PHYSICAL AND MECHANICAL PROPERTIES OF *GIGANTOCHLOA SCORTECHINII* BAMBOO SPLITS AND STRIPS

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ANWAR, U. M. K., ZAIDON, A., HAMDAN, H. & MOHD TAMIZI, M. 2005. Physical and mechanical properties of *Gigantochloa scortechinii* bamboo splits and strips. The results of the physical studies of 4-year-old bamboo splits and strips indicated that within the culm wall, the moisture content decreased from the interior outwards while its relative density increased. Vertically, the moisture content decreased with height while the relative density increased. Bamboo strips shrank more in both radial and tangential directions compared with splits and outer splits. The mean value of the modulus of rupture (MOR) for the bamboo strips (179.6 Nmm^{-2}) showed no significant difference with splits (periphery positioned upward, 158.3 Nmm^{-2}) but a significant difference was observed when compared with the periphery positioned downwards (134.2 Nmm^{-2}). The average value of the compression parallel to grain for splits (85.1 Nmm^{-2}) was higher than that for strips (73 Nmm^{-2}) but was not statistically significantly different ($p < 0.05$).

Key words: Physical and mechanical properties – *Gigantochloa scortechinii* – splits –strips

ANWAR, U. M. K., ZAIDON, A., HAMDAN, H. & MOHD TAMIZI, M. 2005. Ciri-ciri fizikal dan mekanikal untuk belahan dan jalur *Gigantochloa scortechinii*. Ciri-ciri fizikal dan mekanikal belahan dan jalur buluh *Gigantochloa scortechinii* berumur empat tahun dinilai. Keputusan kajian fizikal belahan dan jalur menunjukkan bahawa kandungan lembapan menurun daripada dalam ke bahagian luar dinding buluh manakala ketumpatannya bertambah. Kandungan lembapan menurun dengan ketinggian buluh tetapi ketumpatan relatifnya meningkat. Belahan buluh mengecut lebih pada bahagian radial dan tangen berbanding jalur. Modulus kepecahan bagi jalur buluh (179.6 Nmm^{-2}) tidak menunjukkan perbezaan bererti berbanding belahan apabila kulit diletakkan menghala ke atas (158.3 Nmm^{-2}) tetapi wujud perbezaan apabila dibandingkan dengan belahan (kulit menghala ke bawah, 134.2 Nmm^{-2}). Nilai tekanan mengikut ira bagi belahan ialah 85.1 Nmm^{-2} manakala nilai untuk jalur ialah 73 Nmm^{-2}. Perbezaannya tidak bererti.

Introduction

With the new interest in bamboo for structural applications, the mechanical and physical data for bamboo have to be generated. Generally, the strength of bamboo increases with loss in moisture, which has a similar effect on timber. According to Tamolang *et al.* (1980) the moisture content of bamboo culms varies with height, with the basal portion containing 50% or more moisture than the upper portion. Density is influenced by the anatomical structure of the bamboo (Sharma & Mehra 1970, Abd. Latif *et al.* 1989). Abd. Latif and Wan Tarmeze (1990) reported that the basal portion has the lowest density and highest moisture content when compared with the middle and the upper portions.

Abang Abdullah (1983) stated that compressive, tensile and bending strengths of bamboo are equivalent to those of wood or steel but shear is weak. The low shear property is disadvantageous for structural use, particularly in bending and joints, due to loss of cohesion between bundles in which shear plays an important role. Janssen (1981) found that the compressive stress increases with decrease in moisture content. Sekhar *et al.* (1962) observed that there is a good correlation between maximum crushing strength and relative density of *Bambusa nutans;* the relationship is similarly observed in wood. As such comparing the physical and mechanical properties of strips (without periphery) and splits (with periphery intact) is important if the material is to be used for structural application.

This study focuses on the evaluation of the physical and mechanical properties of 4-year-old culms of *Gigantochloa scortechinii.* The evaluated physical properties were based on the transverse and vertical variations of moisture content and specific gravity from green culms as well as on the dimensional shrinkage of bamboo splits and strips. The mechanical properties evaluated were modulus of elasticity (MOE), modulus of rupture (MOR), and compression parallel to the grain for the bamboo splits and strips.

