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Macroscopic aspects and physical properties of *Dendrocalamus asper* Backer for composite panels

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Abstract: The aim of this research was to determine the basic properties of *Dendrocalamus asper* and its suitability as raw material for manufacture of composite panels. For this purpose, macroscopic characteristics and physical properties such as specific gravity, shrinkage and swelling, and water uptake were studied. The results show that some of the macroscopic characteristics change at different positions along the bamboo culm. Outer internode diameter and wall thickness gradually decrease with the culm height. The internode length increases from the bottom to the middle part and further decreases toward the top. The tissue volume of internodes decreases from the bottom to the top. All physical properties vary with the culm height. The specific gravity increases with culm height; the dimensional stability in the radial direction and water uptake are highly related to specific gravity. The dimensional stability lengthwise is more stable than crosswise. The study shows that *D. asper* has superior physical properties, which are comparable to those of some softwood and hardwood species. It should therefore be promoted as a substitute for wood in the manufacturing of structural composite lumber like Oriented Strand Board or Oriented Strand Lumber.

Key words: *Dendrocalamus asper*, macroscopic characteristics, physical properties, structural composite lumber.

INTRODUCTION

With the rapid development of the global economy and constant increase in population, the overall demand for wood and wood-based products will continue to rise. The available wood supply will decrease due to the global energy demands. Consequently, the search for alternative or substitute materials in place of wood has come into focus. A suitable substitute should be inexpensive, fast-growing, easily available raw material having comparable physical and mechanical properties, and also it should be compatible to the existing processing technologies. Bamboo could be such a non-wood substitution material for the tropical and subtropical regions.

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Bamboo belongs to the large woody grasses (Family Poaceae, Subfamily Bambusoideae) and encompasses about 1,200 species within 50 genera in the world (Chapman, 1996; Qisheng *et al.*, 2002). It is mostly distributed in the tropical and subtropical regions, covering an area of over 36.8 million hectares. In Latin America and Africa, bamboos occupy 10.4 and 2.8 million hectares respectively (Lobovikov *et al.*, 2007). Thailand is one of the richest areas of bamboo in Asia. There are 13 genera and 60 species, mainly of the sympodial type with denser clumps and with long, strong, and flexible culms which lend themselves to be used as a construction material.

Dendrocalamus asper, commonly recognized as a giant bamboo, has 20-30 m tall culms, 20-40 cm long indernodes, a diameter of 8-20 cm with a relatively thick culm wall of 10 to 20 mm (Rao *et al.*, 1998). It has been planted regularly or growing throughout tropical South-East Asia. This bamboo species is commercially important in Eastern parts of India and has been widely introduced elsewhere in tropical and subtropical botanic gardens (Dransfield and Widjaja, 1995). It is one of the most popular bamboo species of Thailand and has been planted in more than 60 provinces. It was brought from China to the farmers in Prachinburi province, which is located in Eastern part of Thailand, nearly 100 years ago (Pungbun, 2000).

D. asper young shoots are sweet and delicious known locally as sweet bamboo. They are widely consumed as vegetable. Young shoots are harvested during the rainy season (in Thailand from May to June). A properly managed plantation may produce 10-11 t young shoots per ha per year. The culms developed after three years of growth have thick walls; they are very strong and durable and are used as building material for houses and bridges, also in furniture, musical instruments, chopsticks, household utensils and handicrafts. Culms are preferably harvested in the dry season (Dransfield and Widjaja, 1995; Rao *et al.*, 1998). In Thailand, a plantation can produce 16 t culms per ha per year (Pungbun, 2000).

