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# Tensile Properties of Untreated *Bambusa Vulgaris, Gigantochloa Levis Gigantochloa Scortechinii, Gigantochloa Wrayi*, and *Schizostachyum Zollingeri* Bamboo Fibers

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## ABSTRACT

In the last couple decades, bamboo is getting interest due to the usefulness in textile application beside the most sustainable plant in earth. Textile fiber requires physically long, featherweight, and fine in diameter. Bamboo fibers impose high cellulose and lignin content. In a single fiber form, bamboo has very short physical length which lesser than 4 mm. This natural characteristic could affect the mechanical properties in fiber bundle or long fiber formation for textile processing. Besides, the extraction of long and fine bamboo fibers is significantly challenging over different species of them. Therefore, the tensile behavior of the untreated bamboo fibers over variety species shall be understanding in-depth. This study is about identifying tensile properties of bamboo fiber bundle of five commercialized bamboo species in Malaysia. Three regions of fiber bundles locations were extracted mechanically and tested. The long bamboo fiber tenacity and fineness were examined besides tensile strength and strain to failure value. Among those species, *G. levis* species demonstrated the highest tensile strength around 98MPa with strain to failure at 4.51%. *G. wrayi* (BT) recorded the coarsest fiber at 231 tex while the highest tenacity was obtained by *B. vulgaris* (MYK) at 10.88 cN/tex.

**Key words**: Bamboo fiber, fiber bundle, strain to failure, tensile strength.

## 1. INTRODUCTION

Natural plant fibers are classified based on their origins such as bamboo, jute, flax, kenaf, coir, etc [1]. Bamboo is an abundant biomass and is available in many countries. Worldwide, bamboo forest area totals 22 million hectares generating over 30 million tons of bamboo fiber per year [2]. Bamboo grows faster unlike normal timber that usually having issues in maintaining their annual crop yield due to longer harvest duration between six to eight months after maturity [3], [4]. Besides, normal timber normally relied on agricultural technologies to reach their sustainable growth [5]. In Malaysia, at least 25 species of bamboo are native to this tropical country and only 13 species are commercially known including *Gigantochloa scortechinii* (buluh semantan), *Gigantochloa wrayi* (buluh beti), *Gigantochloa levis* (buluh beting), *Bambusa vulgaris* (buluh minyak) and *Schizostachyum zollingeri* (buluh kasap) [6].

Bamboo fiber is one of the important lignocellulosic fibers possessing low-density compared to glass and steel fibers, high tensile modulus, and low elongation at break [7]. The chemical contents of the bamboo cell walls consisting of cellulose, hemicelluloses and lignin [6], [8]. Due to the extractive contents that bind fibers, thus it is technically challenging to extract long fiber bundle of bamboo. Often, chemical treatments are adopted on the extraction process to dissolve these binders' content. The removal of the bonding constituents such as hemicelluloses induces a less dense and less rigid interfibrillar region, allowing the fibrils to rearrange along the fiber major axis during tensile deformation and hence improving some properties of the fiber bundles, which in turn influence the properties [9].

Bamboo fiber bundles are distributed densely in the outer region of the culm wall and sparsely in the inner region, and also concentrated in the upper part of the culm compared with the base [9]. A paper in [8] compared four types of *Gigantochloa* species of bamboos has found that *G. levis* has the highest holocellulose content around outer region of culm, while *G. scortechinii* exhibited the highest lignin content at middle position region of internode bamboo culm. This study also found lignin and holocellulose contents significantly affected by the species and position region of bamboo culm. Holocellulose content was found increase toward the outer region while lignin content shows decrease from outer to middle region and increases from middle to inner region.

Previous studies presented chemical compositions of several Malaysian bamboo species [2], [6], [8], [10]–[12]. The extraction of fiber bamboo often implemented chemical extraction that could tempered the tensile properties originally. Specifically, single fiber of bamboo has short physical length, high cellulose and lignin content. Therefore, this study was focused on the untreated extraction of five (5) species of bamboo called *G. scortechinii, G. wrayi, G. levis, B. vulgaris*, and *S. zollingeri* via mechanical extraction. Three (3) regions over bamboo culm thickness were compared among species. Tensile response was experimentally done in order to analyze the mechanical performance among these species and culm thickness region locations.

## 2. MATERIALS AND METHODS

Natural plant fibers are classified based on their origins such as bamboo, jute, flax, kenaf, coir, etc [1]. Bamboo is an abundant biomass.