Materials and methods

Preparation of materials

Six culms of 4-year-old *G. scortechinii,* collected from the Forest Research Institute Malaysia (FRIM), Kepong, Selangor, were cut at about 150 mm above the ground level. Portions cut up to 4 m from the basal portion were used for the evaluation of physical and mechanical properties. The culms were manually split longitudinally. The samples derived from adjacent sides were subsequently labelled as splits, strips and outer splits (Figure 1).

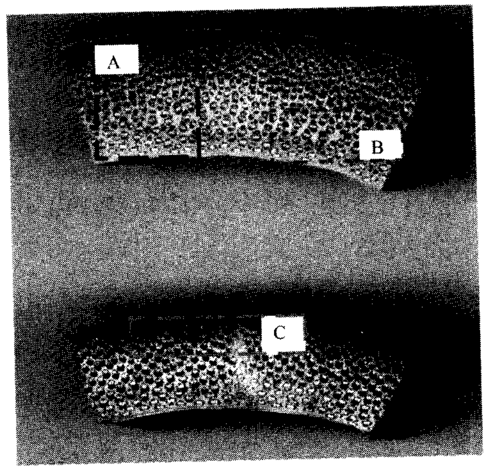

Figure 1 Distribution of vascular bundles structure of 4-year-old culms of *Gigantochloa scortechinii*
A = split
B = strip
C = outer split

Bamboo split refers to the wall thickness as a function of its radial section while strip has both its periphery and inner skin removed. Outer split has its inner skin effectively removed into a 5 mm by about 20 mm rectangular component. For determination of physical properties, samples were tested in green condition. However, the samples for mechanical properties were first air dried under shade and subsequently conditioned in a room at 20 ± 3 °C and 65% relative humidity (EMC 12%) until they reached the desired moisture content.

Determination of physical and mechanical properties

For the determination of moisture content (MC) and relative density, samples were taken from internodes 4 and 7 of the basal portion whilst samples for the dimensional shrinkage study were obtained from internode 5. However, for the determination of MC and density along the culm of each internode height, samples were taken from internodes 3 to 20. The procedures used for the determination of these properties were conducted in accordance with the Indian Standard of Testing Round Bamboo IS 6874 (Anonymous 1973, Sulthoni 1989).

For mechanical properties, the samples were derived from internodes 8 to 12, prepared and tested in accordance with the procedure described by Gnanaharan *et al.* (1994) and Anonymous (1976) in IS 8242:76.

Statistical analysis

The statistical analysis was carried out using the statistical analysis software (SAS). One-way analysis of variance (ANOVA) was employed to analyse the difference in physical properties of bamboo strip, split and outer split. Regression analysis was performed to determine the relationship between MC, density and the culm wall thickness. Regression equations were also developed to predict the MC and density through the culm wall thickness. The strength properties were adjusted for MC and density at the time of test. The analysis of covariance (ANCOVA) was used to detect the differences in mechanical properties among the bamboo specimens (Nash 1972).

Results and discussion

Physical properties

The analysis of variance for the physical properties of splits and strips from the 4-year-old culms of *G. scortechinii* is presented in Table 1. The variability of physical properties was significant within the culm walls. The highest moisture content (MC) from green samples was 141.5% for strips followed by splits (133.4%) and outer splits (84.7%). The MC was found to be higher than in other bamboos studied by other workers (see Table 2). This can be attributed to the time of felling of the bamboo in this study in October which was a rainy season. This is expected as moisture content variation within a culm can be attributed to its age, season of felling and species (Liese 1980).

Liese (1985) also reported that the MC within the culm wall was higher in the middle than in the outer part of *Dendrocalamus strictus*. The variation of MC within the culm wall is very much attributed to the distribution of vascular bundles. In the peripheral zone the vascular bundles are much more compactly distributed than in the inner zone (Figure 1). In the inner zone, most of the cells are parenchyma. The higher content of parenchyma cells in the inner zone increases the water holding capacity of the bamboo (Liese & Grover 1961).

The trend of variation in moisture content (in green condition) along the culms of *G. scortechinii* is shown in Figure 2. The results show that the moisture content

Table 1 Physical properties of 4-year-old culms of *Gigantochloa scortechinii* (green condition)

Specimen	Initial MC (%)	Relative density	Shrinkage from green to oven dry (%)		
			Radial	Tangential	Longitudinal
Strip	141.5[a]	0.55[a]	23.73[b]	19.82[b]	0.21[a]
	(28.6)	(0.01)	(11.9)	(19.82)	(0.3)
Split	133.4[a]	0.51[a]	20.85[a]	12.4[a]	0.45[a]
	(33.6)	(0.05)	(6.55)	(3.88)	(0.51)
Outer split	84.7[b]	0.80[b]	17.59[a]	14.43[a]	0.23[a]
	(17.9)	(0.07)	(5.47)	(2.85)	(0.14)

Values in parentheses are standard deviations.
Means with the same letter are not significantly different ($p < 0.05$).
Number of specimens =117.