The macroscopic characteristics and physical properties of bamboo have significant differences to wood species. The properties of bamboo vary in vertical and horizontal directions in the culm. They are important factors to determine its utilization. The recent research has contributed to understand the properties as well as to improve the processing technologies of bamboos for wider uses (Nugroho and Ando, 2000; Sumardi *et al.*, 2007). In Thailand, several studies were carried out on the fundamental characteristics of *D. asper* and has been used as raw material for particleboard, fiberboard, pulp and paper (Kamthai, 2003; Laemsak and Kungsuwan, 2000; Pakhkeree, 1997; Sutnaun *et al.*, 2005). However, none of these studies focused on bamboo as raw material for the structural composite lumber. The objective of this study was to analyze the suitability of *D. asper* as a raw material for structural composite lumber. Therefore, the variation of the macroscopic characters and physical properties, which influence the specific gravity, shrinkage, swelling and water uptake, were analyzed along the culm length.

MATERIALS AND METHODES

Some of the investigations were done at Wood Science and Engineering Research Unit, Walailak University in Nakhon Sri Thammarat. South of Thailand and further in the Department of Wood Science. University of Hamburg. Germany. Three *D. asper* culms were harvested in April, 2007 from a private plantation, located in Nakhon Sri Thammarat province, South of Thailand. The terrain is mostly rugged hilly forest area with an elevation of about 600 m a.s.l.. 217 mm mean annual rainfall, and 27°C mean temperature. The culms were three-years-old as confirmed by macroscopic features.

Macroscopic characteristics

The culms were cut and marked from the bottom to the top part as shown in Figure 1. The macroscopic characteristics investigated were culm length, number of internodes per culm, internode length, the outer internode diameter and the culm wall thickness from the bottom towards the top.

Physical properties

Each culm was then cut into internodes along its length. From the internodes, three specimens were randomly selected and cut into size to the requirement of ASTM standard (ASTM D 143-94). Altogether, 81 specimens were cut from each culm and analyzed for the various tests. The air-dried specimens (MC 50-60%), were placed for 8 weeks in a conditioning chamber, at a temperature of 20°C and relative air humidity of 65 per cent until the MC reached 12 per cent, before determination of the physical properties.

Specific gravity, shrinkage and swelling, and water uptake

For the determination of the specific gravity, specimens were made from each internode. The testing method was performed with some modification to the ASTM D 143-94, because the specimen shape changes along the culm height. To evaluate the dimensional stability, further specimens were taken from each internode. The bamboo skin was removed (about 1 mm) before the specimens were cut into rectangular dimensions of 2 cm long and 1 cm width with variable wall thickness. The shrinkage and swelling of each internode sample in the radial, tangential and longitudinal directions were measured following the procedure of ASTM D 143-94. Shrinkage of the specimens was measured from 12 per cent MC (after conditioning at 20°C. RH 65%) to the oven-dried condition (0% MC). The swelling was measured starting with the oven-dried condition and after soaking the specimens in distilled water at 20°C for 24 h.

Specimens for the water uptake measurement were also taken from each internode along the culm length (2 cm × 1 cm × culm wall thickness). The water uptake was determined at 12 per cent MC (after conditioning at 20°C, RH 65%) and after soaking at 20°C for 24 h.

RESULTS AND DISCUSSION

Macroscopic characteristics

The values of macroscopic characteristics of the three culms investigated are given in Table 1.

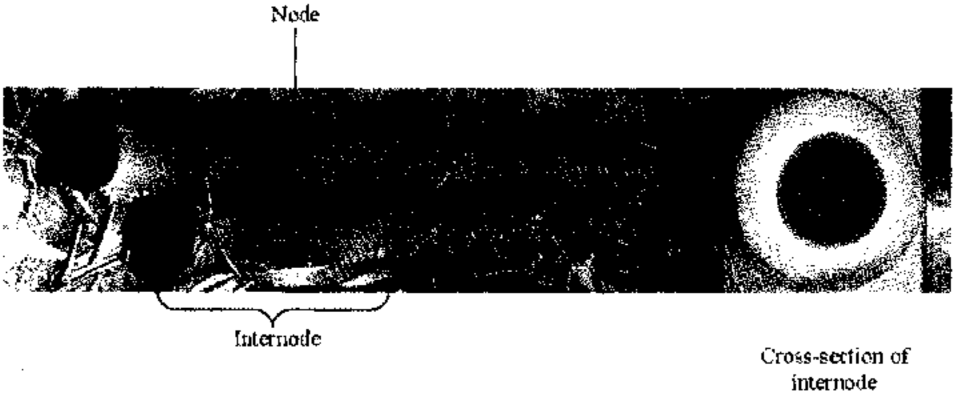


Figure 1. *D. asper* culms showing nodes, internodes and cross section of internode.