### 2.1 Materials

In this study, raw bamboos were supplied from Malaysian Timber Industry Berhad. Four years and elder ages of bamboo were chosen from commercial species of Malaysia bamboo named *G. scortechinii* (buluh semantan), *G. wrayi* (buluh beti), *G. levis* (buluh beting), *B. vulgaris* (buluh minyak) and *S. zollingeri* (buluh kasap).

### 2.2 Methods

Fiber bundle samples were prepared by each of bamboo species were cut into strips with dimension of 100 mm (length), and 25 mm (width). The bamboo strips/culms were divided into three (3) regions of thickness named inner, middle, and outer as illustrated in Figure 1. The fiber bundle was extracted by steaming the bamboo strips in the steamer machine at 100°C in more than six (6) hours until the sample softened before the strips were crushed mechanically. The extracted fiber bundle was screening by optical microscope before the selection of sample been made according to 0.5 mm size of the diameter.

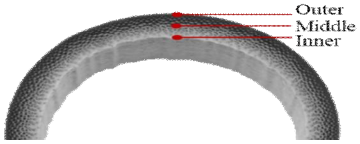

**Figure 1:** Fiber bundle region's location; outer, middle, and inner

Tensile experiment was conducted according to standard D3822 (2001) [13]. As suggested in the standard, a special method was adopted by gluing the fiber in a piece of paper card frame as illustrated in Figure 2.

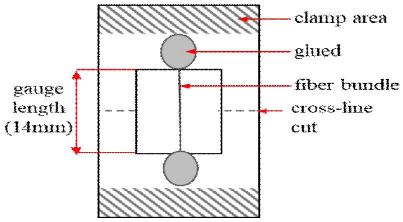

**Figure 2:** Schematic illustration of paper frame for a single-fiber tensile test

The circular cut determines the gauge length of 14 mm. To control condition of sample, the untreated fibers were left at least 48 hours in room ambient before tensile test being conducted. Moisture contents were recorded before the tensile test was performed on a tensile testing machine developed by Lloyd Instruments Ltd. In this experiment, the crosshead speed was set at 1 mm/min and a 500-N load-cell was used. The paper frame is clamped in the machine before pre-tension was applied for straightening the paper frame. Subsequently, the frame paper was cut to leave the fiber hang on it.

Fiber breaking behavior was determined through a stress-strain curve behavior. Maximum stress, $\sigma_{max}$ was obtained from the maximum load, $F_{max}$ value over cross a sectional area, A of bamboo fiber as shown in equation (1). While, strain, $\varepsilon$ was calculated using equation (2) where initial length, lo attained from gauge length and displacement length, ld obtained from the machine extensometer. Bamboo fibers were set to the length of 3.5 cm and was divided with their mass values to identify tex values for each 5 bamboo species as per standard method JUS F.S2.212 (1963)[14] specified in equation (3). Tenacity refers to force requires to break the fiber associated to the fibers' linear density [15] whereby force required to break the fiber, cN was divided by the tex value as shown in equation (4). Fineness, tex value was obtained by weighting over length of fiber using precision digital balance.

$$\sigma_{max} = \frac{F_{max}}{A} \tag{1}$$

$$\varepsilon = \frac{l_d}{l_o} \times 100 \tag{2}$$

$$tex = \frac{mass}{length} \tag{3}$$

$$tenacity = \frac{cN}{tex} \tag{4}$$

## 3. RESULTS AND DISCUSSION

Table 1 presents overall physical and tensile performance of *G. wrayi* (BT), *G. levis* (BTG), *S. zollingeri* (KSP), *B. vulgaris* (MYK), and *G. scortechinii* (SMT) species with three (3) regions each of the extracted fiber bundle. In this study, the moisture contents were recorded ranging between 8 to 13% under room ambient condition.

Overall results showing no signifcant trend over different region of fiber on each tested species. These results could be contributed by many factors such as chemical composition, single fiber formation and distribution. Previous findings reported that lignin acts as cement in a fibrous material while holocellulose are the reinforced of the fibrous structure [8]. Thus, these contents could affect tensile properties of bamboo fiber bundle. As reported in [8], chemical composition showed different trend over culm thickness region (inner, middle, outer) of each species. Most of species have higher holocellulose and lignin content at outer region, yet few of them exhibited at middle region.