Table 2 Moisture content and relative density of some bamboo species (in green condition)

Species	Moisture content (%)	Relative density
*Bambusa arundinacea**	65.1	0.58
*B. nutans**	88.3	0.60
*B. polymorpha**	95.1	0.62
*B. tulda**	73.6	0.66
B. vulgaris var. *striata***	93.4	0.51

Sources: * Sanyal *et al.* (1988)
** Abd.Latif *et al.* (1990)
Specimens were tested in split form.

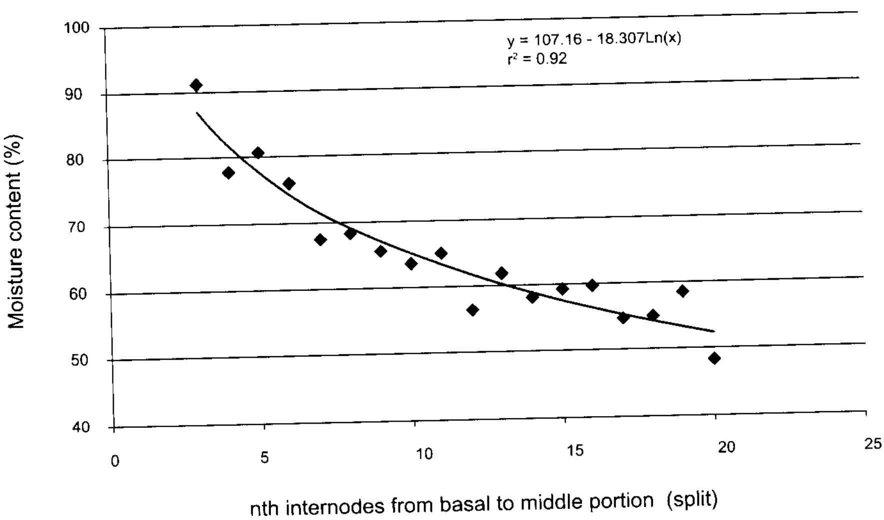

Figure 2 Moisture content of 4-year-old *G. scortechinii* along the culms

decreases from the 3rd to the 20th internodes with a sharp decrease beginning from internodes 3 to 11 and a gradual decrease thereafter. The 3rd internode had the highest MC (91%) whilst internode 20 had the lowest (48%). Abd. Latif *et al.* (1995) also found that the MC of *Bambusa heterostachya* decreases as the culm wall thickness decreases.

Tamolang *et al.* (1980) and Jamaluddin (1999) also found that MC decreases with the culm height in the species studied. This phenomenon is probably due to the decrement of the culm wall thickness as it goes upward. The lower MC at the top portion is associated with the decrease in the percentage of parenchyma cells (Abd. Latif & Mohd Zin 1992). The higher MC at the basal portion, on the other hand, is probably due to the lower concentration of vascular bundles distributed per unit area of culm wall thickness, thus giving rise to a higher percentage of parenchyma cells that serve as sites for water storage (Abd. Latif & Mohd Tamizi 1992).

In this study, the relationship between MC and culm wall thickness was also investigated. The fitted regression line (Figure 3) indicates a strong linear relationship between MC and culm wall thickness of the 4-year-old *G. scortechinii.* The predictive equation to relate the MC was found to be significant with a coefficient of determination (r^2) of 0.93. The linear correlation between the MC and culm wall thickness can be illustrated as follows:

$$y = 24.3 + 4.0334\,x \qquad \text{Equation 1}$$

where,

y = moisture content, %
x = culm wall thickness, mm

The mean relative density values for the splits, strips and outer splits (in green condition) were 0.51, 0.55 and 0.81 respectively. The density is relatively lower compared with those of other species like *Bambusa arundinacea, B. nutans, B. polymorpha* and *B. tulda* (Table 2) in the form of splits. This indicates that the density increases from the inner to the peripheral layer of the culm. This phenomenon is also associated with the distribution of vascular bundles in the culm wall (Figure 1). Their size and shape vary across the culm wall as well as along the culm height. The decrease in density of culm wall from the periphery to the inner layer has also been reported in 1- to 3- year-old *G. scortechinii* (Jamaluddin *et al.* 1992).