Table 1. Culm characteristics of *D. asper*

Macroscopic characters	Culm number		
	1	2	3
Culm height (m)	20.90	19.50	17.50
Number of internodes per culm	53	47	42
Internode length (cm)	25-50	28-50	26-48
Diameter along the culm from bottom to top (cm)	12.2-1.59	11.64-2.44	10.74-2.17
Wall thickness along the culm from bottom to top (cm)	2.67-0.55	2.54-0.58	2.72-0.63

Figure 2 shows the variation of macroscopic characteristics along the culm height. It demonstrates that the internode length, wall diameter and thickness change in accordance to the culm position. The internode length of the culm increases from the base to the middle part (from about 26 to 50 cm) and decreases toward the top part (from about 50 to 25 cm). The maximum internode length is located in the 1st third of the culm (approximately 10 m above ground level). The culm diameter varies from 12.2 cm at the bottom to 1.6 cm at the top. Bamboo culms taper towards the top with a gradual decrease in diameter. The culm wall thickness significantly decreases with height from 2.7 at bottom to 0.5 cm at the top.

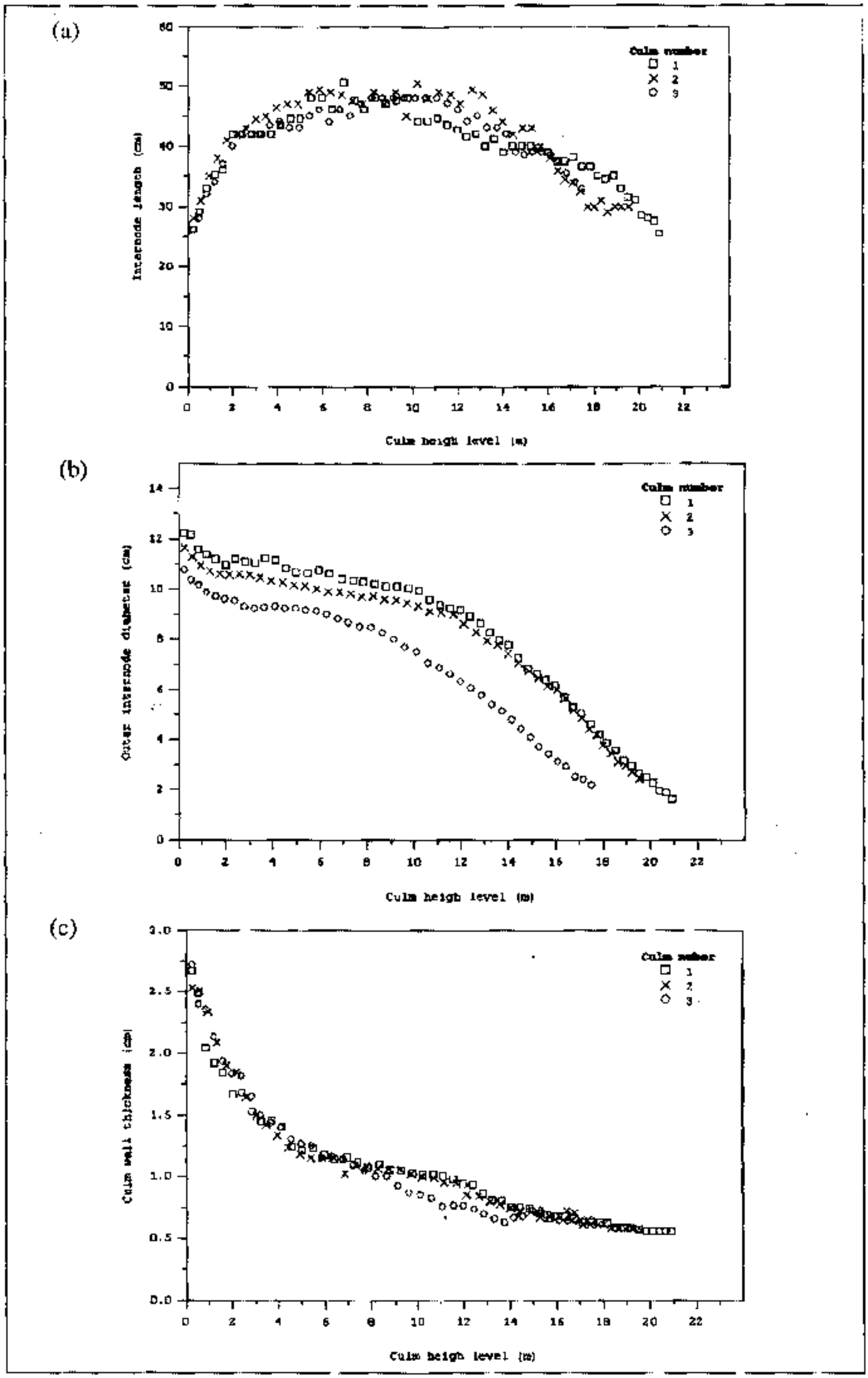


Figure 2. Variation of macroscopic characteristics along the height of *D. asper* (a) internode length, (b) outer internode diameter, and (c) culm wall thickness.