Other factors that could affected the tensile performance is single fiber physical properties and formation within fiber bundle. Interfacial bonding between single fibers could also affected on hemicellulose and lignin content. Different species have different physical fiber dimension over longitudinal location ranging from 2 to 4 mm [6]. Larger physical dimension of single fiber could affect fiber bundle fineness (tex). Moreover, this study was performed with similar size of fiber bundle during sample collection. Thus, the higher fineness could have lower single fiber physical dimension and distribution over thickness region of each bamboo culm species. The larger tex value revealed on BTG (O) about 249 tex, while the fineness fiber bundle which have the lowest tex value depicted on MYK (M) and KSP (I) around 106 tex and 109 tex respectively.

**Table 1:** Mechanical performance of fiber bundle bamboos for different species and regions

| Designation | Species | Region | Max stress (MPa) | Strain to failure (%) | Tex (g/1000m) | Tenacity (cN/tex) |
|---|---|---|---|---|---|---|
| BT (I) | Wrayi | Inner | 76.68 | 4.19 | 261.78 | 5.75 |
| BT (M) | Wrayi | Middle | 58.01 | 3.04 | 205.93 | 5.53 |
| BT (O) | Wrayi | Outer | 76.50 | 4.01 | 228.18 | 6.58 |
| BTG (I) | Levis | Inner | 98.37 | 5.33 | 177.86 | 10.86 |
| BTG (M) | Levis | Middle | 65.50 | 4.18 | 211.26 | 6.09 |
| BTG (O) | Levis | Outer | 78.94 | 4.02 | 248.98 | 6.23 |
| KSP (I) | Zollingeri | Inner | 59.45 | 3.23 | 109.52 | 10.66 |
| KSP (M) | Zollingeri | Middle | 70.53 | 5.78 | 127.41 | 10.87 |
| KSP (O) | Zollingeri | Outer | 50.92 | 2.59 | 142.86 | 7.00 |
| MYK (I) | Vulgaris | Inner | 70.05 | 4.99 | 114.29 | 12.03 |
| MYK (M) | Vulgaris | Middle | 67.18 | 3.49 | 106.49 | 12.39 |
| MYK (O) | Vulgaris | Outer | 74.72 | 4.71 | 178.57 | 8.22 |
| SMT (I) | Scortechinii | Inner | 47.53 | 3.05 | 224.39 | 4.16 |
| SMT (M) | Scortechinii | Middle | 67.24 | 5.52 | 232.51 | 5.68 |
| SMT (O) | Scortechinii | Outer | 68.74 | 3.29 | 209.96 | 6.43 |

Tenacity is a specific tensile performance values showing strength of fiber over specific fineness. The lower tex value and higher breaking load could have higher tenacity value. The higher tenacity could have better strength of fiber for textile processing. Similar as other results, tenacity values have showed no significant trend on fibers inter-region of bamboo culm. To ease of analysis, average values of each response were calculated to compare among bamboo species. Figure 3 to Figure 6 shows the average values of maximum stress, tex, tenacity and strain to failure over bamboo species.

Figure 3 demonstrate comparison of maximum stress over different species of bamboo. The highest maximum stress depicted on BTG around 82MPa while MYK has obtained the lowest about 61MPa.

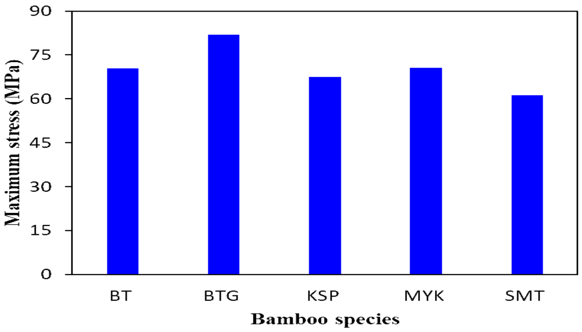

**Figure 3:** Maximum tensile stress of different bamboo species and location

As reported in [8], the lignin content of *G. scortechinii*, *G. wrayi*, and *G. levis* were 32%, 30%, and 26% respectively. The report also presented holocellulose content were recorded as *G. levis* (85%), *G. wrayi* (84%), and *G. scortechinii* (74%). These results could be implied with the present study whereby the highest tensile stress was exhibited on *G. levis* (BTG) species. A report in [16] suggested that bamboo from species *G. levis* and *G. scortechinii* showed low lignin reactivity due to peculiarities in their chemical structures thus, correlated with paper in [8] that shows high lignin content for both species.

