

# EQUILIBRIUM MOISTURE CONTENT AND VOLUMETRIC CHANGES OF *GIGANTOCHLOA SCORTECHINII*

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**HAMDAN, H., HILL, C. A. S., ZAIDON, A., ANWAR, U. M. K. & ABD. LATIF, M. 2007. Equilibrium moisture content and volumetric changes of *Gigantochloa scortechinii*.** Relative humidity (RH) is known to affect the moisture content (MC) of bamboo but to date, only the maximum shrinkages at the tangential and radial directions were commonly determined. For bamboo to be glue-laminated and used as building components, the hygroscopicity of bamboo split and strip, and its effects on the shrinkage/swelling behaviour in relative humidities between 12 and 93% were studied. The equilibrium moisture content (EMC) and dimensional changes of *Gigantochloa scortechinii* (buluh semantan) were determined with the fibre saturation point (FSP) obtained by extrapolation. Experimental EMC values obtained at various levels of RH showed little variation between bamboo split and strip. However the degree of volumetric shrinkage and swelling changes varied between the variables studied. In transverse section, the bamboo strip is relatively stable in shrinkage at lower relative humidity, although during adsorption the volumetric swelling is high. The mean FSP for *G. scortechinii* was 24.28%. This study showed that the readiness of bamboo to dimensional changes below FSP was of prime concern. By understanding the hygroscopic characteristics and behaviour of *G. scortechinii*, users would be able to understand the limitations of the material and find alternatives to prevent these changes before it could be used as building components.

Keywords: Bamboo, fibre saturation point, volumetric shrinkage and swelling

**HAMDAN, H., HILL, C. A. S., ZAIDON, A., ANWAR, U. M. K. & ABD. LATIF, M. 2007. Kandungan lembapan seimbang dan perubahan volumetrik *Gigantochloa scortechinii*.** Kelembapan relatif (RH) mempengaruhi kandungan lembapan (MC) buluh tetapi sehingga kini hanya pengecutan maksimum pada arah tangen dan jejari sahaja banyak ditentukan. Bagi buluh untuk dilaminakan dan digunakan sebagai bahan binaan, kajian terhadap ciri higroskopik buluh belah dan buluh jalur serta kesannya terhadap kelakuan pengecutan/pembengkakan pada kandungan lembapan antara 12% hingga 93% dikaji. Kandungan lembapan seimbang (EMC) dan perubahan dimensi *Gigantochloa scortechinii* (buluh semantan) ditentukan dan takat tepu gentian (FSP) diperolehi secara ekstrapolasi. Nilai EMC pada pelbagai tahap RH menunjukkan sedikit perbezaan antara buluh belah dengan buluh jalur. Namun darjah perubahan pengecutan dan pembengkakan isi padu berbeza antara pemboleh ubah yang dikaji. Pada keratan melintang, pengecutan buluh jalur secara relatifnya agak stabil pada RH rendah walaupun semasa jerapan air, kadar pembengkakan tinggi. Purata FSP untuk *G. scortechinii* ialah 24.28%. Kajian menunjukkan bahawa faktor FSP perlu dititikberatkan kerana mempengaruhi perubahan dimensi buluh. Dengan memahami ciri higroskopik dan kelakuan *G. scortechinii*, pengguna boleh memahami keupayaan bahan tersebut dan mencari pilihan bagi mengurangkan perubahan dimensi sebelum ia boleh digunakan sebagai bahan binaan.

## INTRODUCTION

Like other lignocellulosic materials, bamboo is hygroscopic. It adsorbs and desorbs moisture until it is in equilibrium with the moisture content (MC) of the surrounding. When exposed to humidity changes, the material responds by shrinking and swelling readily. Knowledge of the bamboo–water relationship is necessary because it influences dimensional changes and mechanical strength. These properties decrease

as bamboo adsorbs moisture in the hygroscopic range (Janssen 1981). Understanding of the sorption behaviour and shrinkage/swelling characteristics is important as it would affect the properties of the material.