The density of *G. scortechinii* was found to increase as the height of the bamboo culm increased. The density at the basal portion (internode 3) was 0.62 compared with 0.74 at the top (internode 20). Variation in density as a function of height is presented in Figure 4. The trend generally increases from the base upwards and has also been reported in *Malocanna baccifera* and *B. bacooa* (Sattar *et al.* 1992) and

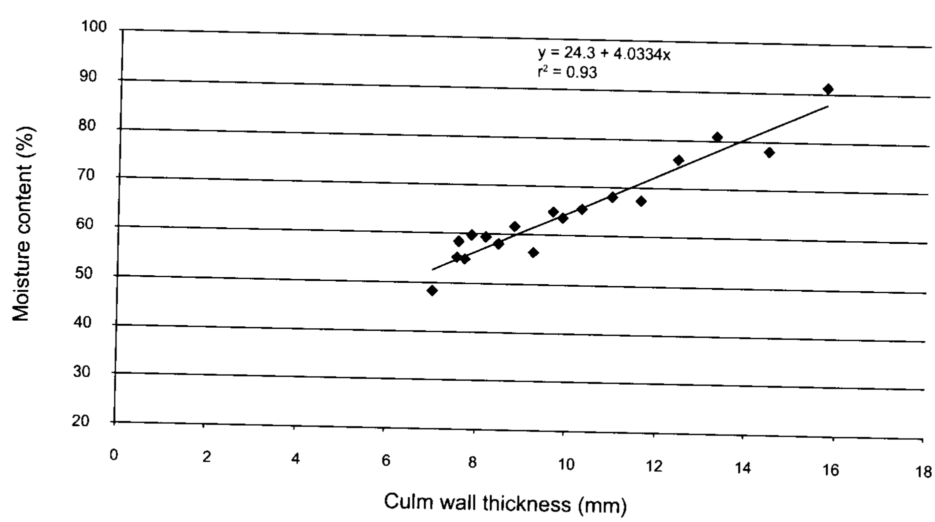

Figure 3 Relationship between moisture content and culm wall thickness of 4-year-old culms of *G. scortechinii*

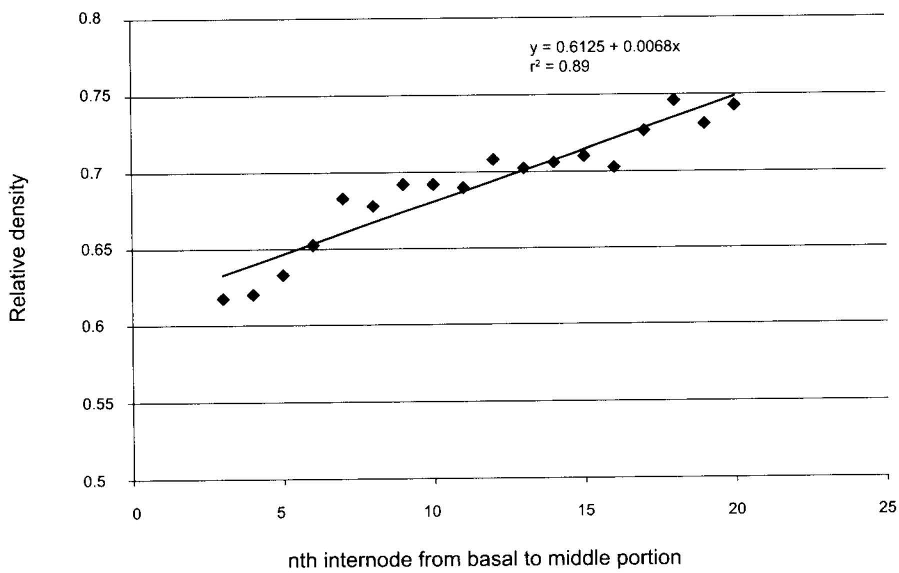

Figure 4 Distribution of relative density of 4-year-old *G. scortechinii* along the culms

also for *G. scortechinii* by Jamaludin and Abd. Latif (1993). They concluded that the higher density at the top portion was attributed to the distribution of vascular bundles and silica content. In most bamboos higher density in a culm was influenced by the higher frequency of vascular bundles (Liese 1998). Bamboo generally tapers from the basal to the top portions and the culm wall becomes thinner with increasing height.

