Physical and Mechanical Properties of Some Thai Bamboos for House Construction

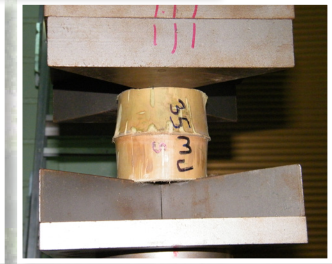
Contribution to Forest Rehabilitation in Thailand's Areas Affected
by Tsunami Disaster
Project PD 372/05 Rev. 1 (F)
Royal Forest Department
Supported by
The International Tropical Timber
Organization (ITTO)
2013

Bounsong Sompoh
Vallayuth Fueangvivat
Piyawade Bauchongkol
Waranyu Ratcharoen

Physical and Mechanical Properties of Some Thai Bamboos for House Construction







Contribution to Forest Rehabilitation in Thailand's Areas Affected
by Tsunami Disaster
Project PD 372/05 Rev. 1 (F)
Royal Forest Department
Supported by
The International Tropical Timber
Organization (ITTO)
2013

Physical and Mechanical Properties of Some Thai Bamboos for House Construction

Bounsong Sompoh
Vallayuth Fueangvivat
Piyawade Bauchongkol
Waranyu Ratcharoen

Forest Research and Development Bureau,
Royal Forest Department. Bangkok 10900, Thailand

ABSTRACT

The study was conducted to determine the physical and mechanical properties for house construction of five bamboo species: Pai Hok (*Dendrocalamus hamiltonii* Nees et Arn. Ex Munro), Pai Pa (*Bambusa bambos* (L) Voss), Pai Ruak Yai (*Thyrsostachys oliveri* Gamble), Pai Ruak Lek (*Thyrsostachys siamensis* Gamble), and Pai Lammalok (*Dendrocalamus longispathus* Kurz), harvested from Maehongson and Kanchanaburi Provinces.

The highest shrinkage and fiber saturation point were found in *B. bambos*. This bamboo species also exhibited the highest static bending strength followed by *T. siamensis, T. oliveri, D. longispathus* and *D. hamiltonii*. The mechanical properties of these five bamboo species were found to be at about the same level compared to those exhibited in the previous studies, as well as to some hardwoods such as *Dipterocarps*. Therefore, these five bamboo species could be used as a general utility timber for housing components due to their culm form and the bending properties.

Keywords: *Dendrocalamus hamiltonii* Nees et Arn. Ex Munro, *Bambusa bambos* (L) Voss, *Thyrsostachys oliveri* Gamble, *Thyrsostachys siamensis* Gamble, *Dendrocalamus longispathus* Kurz, physical properties, mechanical properties, bamboo

INTRODUCTION

Increasing demand for timber and the depletion of natural forest have encouraged the utilization of many less popular species. Bamboos have for a very long time been used as timber. However, more understanding of properties and behavior of bamboo timber is important to evaluate the potential of bamboos to produce high quality end products.

In 1999, the Royal Forest Department (RFD) received the support from the International Tropical Timber Organization (ITTO) to undertake the research project on *Promotion of the Utilization of Bamboo from Sustainable Sources in Thailand*, Project PD 56/99 Rev.1 (I), aiming to develop and disseminate the knowledge on management of bamboo resources. Special emphasis was placed on processing technology to promote bamboo utilization in rural communities. Five bamboo species were included in order to determine their potential for housing and furniture components. Moreover, ITTO supported the Project PD 372/05 Rev.1 (F), *Contribution to Forest Rehabilitation in Thailand's Areas Affected by the Tsunami Disaster*, to promote bamboo utilization in Tsunami affected areas in order to meet medium- and long-term needs for house construction.

Physical and mechanical properties are very important characteristics in determining the use potential of bamboo timber. The physical properties are the quantitative characteristics of bamboo and its behavior to external influences other than applied forces, while the mechanical properties of bamboo are an expression of its behavior under applied forces. This behavior is modified in a number of ways depending upon the kinds of force exerted on the bamboo and the way of application. The main testing on the strength of bamboo is the bending-strength. Additionally, bending stress is the result of a combination of all three primary stresses, *i.e.* compressive, tensile and shear which act together and cause flexure, or bending in the body. The bending strength of bamboo as an important factor in building construction has been studied by Limaye (1952), Sekhar *et al.* (1962) and Janssen (2000).

Under the Project PD 56/99 Rev.1 (I) and PD 372/05 Rev.1 (F), the physical and mechanical properties of each set of five bamboo species commonly grown and utilized in local communities of Thailand were studied to determine their use potential.