Sorption is a process whereby vapour molecules are attached to sites distributed throughout the bulk phase of an amorphous or partially crystalline region (McLaren & Rowen 1951).

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Over time, it gradually attains certain moisture content depending on the RH it is exposed to and this is called the equilibrium moisture content (EMC). As this happens, it also changes the dimensional volume of the material. The relative change in dimensions associated with changes of MC is linear over most of the hygroscopic range. In a previous study, Sadoh and Christsen (1967) showed that the relationship between EMC and longitudinal swelling is not linear. Unlike wood, the culm wall of bamboo shrinks about 4 to 14% from green to about 20% MC, which is mainly observed at the radial section (Liese 1985). Information on shrinkage of bamboo from green to oven-dry is available (Tewari 1992, Abd. Razak *et al.* 1995, Mansur 2000). However, the hygroscopicity of bamboo and its swelling/shrinkage characteristics below fibre saturation point (FSP) observed at different RHs for Malaysian bamboo have not been reported.

FSP is defined as the moisture content corresponding to saturation of the cell wall with no free water in the lumen present. In bamboo, the FSP is influenced by the composition of the tissue and probably the amount of chemical constituents present (Liese 1985). FSP may differ with culm and between species. Ota (1955) reported that *Dendrocalamus strictus* has a mean value of about 20% while *Phyllostachys pubescens*, 13%.

This paper discusses on the hygroscopicity of *G. scortechinii* bamboo when exposed to various moisture conditions below FSP.

## MATERIAL AND METHODS

### Sample preparations

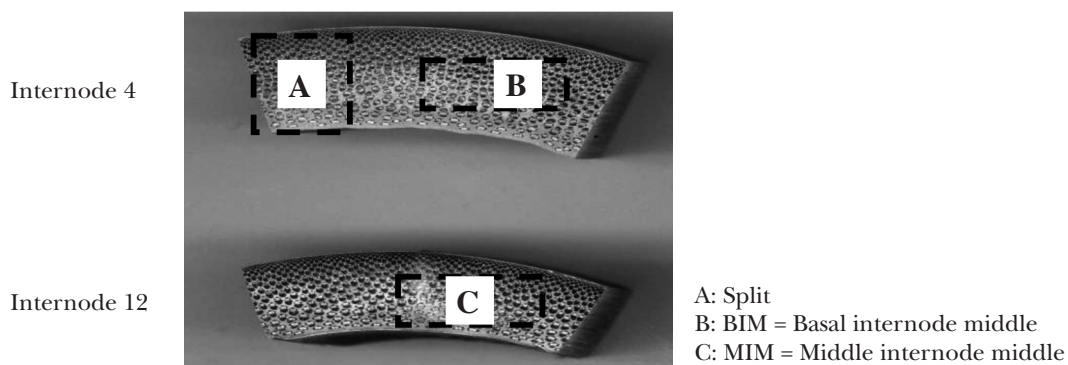
Culms of 4-year-old *G. scortechinii* were harvested from natural stands at the Forest Research

Institute Malaysia. The bamboo culms were cut at 150 mm above ground level. Samples obtained from internode 4 were subsequently labelled as splits and strip basal [Basal Internode Middle (BIM)] while internode 12 was labelled as Middle Internode Middle (MIM) [Figure 1]. Bamboo split refers to the wall thickness as a function of its radial section (20 × 20 mm × culm wall thickness), while strip has both its periphery and inner skin removed with the resultant wall thickness approximately 4 mm. All the samples were smoothly sanded to remove loose fibres. Steps were taken to ensure that all samples were obtained from adjacent location to eliminate biasness. Ten replicates each for the treatment group were prepared for the sorption study.

