau_{\text{max}}$ value for strips with absence of node was 5.94 N/mm$^2$ while $\tau_{\text{max}}$ value for strips with presence of node was 4.96 N/mm$^2$.

**Classification and analysis of fracture modes at macroscopic level**

Failure modes of Semantan bamboo loaded in shear were classified as Even Splitting (Mode I) and Uneven Splitting (Mode II). The modes were similar to failure modes of Betong bamboo strips documented by Bahari et al. (2006). Generally, the failure was generated at radial surface from upper to lower side of specimen caused by loading direction at notched section. Figure 5 shows the Mode I and II shear failure at front view:

![Mode I and II shear failure at front view](image_url)
failure. Mode I occurred in internodes of all portions. The “even splitting” behaviour of Mode I was due to the even grain direction at internodes. Mode II occurred in nodes of all portions. “Uneven splitting” behaviour of Mode II was caused by uneven grain directions in node.

Table 1 presents the distribution of shear failure modes at different portions and parts of Semantan bamboo. Mode I shear failure occurred in internodes of all portions, while Mode II in nodes of all portions.

Table 1. Distribution of Shear Failure Modes at Different Portions and Parts of Semantan Bamboo

<table>
<thead>
<tr>
<th>Portions</th>
<th>Bottom</th>
<th>Middle</th>
<th>Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts</td>
<td>IN</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Shear Failure Modes</td>
<td>MI</td>
<td>MII</td>
<td>MI</td>
</tr>
</tbody>
</table>

Note: IN = Internodes, N = Node, MI = Mode I, MII = Mode II

Analysis of $\tau_{\text{max}}$ value for Semantan bamboo strips in Figure 4 can be used in analyzing the fracture modes at macroscopic level. Since Mode I and II were collected from internodes and node parts in bottom to top portions, the similar discussion can be made for both modes based on this result. The orientation of cells and the properties of fibro vascular bundles play an important role for the strength behaviour of bamboo strips. Internodal parts show axial orientation of cells and greatest fibre length compared to nodes (Liese 1998; Sulthoni 1989). Fibres in internodes are oriented uniformly and parallel to each other (Liese 1998; Sulthoni 1989), which provided better resistance to bending load at internodes. Vascular bundles in nodal regions are oriented randomly and fibres in nodes are short, forked and crossed (Liese 1998; Sulthoni 1989) which does not contribute to strength. This is probably the reason for differences of failure behaviour and significant different of $\tau_{\text{max}}$ values between Mode I (occurred in internodes of all portions) and Mode II (occurred in node of all portions).

**Observation of fracture modes at microscopic level**

Figure 6 illustrates the microscopic views of Mode I and II in Semantan bamboo. Mode I shear failure (occurred in internodes of all portions) exhibited even splitting within the parenchyma without any failure in vascular bundles region. This result could be related to the statements of Liese (1998) and Sulthoni (1989). The orientation of cells and the properties of fibro vascular bundles influenced the microscopic failure behaviour as well as load resistance. Internodes contain axial orientation of cells and greatest fibre length compared to node, and fibres in internodes are oriented uniformly and parallel to each other (Liese 1998; Sulthoni 1989).

Liese (1998) stated that the anatomical structure of most fibres is characterized by thick lamellate secondary walls. This influences the strength properties and provides protection of vascular bundles compared to parenchyma where failure initiated. According to Ho (1993), fibres reacted as mechanical support rather than parenchyma that reacted as food and water storage. The culm tissue comprises about 50% parenchyma which induces initial failure in the parenchyma region (Liese 1998). This reason had influenced the behaviour of “even splitting” failure and significantly higher $\tau_{\text{max}}$ value for Mode I shear failure compared to Mode II in Semantan bamboo.

Mode II shear failure (occurred in nodes of all portions) exhibited uneven splitting failure in both parenchyma and vascular bundles region. This result could be related to the statement by Liese (1998) and Sulthoni (1989). According to Liese (1998), the main vascular bundles in nodes are swollen, and branching vascular anastomoses develop intensively. Many small vascular bundles turn horizontally and twist repeatedly, as illustrated by Liese (1998). Aside from vascular bundles and fibres
behaviour, Sulthoni (1989) stated that many vessels crossed the fibres to reach the diaphragm in nodes. These reasons are believed to influence the behaviour of “uneven splitting” failure and significantly lower $\tau_{\text{max}}$ value of Mode II shear failure compared to Mode I in Semantan bamboo.

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