The fitted regression line (Figure 5) indicates a high inverse linear relationship between the density and culm wall thickness of the 4-year-old *G. scortechinii.* The predictive equation for density was significant with a coefficient of determination (r^2) at 0.90. The correlation between density and culm wall thickness can be expressed as:

$$y = 0.84 - 0.015x \quad \text{Equation 2}$$

where,
y = relative density
x = culm wall thickness, mm

Table 1 shows the shrinkage of *G. scortechinii* from green to oven-dry condition in three directions. The overall results indicate that samples in the form of strips shrank more than the splits and outer splits in the radial and tangential directions. The radial and tangential shrinkages for the strips were 23.7% and 19.8% respectively whereas the outer split shrank 17.6% in the radial and 14.4% in the tangential directions. For the splits, the radial and tangential shrinkage values were

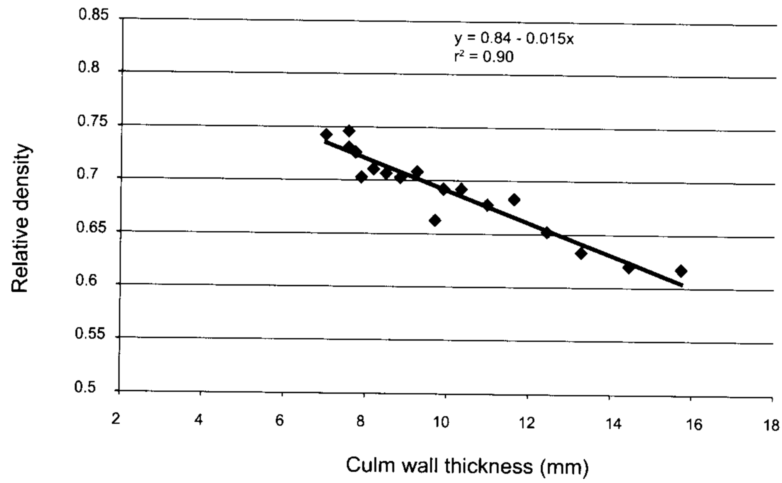

Figure 5 Relationships between relative density and culm wall thickness of 4-year-old *G. scortechinii*

respectively 20.9% and 12.4%. The magnitude of shrinkage for *G. scortechinii* was similar to that of 4-year-old culms of *B. heterostachya* at the basal portion. A similar trend in shrinkage was also reported by Abdul Latif *et al.* (1995).

Within the culm wall, the shrinkages in both the radial and tangential directions were significantly higher at the middle layer (strips) than at the peripheral layer (outer splits) while a slightly lower longitudinal shrinkage was observed at the middle layer compared with the outer. This difference, however, was not significant. Comparatively, it is also interesting to note that the percentage of tangential shrinkage for the splits was significantly lower while the longitudinal shrinkage was relatively higher than that of the outer split and strip samples.

All the samples shrank more in the radial direction than in the tangential direction. This is contradictory to the shrinkage behaviour of wood. The higher shrinkage in the radial direction than in the tangential direction is probably due to the collapse of the parenchyma cells during drying. Zaidon (1995) found collapse of the ground parenchyma cells in three rattan species. This collapse normally occurs during the removal of free or capillary water in the cavities of the bamboo and rattan cells. Chafe (1986) in his study on eucalyptus wood reported that the occurrence of collapse has a relationship between volumetric shrinkage and specific gravity. Due to the differences in anatomical structure and density, there is a large variation in tangential shrinkage from the interior to the outermost portion of the wall (Sharma & Mehra 1970). The reasons for the difference in magnitude of shrinkage of bamboo in different directions, however, still remain unclear.

The shrinkage of bamboo culms in the longitudinal direction is almost similar to that in wood. The smaller shrinkage found in the longitudinal direction for the 4-year-old culms of *G. scortechinii* (Table 1) was probably due to the fibrillar orientation in the cell wall. The alternate orientation of the polylamelated cell wall probably restrains the longitudinal movement (Parameswaran & Liese 1976).

Mechanical properties

The mean values for the mechanical properties of *G. scortechinii* splits and strips are tabulated in Table 3. The modulus of rupture (MOR), modulus of elasticity (MOE) and compressive stress for splits (periphery layer upwards and downwards) and strips were correlated with MC and density. The relative density values for splits and strips at 12% MC were 0.72 and 0.81 respectively.