### Determination of EMC and dimensional changes

One set of samples was oven dried at  $103 \pm 2$  °C. The samples were placed in desiccators to stabilize any possible residual humidity and effects of internal drying stress. The samples were then weighed and the oven-dry dimensions in all principal directions were taken with a digital veneer calliper. Oven-dried test samples were kept above saturated solutions of various salts in desiccators and were located in a conditioning room maintained at 65% RH and 20 °C. Seven salts were chosen as listed in Table 1.

The sorption test was conducted in stages beginning with the lowest at 12% RH following the methods by Stamm (1964) and Esteban *et al.* (2005). A volume of 100 ml of distilled water were poured into the desiccators and the salts were subsequently poured and stirred. Excess salt was always maintained to ensure saturation level. The solution in the desiccators was constantly agitated with air pump to ensure



**Figure 1** Internodes 4 and 12 of *G. scortechinii* along the culm height

**Table 1** Saturated salt solutions and their resultant relative humidities at 20 °C

Salt	RH (%)
Lithium chloride	12
Potassium acetate	20
Calcium chloride	32
Potassium carbonate	44
Sodium dichromate	55
Sodium chloride	76
Potassium nitrate	93

even distribution of vapour. The samples were left to equilibrate and subsequently weighed until no more change in weight. The final weight and dimensions were measured and the values were used to determine the EMC and shrinkage/swelling using the following formulas:

$$\text{EMC (\%)} = \frac{\text{Weight}_{\text{wet}} - \text{Weight}_{\text{od}}}{\text{Weight}_{\text{od}}} \times 100 \quad (1)$$

Volumetric shrinkage (%)

$$= \frac{\text{Decrease in dimension (L} \times \text{R} \times \text{T)}}{\text{Original dimension}} \times 100 \quad (2)$$

Volumetric swelling (%)

$$= \frac{\text{Increase in dimension (L} \times \text{R} \times \text{T)}}{\text{Original dimension}} \times 100 \quad (3)$$

L = longitudinal

R = radial

T = tangential

The samples were then transferred into another desiccator which had the next lowest relative humidity and the process continued in ascending order so that adsorption isotherms could be derived. Another set of samples were subjected to the humidity conditions in descending order. The EMC and volumetric changes during shrinkage and swelling were determined.

### Determination of isotherm and fibre saturation point (FSP)

The isotherm fitting and FSP values were obtained by extrapolation using the Hailwood–Horrobin model:

$$\frac{H}{M} = A + BH - CH^2 \quad (4)$$

where

M = total moisture content

H = at any given humidity (water of hydration and water of solution)

## RESULTS

### EMC and isotherm fitting

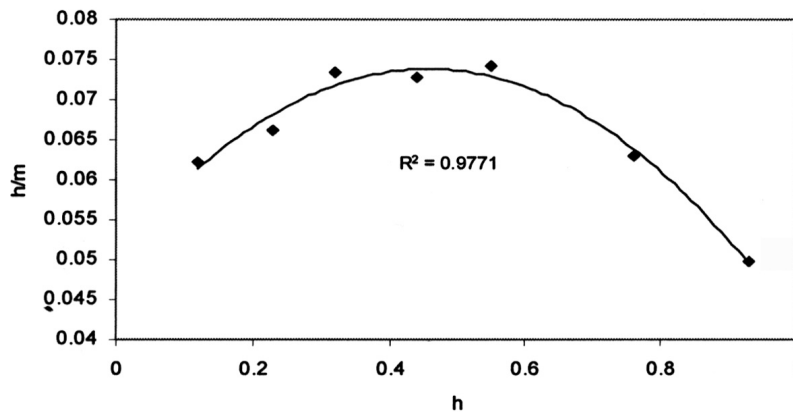
The EMC attainable was higher during desorption than adsorption (Table 2). At the respective humidity, EMC obtained for BIM was generally higher than split and MIM in both adsorption and desorption with MIM showing the least. The experimental mean values were analysed by the Hailwood and Horrobin (1946) single-hydrate sorption model. The data were transformed by dividing the relative vapour pressure (h) with the equilibrium moisture condition (m) obtained earlier. A quadratic curve of the polynomial function was obtained from these data points. A graphical illustration of the ratio h/m against vapour pressure h, using the parabolic equation, is shown in Figure 2 and was deduced and the values A, B, C and R<sup>2</sup> obtained.