Culm almost reaches its maximum growth within the first year. This implies that the main culm characteristics, such as culm length, length of internodes, and culm wall thickness show no further increment in the following years. It confirms results on the relation between culm characteristics and age of *Bambusa vulgaris* and *Gigantochloa scortechinii* (Abd. Latif and Liese, 2002). Figure 3 presents the tissue volume of internodes obtained for each culm at different internode positions along the culm length. The volume decreases from the bottom to the top part from 2,800 to 70 cm^3 due to the decreasing culm diameter and wall thickness.

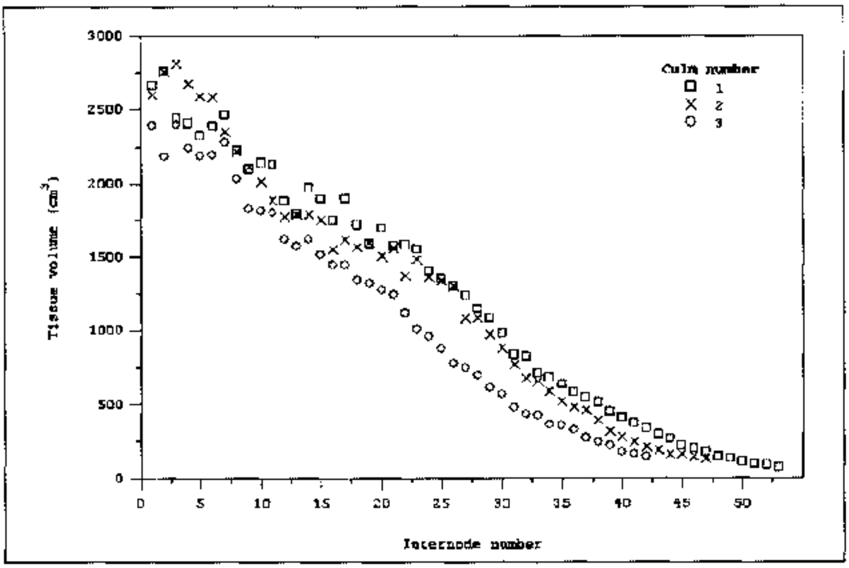


Figure 3. Decrease of the tissue volume of each internode along culm length of *D. asper.*

Utilization *D. asper* as raw material for structural composite lumber would be affected by culm wall thickness. The width of strands used in Oriented Standard Lumber (OSL) manufacture shall not be less than 12.5 mm (Lowwood, 1997). For bamboo, this mainly depends on the culm wall thickness, which significantly decreases from the bottom to the top part. Therefore, bamboo strands might be only produced from the lower half of the culm, because the culm wall thickness is more than 12.5 mm. However, bamboo has a long straight grain which can compensate the potential shortcoming. It can easily be cut into thin pieces in radial direction using a strand disc-flaker.