MATERIALS AND METHODS

MATERIALS

Following were five bamboo species included in the study under the Project PD 56/99 Rev.1 (I):

Pai Liang (*Bambusa sp*.) from Sakon Nakhon (Figure 1); Pai See Suk (*Bambusa blumeana* Schultes) from Nakhon Ratchasima (Figure 2); Pai Tong (*Dendrocalamus asper* Backer) from Prachinburi (Figure 3); Pai Sang (*Dendrocalamus strictus* Nees) (Figure 4); and Pai Rai (*Gigantochloa albacilliata* Munro) from Chiangmai (Figure 5).

The Project PD 372/05 Rev.1 (F) included another five bamboo species collected from two locations as follows.

1. Pai Hok (*Dendrocalamus hamiltonii* Nees et Arn. Ex Munro) (Figure 6) from Tambon Mae Ukor, Amphur Khunyuam, Maehongson province at 18^{O} 53′ north latitude and 98^{O} 02′ east longitude, and 1,000 meters elevation above mean sea level.

2. Pai Pa (*Bambusa bambos* (L) Voss) (Figure 7), Pai Lammalok (*Dendrocalamus longispathus* Kurz) (Figure 8), Pai Ruak Yai (*Thyrsostachys oliveri* Gamble) (Figure 9) and Pai Ruak Lek (*Thyrsostachys siamensis* Gamble) (Figure 10) from Hinlab Silviculture Research Station, Tambon Hinlab, Amphur Borploy, Kanchanaburi Province at 14^{O} 13′ north latitude and 99^{O} 27′ east longitude, and 80 meters elevation above mean sea level.

Figure 1 Pai Liang (*Bambusa sp.* scientific name not yet finally identified).

Figure 2 Pai See Suk (*Bambusa blumeana* Schultes).

Figure 3 Pai Tong (*Dendrocalamus asper* Backer).

Figure 4 Pai Sang (*Dendrocalamus strictus* Nees).

Figure 5 Pai Rai (*Gigantochloa albacilliata* Munro).

Figure 6 Pai Hok (*Dendrocalamus hamiltonii* Neeset Arn. Ex Munro).

Figure 7 Pai Pa (*Bambusa bambos* (L) Voss).

Figure 8 Pai Lammalok (*Dendrocalamus longispathus* Kurz).

Figure 9 Pai Ruak Yai (*Thyrsostachys oliveri* Gamble).

Figure 10 Pai Ruak Lek (*Thyrsostachys siamensis* Gamble).

METHODS

The culms selected for the study were at least 3 years old, sound and free from any defects (Figures 11 and 12). These culms were sprayed with wood preservatives to avoid pest infestation (Figure 13). The number of samples ranged from 10–15 pieces for each test.

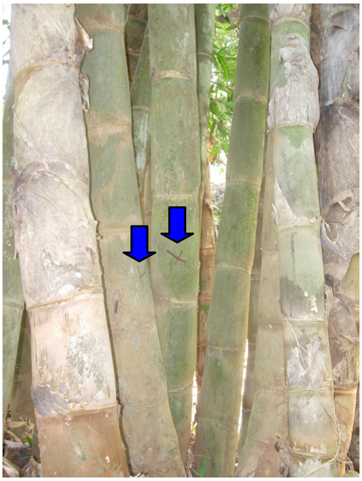


Figure 11 Selection of bamboo culm.

Figure 12 Cutting.

Figure 13 Wood preservative spraying.

The samples were taken from 3 parts of the culm, *i.e.* bottom, middle and top parts depending upon the length and the number of internodes. The results were presented in terms of average values from each culm part.

The test of physical and mechanical properties was based on the standard of ISO 22157-2: 2004 (Figures 14–17)

1. Physical properties
   1.1 Moisture content
   1.2 Mass per volume or density
   1.3 Specific gravity
   1.4 Shrinkage
   1.5 Fiber saturation point

Fiber saturation point (FSP) is a term used in wood mechanics and especially wood drying, to denote the point in the drying process at which only water bound in the cell walls remains-all other water, called free water, having been removed from the cell cavities. Further drying of the wood results in strengthening of the wood fiber, and is usually accompanied by shrinkage. Wood is normally dried to point where it is in equilibrium with the atmospheric moisture content or relative humidity, and since this varies so does the equilibrium moisture content. According to wood handbook the average FSP is 30%. Individual species may differ from the average.

Figure 14 Preparation of samples.