Figure 4 shows the average tex values of each specimen. Even though the fibers were chosen with similar fineness (physical dimension), however tex values were revealed differently on different species.

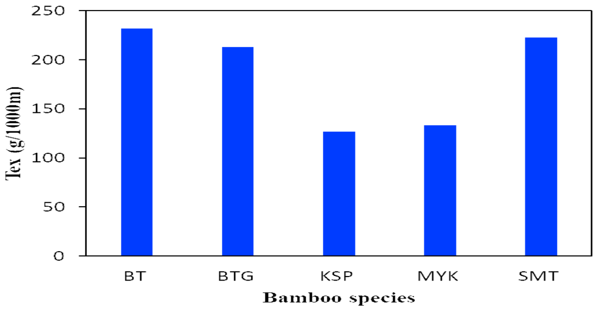

**Figure 4:** Average tex values for different bamboo species

Bamboo species *G. wrayi* (BT) exhibited highest value of 231 tex while the *S. zollingeri* (KSP) was the lowest at 126 tex value. This indicated that *G. wrayi* (BT) is coarser than *S. zollingeri* (KSP) by physical means as tex value correlated to the fineness of fiber and the higher tex value, the courser the fibers [17]. The fineness of bamboo fibers increased from species *G. scortechinii* (SMT), *G. levis* (BTG) and *B. vulgaris* (MYK). The presence of single fibers plays an important role in determining the fiber finenes of same bamboo species set at the same physical dimension of fiber bundle. This is because different amount of singular fibers within a strand of fiber bundle could contribute in different mass values resulting in varrying tex values.

The method of mechanical extracted implied from this study could be improved by using a combing machine as discussed in [18]. The machine produced finer bamboo fiber at 18 tex assisted with alkaline treatment compared with 32 tex for the untreated process. Compared to this study, the aid of combing machine can significantly improve the fineness of bamboo fiber to be produced in order to qualify the fibers to be processed in the next textile processing. Similarly, a paper in [19] produced natural bamboo fiber with fineness at ranges between 13.41 tex to 38.93 tex and suggested combination bamboo manufacturing methods with further carding and combing process could improve the spinnability of natural bamboo fiber for the next yarn production. The average tenacity of five different bamboo species were compared in Figure 5.

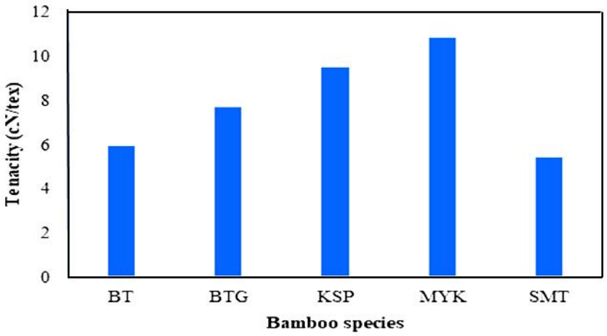

**Figure 5:** Average tenacity values for different bamboo species

Bamboo species *B. vulgaris* (MYK) was revealed to have the highest tenacity value at 10.88 cN/tex, followed by *S. zollingeri* (KSP), *G. levis* (BTG), *G. wrayi* (BT) and *G. scortechinii* (SMT) having the lowest tenacity value at 5.42 cN/tex. Strength property of bamboo fiber is closely related to its non-cellulose matters such as pectin and hemicellulose [20]. Low tenacity bamboo fiber indicates high lignin content resulting in low degree of polymerization (DP) of cellulose macromolecule [21]. Thus, as referred to Figure 5, it can be predicted that lignin content in bamboo fiber bundle species *B. vulgaris* (MYK) has lowest lignin content while *G. scortechinii* (SMT) has highest lignin content. Lignin content can relatively affect the fiber fineness as shown in figure 4 whereby high lignin content predicted for *G. scortechinii* (SMT) showing high tex value indicating coarse fiber fineness of the species [21].

A paper in [22] had chemically modified the bamboo from genus *Phyllostachys pubescens*, obtained the tenacity value of 0.241 cN/tex for the treated bamboo. Consequently, tempted on the biological modification of bamboo fiber in [23] using 0.6% pectin lyase, 1.2% cellulase, 0.3% xylanase, and 1.2% laccase revealed to have tenacity value of 0.262 cN/tex. Comparatively, tenacity value in this study are higher than those paper with its lowest value at 5.42 cN/tex for *G. scortechinii* (SMT). It could reflect with this study was not using chemical extraction and thus, could maintain the natural tenacity of fibers.