Physical properties

Specific gravity

The suitability of *D. asper* for OSL will be dependent upon its physical properties. The specific gravity of *D. asper* at 12 per cent MC is in the range of 0.55 to 0.90, as presented in Figure 4. The result indicates that the location along the bamboo culm is

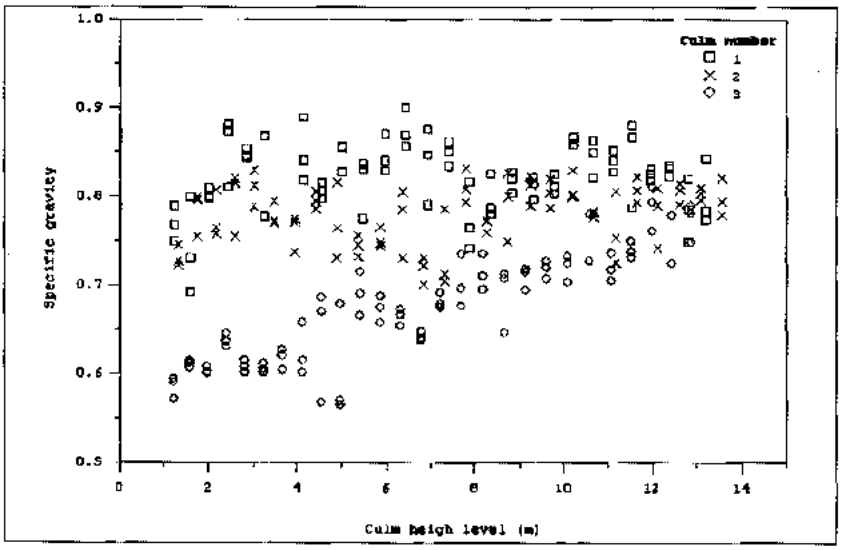


Figure 4. Variation of specific gravity along the culm length of *D. asper.*

significant for the specific gravity value. The value slightly increases from the bottom to the top of the culm.

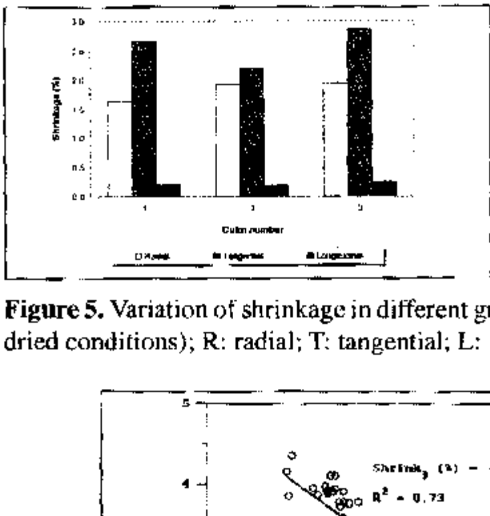
Several studies (Abd. Latif *et al.*, 1993; Abd. Latif and Liese, 2002; Liese, 1998) have shown that the specific gravity increases along the culm from bottom to the top due to the higher fiber density at the culm periphery. The amount of these fibers strongly increases from the bottom to the top. The increment of specific gravity during the first year depends on the fiber cell wall thickening with ageing (Liese and Weiner, 1996; Abd. Latif and Liese, 2002). When compared to the hardwoods or heavy tropical timber species which are normally used in composites panels manufacturing, the specific gravity of *D. asper* is relatively high (> 0.60) (Blomquist *et al.*, 1983). On the other hand, specific gravity of *D. asper* would be affected by its position along the culm. Thus, if the composites are made from *D. asper*, a potential higher specific gravity variation should be considered.