The statistical proportion of variation, R<sup>2</sup>, is used to explain the regression line whereby higher or lower R<sup>2</sup> would indicate the goodness of fit to the regression line. Therefore, an example representing the worst overall variation in internode for EMC attained through the model in this study was chosen to assess the sensitivity of the EMC obtained by means of the equation to the degree of fitting. The example given in Table 3 shows deviation between the experimental and calculated data of about 0.31% MC or less. This is in good agreement with the work of Simpson (1980) who found that the worst deviation between experimental and calculated

**Table 2** Experimental EMC values obtained at various levels of RH

RH (%)	Adsorption			Desorption		
	Split	BIM	MIM	Split	BIM	MIM
12	1.93 (0.21)	2.15 (0.15)	1.81 (0.16)	3.67 (0.22)	3.62 (0.21)	3.38 (0.33)
23	3.47 (0.22)	3.85 (0.18)	3.37 (0.13)	5.18 (0.14)	5.31 (0.15)	5.20 (0.21)
32	4.36 (0.25)	4.69 (0.17)	4.20 (0.13)	6.34 (0.21)	6.45 (0.24)	6.40 (0.16)
44	6.05 (0.39)	6.82 (0.49)	6.14 (0.40)	8.22 (0.71)	8.62 (0.32)	8.45 (0.36)
55	7.41 (0.42)	8.34 (0.81)	7.31 (0.93)	9.89 (0.28)	10.08 (0.36)	9.86 (0.44)
76	12.05 (0.59)	13.10 (0.77)	12.28 (0.66)	12.92 (0.30)	13.54 (0.99)	12.80 (0.56)
93	18.70 (0.65)	18.67 (0.55)	18.46 (0.44)	20.55 (0.52)	20.35 (0.26)	20.32 (0.31)

BIM = basal internode middle  
MIM = middle internode middle  
Values in parentheses are standard deviations (n=10).



**Figure 2** Selected plots of h/m in order to obtain A, B, C and R<sup>2</sup> values. Constants A, B and C are obtained from the fitting parameters of the second order polynomial. Best fit to data points internode split at adsorption.

**Table 3** Comparison of experimental mean EMC values with those calculated using the H–H equation

RH(%)	EMC (%)		Deviation from experimental value (% of MC)
	Experiment	Calculated	
12	2.15	2.14	+0.01
23	3.85	3.74	-0.11
32	4.69	4.97	+0.28
44	6.82	6.65	-0.17
55	8.34	8.37	-0.03
76	13.10	12.70	-0.40
93	18.67	18.98	+0.31

Comparison is data for BIM at adsorption.

sorption data was about 0.8% MC by analysing experimental sorption data from Anonymous (1974) using the Hailwood–Horrobin model.