The MOR, MOE (tested with periphery layer positioned upwards) and compression parallel to grain for splits were 156.2 Nmm^{-2}, 15 036 Nmm^{-2} and 81.3 Nmm^{-2} respectively. The MOR and MOE values for *G. scortechinii* were relatively higher than those found for *Guadua angustifolis* and Calcutta bamboo as shown in Table 4 (Ghanaharan *et al.* 1994, Mansur 2000).

The split specimens with their periphery layers positioned upwards exhibited higher MOR and MOE values than the specimens with periphery layers oriented downwards. The differences in the strength values are most probably due to the fibre cells, which are more concentrated at the periphery compared with the inner layer. Near the epidermis, there are generally one or two layers of fibre strands that provide more mechanical strength (Taihui & Wenwei 1985). These results are similar to those found by Lee *et al.* (1994). According to the Ghanaharan *et al.* (1994) in their studies on *G. angustifolis,* there was no significant difference in strength properties when the basal portions of bamboo culms were tested with the skin periphery oriented upwards or downwards.

A significant difference ($p < 0.05$) was observed for MOR between strips and splits with the periphery layer downwards, but no significant difference ($p < 0.05$) was found when the splits were tested oriented upwards. On the contrary, no

Table 3 Mechanical properties of 4-year-old *G. scortechinii*

Specimen	Mean value			Strength adjusted at 12%		
	MOR (Nmm^{-2})	MOE (Nmm^{-2})	Compression parallel to grain (Nmm^{-2})	MOR (Nmm^{-2})	MOE (Nmm^{-2})	Compression parallel to grain (Nmm^{-2})
Split (periphery upwards)	158.3 (20.7)	14 963 (2717)	85.1 (9.7)	156.2^{ab}	15 036^{a}	81.29^{a}
Split (periphery downwards)	134.2 (33.5)	13 604 (2609)		142^{b}	14 897^{a}	
Strip	179.6 (33.7)	18 774 (6519)	73.0 (16.3)	173.9^{a}	17 406^{a}	76.76^{a}

MOR = modulus of rupture, MOE = modulus of elasticity
Values in parentheses are standard deviations.
Means with the same letter are not significantly different at $p < 0.05$.
Relative density = strip 0.81, split 0.72.
Values are average of 150 specimens.

Table 4 Mechanical properties of some bamboo species

Species	Modulus of rupture (Nmm^{-2})	Modulus of elasticity (Nmm^{-2})
*Guadua angustifolis**	85.0	8600
Calcutta bamboo**	137.08	9700

* Ghanaharan, *et al.* (1994)
** Mansur (2000)
The specimens were tested in split form.

significant differences at ($p < 0.05$) in MOE and compressive stress were found between the strips and splits. The MOR values were higher at the strips than the splits (periphery tested downwards). They differ significantly at $p < 0.05$ which may be attributed to the difference in the amount of fibre content in the specimens. The strips as a function of per millimeter square contain relatively more fibres than the splits. Liese (1998) showed that the fibre length increases inwards to a maximum in the culm wall and decreases again towards the inner wall.

In other words, this could be explained by differences in specific gravity of the strips and splits. The density depends mainly on the fibre content and cell wall thickness. According to Janssen (1981), the strength properties in the bending of bamboo are correlated with density.

Conclusions

The 4-year-old *G. scortechinii* strips have the highest moisture content followed by splits and outer splits. On the other hand, the latter have the highest relative density while splits have the lowest. The moisture content within the splits varies greatly (standard deviation 33.6%) while the outer splits have much more uniform moisture content (s.d. 17.9%). The moisture content in the culm wall increases from the periphery to the inner layer whilst the relative density decreases. Along the bamboo culm, the moisture content decreases from the basal to the top portions while the density increases. The moisture content is directly proportional to the thickness of the culm wall, but the density is inversely proportional. The shrinkage of the strips is significantly higher than that of the splits in both radial and tangential directions. The radial shrinkage of the bamboo is somewhat higher than the tangential shrinkage. Longitudinal shrinkage, however, is negligible.

The mechanical properties of the bamboo strips and splits do not differ significantly. A significantly higher value is found for MOR in the strips than in the splits when the periphery is positioned downwards. The orientation of the periphery layer (tested downwards or upwards) during static bending test gives no significant difference in strength values.

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