Shrinkage and swelling

The dimensional shrinkage of *D. asper* in different directions, following the three orthotropic directions, is illustrated in Figure 5. The average shrinkage is 1.8 per cent radial, 2.5 per cent tangential and 0.2 per cent longitudinal directions. The tangential shrinkage is about one-half as much in radial, and much less along the longitudinal direction. When compared to the wood species, it shrinks less than some softwood and hardwood species, which mean value are 8 per cent tangential, 4 per cent radial and 0.1 per cent longitudinal shrinkages from the green to oven-dried condition (Skaar, 1988).

The regression equations with the coefficient of determinations (R^2) are plotted in Figure 6 to perform the relation between specific gravity and radial shrinkage. The results indicate a strong relationship between radial shrinkage and specific gravity. The shrinkage value decreases, when specific gravity value increases. When position and specific gravity are considered, radial shrinkage shows significant difference from another. Some sources explained that in bamboo, the tangential shrinkage is higher in the outer part of the wall than in the inner part. The shrinkage of the whole wall appears to be governed by shrinkage of the outermost portion, which possesses also the highest specific gravity due to the higher fiber content. Mature culms shrink less than younger ones.

Figure 7 shows the different directional swelling of the *D. asper* culms. The mean-swelling value is 5.8 per cent radial, 4.7 per cent tangential and 0.4 per cent longitudinal. Radial and tangential shrinkages are slightly different from one another, but the longitudinal shrinkage is distinctly lower than in the other two directions. Similarly, the swelling behaviour varies in the growth direction in the same ratio like the shrinkage.



Culm No.	1			2			3		
Direction	R	T	L	R	T	L	R	T	L
Minimum (%)	0.42	0.59	0.00	1.14	0.79	0.00	0.80	1.12	0.00
Maximum (%)	3.16	4.91	0.71	3.13	4.22	0.64	3.85	4.34	0.60
Average (%)	1.64	2.66	0.20	1.93	2.19	0.19	1.94	2.86	0.25
SD (%)	0.58	0.96	0.18	0.45	0.80	0.17	0.63	0.80	0.97

Figure 5. Variation of shrinkage in different growth directions of *D. asper* (12% MC to oven-dried conditions); R: radial; T: tangential; L: longitudinal.

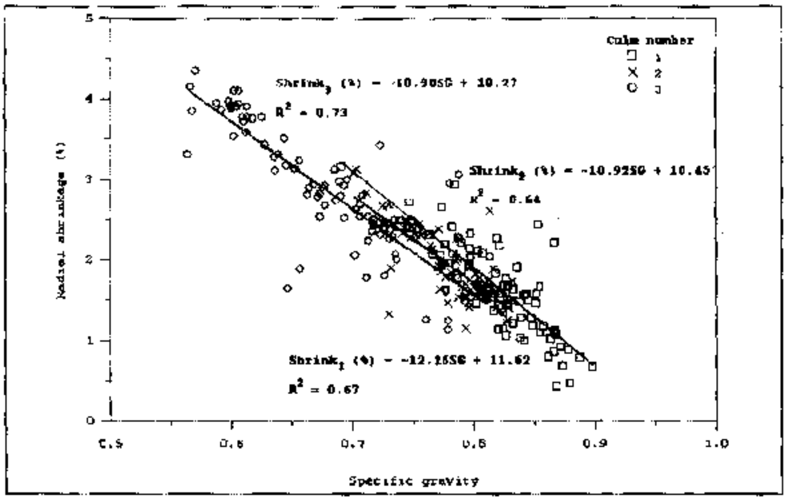
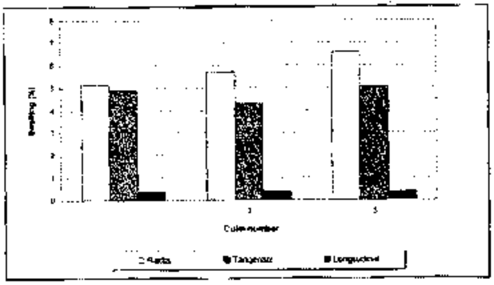