### Fibre saturation point

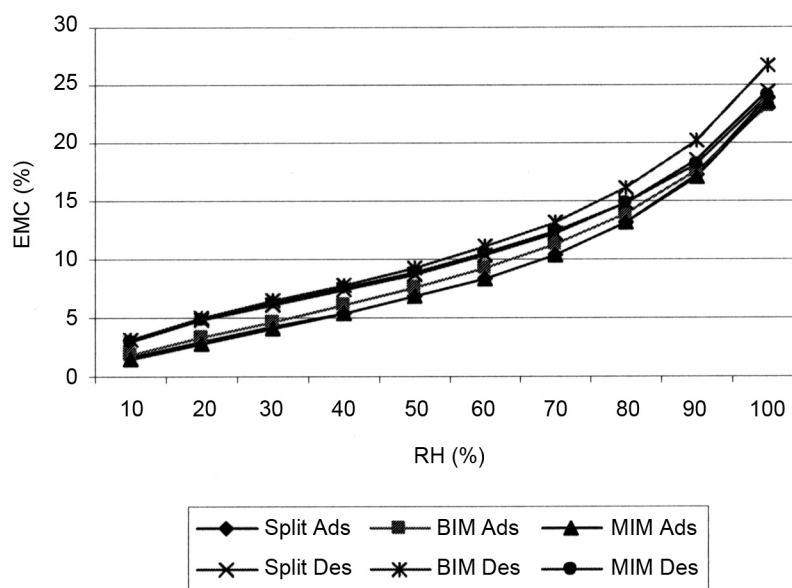
The extrapolated FSP for *G. scortechinii* calculated at 100% RH is shown in Figure 3. The FSP at adsorption isotherm was consistently lower than desorption isotherm in all variables. The isotherms were extrapolated to a common intersection point at 0% RH where no moisture can be sorbed, irrespective of substrate hygroscopic properties. On extrapolation to the saturation limit of 100% RH, the adsorption curve is consistently lower than desorption curve resulting in an open hysteresis loop at the upper end (Spalts 1958). This is expected since these values were extrapolated from lower relative humidities (Martins 1992). Stamm (1964) concurred that EMC values by extrapolation to 100% RH, in fact, estimate the FSP of the material at a relative vapour pressure of about 0.995 and not the moisture content at which the relative humidity becomes unity. As a result, the curves at the upper end remain open because an upward break occurs in the adsorption curve since simple extrapolation from lower values cannot adequately account for the sharp increase which occurs due to the capillary condensation (Stamm 1964).

### Volumetric changes

Below FSP value, shrinkage and swelling occur, and volumetric changes of bamboo splits are illustrated in Figure 4. Minimal shrinkage and swelling were observed at MIM in the lower relative humidity range (between 12 and 55%) but the properties increased from 76% RH. On the contrary, BIM experienced dimensional changes as early as 12% RH. With regard to the position along the culm height and on the transverse section, there was not much variation in volumetric swelling and shrinkage between the samples at different RHs. However, when differences did exist, they could be attributed to the difference in density.