Strain to failure is the amount of length the fiber needs to elongate before it breaks. Figure 6 shows strain to failure values for all tested bamboo species. *G. levis* (BTG) has the highest strain to failure value at 4.51%, closely followed by *B. vulgaris*, MYK (4.40%); *G. scortechinii*, SMT (3.95%); *S. zollingeri*, KSP (3.87%), and *G. wrayi*, BT (3.75%).

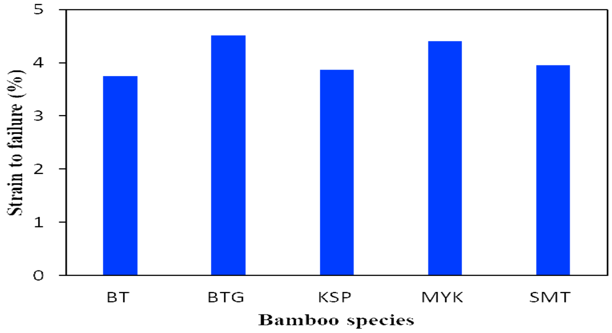

**Figure 6:** Strain to failure for different bamboo species

Higher strain to failure percentage means the fiber is capable to resist changes in fiber structure and eliminates crack formation [24]. Thus, 4.51% *G. levis* (BTG) is better than 3.75% *G. wrayi* (BT) in term of fiber elongation before failure. A paper in [25] studied the physical and mechanical properties of natural fibers identified that bamboo fiber has 4.11% strain to failure. Bamboo fiber manufactured from steam explosion process were identified to have strain to failure at a range between 2.2 to 3.0% [26]. This made the strain to failure of bamboo fiber in this study to be quite superior than those papers.

A paper in [27] has identified that bamboo fiber have different strain to failure percentage depending on their manufacturing process in which untreated, alkaline and steam explosion methods having respective 9.8%, 2.82%, and 2.51% strain to failure. According to paper in [9], untreated bamboo fiber proposed 1.3% strain to failure while alkali treatment (3% NaOH) increased the value into 1.4%. This suggested that untreated bamboo fiber itself is adequate for its interfacial strength as there is not much difference between untreated and treated bamboo fibers proposed in the paper.

## 4. CONCLUSION

Tensile experiment on five (5) commercialize species of Malaysian bamboo *G. wrayi* (BT), *G. levis* (BTG), *S. zollingeri* (KSP), *B. vulgaris* (MYK), and *G. scortechinii* (SMT) successfully conducted in this study. Overall results show no significant trends over different bamboo culm thickness region. The trend mainly could contribute by chemical composition and single fiber formation and distribution within fiber bundle.

Overall tensile strength performance for all tested species were ranging from 48MPa to 98MPa. The highest average tensile strength of fiber bundle was obtained from *G. levis* (BTG) species about 82MPa followed by *G. wrayi* (BT), and *B. vulgaris* (MYK) around 71MPa. While, the highest tex value was gained from *G. wrayi* (BT) at 231 tex followed by *G. scortechinii* (SMT), *G. levis* (BTG), *B. vulgaris* (MYK) and *S. zollingeri* (KSP) as the lowest tex value at 126 tex. The highest tenacity was obtained by *B. vulgaris* (MYK) at 10.88 cN/tex followed by *S. zollingeri* (KSP), *G. levis* (BTG), *G. wrayi* (BT), and *G. scortechinii* (SMT) having the lowest tenacity value at 5.42 cN/tex. The highest strain to failure was by *G. levis* (BTG) at 4.51%, closely followed by *B. vulgaris* (MYK) (4.40%); *G. scortechinii*, (SMT) (3.95%); *S. zollingeri* (KSP) (3.87%) and *G. wrayi* (BT) (3.75%).

Fiber fineness, length and tenacity are important aspects in determining the spinnability of textile material. As for natural fibers, fineness property validify if the fibers can be proceeded to the next textile processing complying with length and tenacity value. This paper suggested the mechanical properties of custom-stripped untreated bamboo fibers with controlled samples' dimensions has adequate interfacial strength but requires more improvement for the next textile processing.

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