Figure 6. The relation between radial shrinkage and specific gravity of *D. asper.*



Culm No.	1			2			3		
Direction	R	T	L	R	T	L	R	T	L
Minimum (%)	3.28	1.21	0.03	3.92	2.59	0.10	5.19	1.70	0.03
Maximum (%)	6.49	7.60	1.18	7.33	6.82	1.00	7.95	9.78	0.81
Average (%)	5.12	4.89	0.39	5.71	4.27	0.40	6.56	5.03	0.40
SD (%)	0.74	1.32	0.27	0.74	1.02	0.21	0.64	1.69	0.18

Figure 7. Variation of swelling of *D. asper* culms (from oven-dried condition till after 24 h soaking in water at 20°C).

The study reveals that the dimensional stability of *D. asper* culms in lengthwise direction is less than crosswise. This behaviour is the same as in softwoods and hardwoods. In these wood species, most of the microfibrils orientations are aligned nearly parallel to the longitudinal axis. The explanation can also be applied to bamboo. Moreover, the shrinkage and swelling are slightly different between radial and tangential directions. This is in contrast to wood species which have greater dimensional stability in the tangential direction. The explanation is that bamboos have a different anatomical structure compared to wood with no radial cells and no growth rings (Liese, 1998). Thus, the dimensional movement is similar in the two directions.

Although the dimensional stability in the radial direction is affected by the position along the culm, the dimensional stability in all directions of *D. asper* is more favourable compared to that of wood. Moreover, the dimensional stability in tangential direction has no variation along the culm length. These are the favourable properties for the use of *D. asper* as a raw material in composite panels. Thus, *D. asper* has higher dimensional stability than that of wood.

Water uptake

The water uptake values are in the range of 20-55 per cent (Fig. 8). The third culm has an average value higher (approximately 15% more) than the other culms because of its lower specific gravity. Water uptake is slightly different in each position and strongly related to specific gravity, as shown in Figure 9. As the specific gravity increases, the water uptake value slightly decreases from the bottom to the top. This is mainly due to the variation in the amount of parenchyma cells, which corresponds to water holding capacity.

As a result, water uptake is influenced by position in culm which has different cell types and amounts. The tissue of a culm consists of parenchyma cells and the vascular bundles, which are composed of vessels, sieve tubes with companion cells, and fibers. The percentage distribution of cells shows a defined pattern within the culm, both horizontally and vertically. Parenchyma and conducting cells are more frequent in the inner third of the wall, whereas in the outer third, the percentage of fibers is distinctly