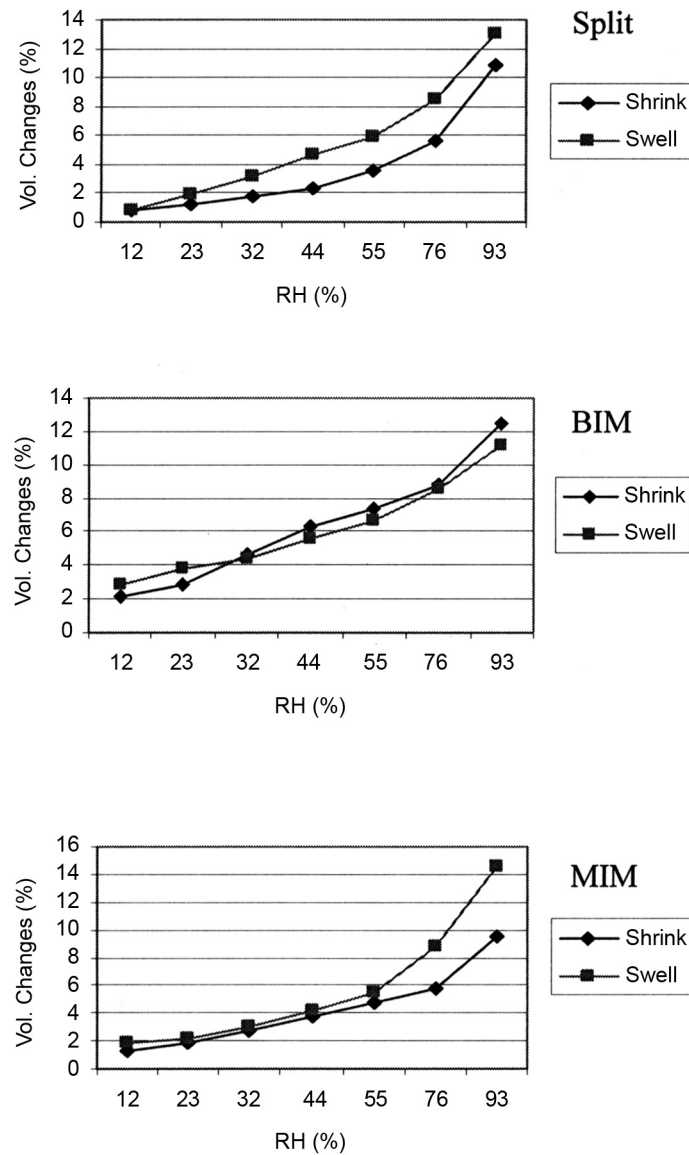
### DISCUSSION

The relatively low EMC values observed in *G. scortechinii* bamboo as compared with timbers of similar density group may be accounted for by the presence of lignin and extractives content. Hernandez (1993) reported that variation in EMC in the same RH may be due to presence of variable amounts of extraneous substances. Nearn (1955) cited by Higgins (1957) found that EMC values would increase appreciably by the removal of water-soluble extractives. The sample geometry may also have some effect on the sorption as observed in both BIM and MIM



**Figure 3** Curve-fitted isothermal equilibrium moisture content (EMC) data at 10 percentile levels of relative humidity





**Figure 3** Volumetric changes of bamboo split, BIM and MIM at different RHs

(all sides exposed) being more hygroscopic than split.

The hysteresis loops observed between desorption and adsorption were 2 to 5%. This concurs with Sulthoni (1989) who reported that a single layer of epidermal cells and highly lignified fibre bundles form the outermost part of the culm resulting in a lower OH content and swelling. This is also in tandem with the findings of Spalts (1958) that in most cases the EMC measured from desorption were only 3 to 5% higher than adsorption.

The FSP values were obtained by taking the EMC value at 100% RH given by the fitted isotherm. The mean FSP for *G. scortechinii*, 24.28%, is higher than the mean FSP values

for *Dendrocalamus strictus* and *Phyllostachys pubescens* at 20 and 13% respectively (Ota 1955). Comparatively, it is slightly lower than timber, in the range of 25 to 30% (Skaar 1988, Hamami *et al.* 1998). Liese (1985) indicated that the difference in FSP in bamboo within the culm position and section may be due to varying FSP for fibres and parenchyma. This is reflected in the different FSP values observed between splits, BIM and MIM. This is anticipated as difference in magnitude of material properties could be a contributory factor (Kollmann 1968). This shows that the Hailwood–Horrobin model fitted quite well for bamboo.

The dimensional swelling and shrinking of samples corresponded linearly with EMC.

This would suggest that the variation caused by condensation or other effects as suggested by Skaar (1988) is minimal and some of them probably lie beyond the limit of detection by the swelling/shrinkage determination technique used. In practical application, MIM is more dimensionally stable than BIM and will respond minimally with the changing EMC.

## CONCLUSIONS

There is not much variation in EMC observed at different RHs with regard to position and sections. The information obtained in this study is important to the future of the bamboo-based industry. The recommended moisture content attainable for any piece of bamboo splits and strips in service is intended to reduce effect of the surrounding conditions, thereby minimizing dimensional changes due to swelling and shrinkage. The EMC provides a crucial indicator of the responses and hygroscopicity of bamboo splits and strips to changes in surrounding condition and temperature. With an accurate knowledge of EMC of bamboo in different moisture conditions and knowledge of dimensional changes/behaviour, pertinent problems associated with bamboo can be avoided or may be reduced. This implies that to use bamboo for exterior application, bulking of the strips is needed to minimize movement. This can be done by chemical modification and resin impregnation. The FSP determined is an indicator to bamboo user to expect changes in mechanical properties below its saturation point.

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