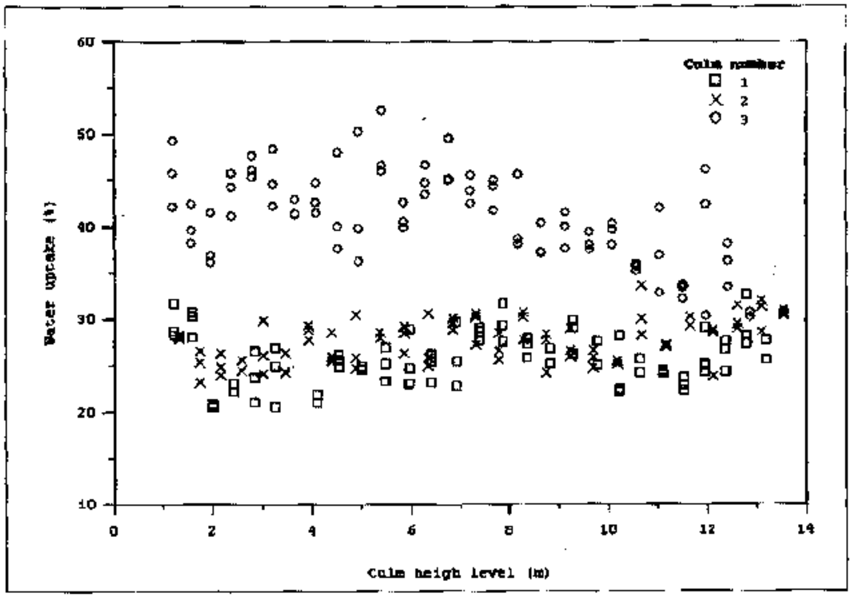


Figure 8. Variation of water uptake along the culm of *D. asper* (start at 12 per cent MC after 24 h soaking in water at 20°C).

higher. In the vertical direction, the amount of fibers increases from bottom to top, whereas that of parenchyma decreases (Liese, 1998).

Compared to wood, water uptake behaviour of bamboo could reveal certain permeability. This property will be analyzed for further processing, especially coating and gluing. The permeability of the pore structure in wood greatly influences the adhesive penetration. From an appropriate point of view, the variation of *D. asper* anatomical structure causes differences in water uptake in the radial and longitudinal directions. In strands originating from the bottom internodes of bamboo, composed of more parenchyma cells with lower specific gravity, the adhesive can more deeply penetrate, it will perform the sufficient bonding strength and can produce a high quality composite. In radial direction, the water uptake varies within the same piece of strand because of the specific gravity variation of inner and outer side of culm. Thus, if the composite panels from *D. asper* are to be produced, the variation of this property should be considered.

The information generated will be used to assess the suitability of this bamboo species for composite applications. The results demonstrate some typical properties like a higher specific gravity of *D. asper* compared to wood, which will limit its use only for higher specific gravity composite products. The dimensional stability is an important property due to the small shrinkage and swelling value. However, further research on mechanical properties and gluability, are needed to optimize the board properties made from this bamboo species.

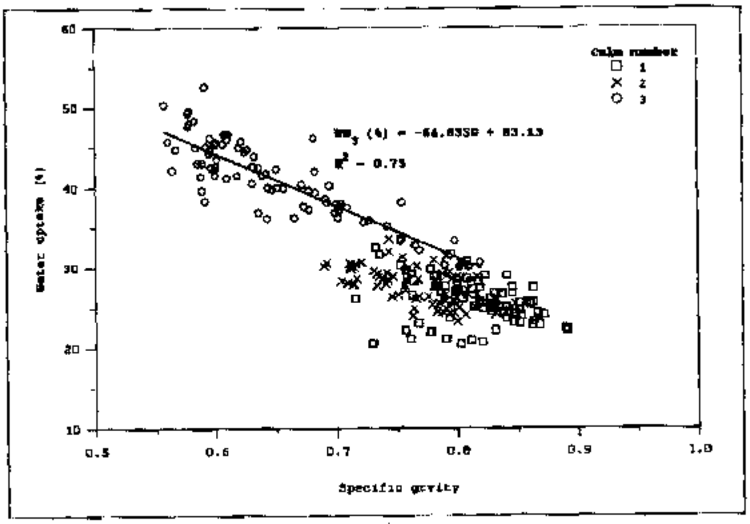


Figure 9. The relation between water uptake and specific gravity of *D. asper* (start at 12% MC after 24 h soaking in water at 20°C)

CONCLUSIONS

- Culm macroscopic characteristics and some physical properties of *D. asper* were analyzed. The following conclusions can be drawn from this study:

- All the culm characteristics differ within each internode along the culm; its outer diameter and wall thickness gradually decrease with the height; internode length increases from the bottom to the! middle part and decreases towards the top.

- The tissue volume of each internode also decreases from bottom to the top. The decrease is strongly related to the macroscopic characteristics of the culm.

- Specific gravity significantly increases from bottom to the top of the culm.

- Longitudinal shrinkage and swelling are small. Dimensional stability in radial direction is not significantly different from the tangential direction.

- Water uptake decreases with increased specific gravity.

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