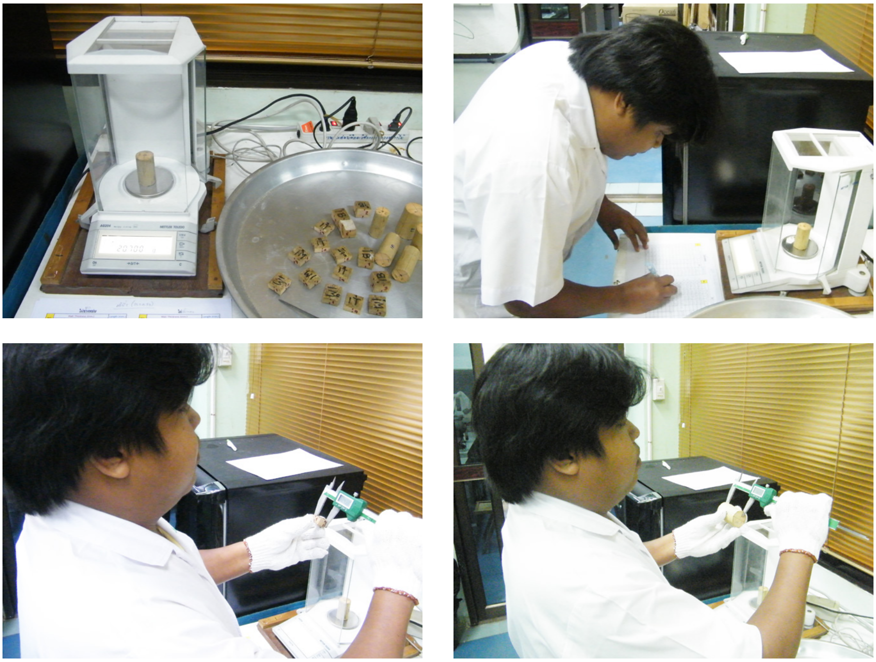


Figure 15 Physical properties test.

Figure 16 Mechanical properties test.

2. Mechanical properties

2.1 Modulus of rupture

Modulus of rupture (MOR) or flexural strength is a mechanical parameter for brittle material is defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its modulus of rupture. It is measured in terms of stress.

Royal Forest Department (RFD) classified hard wood and soft wood compared with *Hopea odorata* Roxb. (at 12% moisture content) are shown in Table 1.

Table 1 RFD standard for hard wood classification.

Degree	Modulus of rupture		Natural durability
	(kg/cm^2)	(MPa)	(year)
Hard	> 1,000	> 100	> 6
Intermediate	600-1,000	60-100	2-6
Soft	< 600	< 60	< 2

Source: adapt from Forest Products Development Division (2005)

2.2 Stress at proportional limit

Stress at proportional limit is the maximum stress that a material can with stand while being stretched or pulled before failing or breaking. Some materials will break sharply, without deforming, in what is called a brittle failure. Others, which are more ductile, including most metals, will stretch some-and for rods or bars, shrink or neck at the point of maximum stress as that area is stretched out.

2.3 Modulus of elasticity

Modulus of elasticity (MOE) or Young's modulus is a measure of the stiffness of an elastic material and is quantity used to characterize material. It is the mathematical description of a material's tendency to be deformed elastically when a force is applied to it. The elastic modulus of a material is defined as the slope of its stress-strain curve in the elastic deformation region.

MOE enables the calculation of the change in the dimension of a bar made of an isotropic elastic material under tensile or compressive loads. For instance, it predicts how much a material sample extends under tension or shortens under compression. MOE is used in order to predict the deflection that will occur in a statically determinate beam when a load is applied at a point in between the beam's supports.

2.4 Compression

Compression is the application if balanced inward forces (pushing) to different points a material or structure, that is, forces with no net sum or torque directed so as to reduce its size in one or more directions. It is contrasted with tension or traction, the application of balanced outward (pulling) forces; and with shearing forces, directed so as to displace layers of the material parallel to each other.

When put under compression (or any other of stress), every material will suffer some deformation, even if imperceptible, that causes the average relative positions of its atoms and molecules to change. The deformation may be permanent, or may be reserves when the compression forces disappear. In the latter case, the deformation gives rise to reaction forces that oppose the compression forces, and may eventually balance them.

2.5 Shear stress

Shear stress is defined as the component of stress coplanar with a material cross section. Shear stress arises from the force vector component parallel to the cross section. Normal stress, on the other hand, arises from the force vector component perpendicular or antiparallel to the material cross section on which it acts.

2.6 Tension

Tension is the pulling force exerted by a string, cable, chain, or similar solid object on another object. It results from the net electrostatic attraction between the particles in a solid when it is deformed so that the particles are further apart from each other than when at equilibrium, where this force is balanced by repulsion due to electron shell; as such, it is the pull exerted by a solid trying to restore its original, more compressed shape. Tension is the opposite of compression. Slackening is the reduction of tension.

RESULTS AND DISCUSSION

Physical properties

The physical properties of the ten bamboo species from different part of the culm are shown in Tables 2 and 3.

1) Feature

Among ten bamboo species, largest outer diameter of culm was that of *D. hamiltonii* followed *by D. asper, B. bambos*, *B. bluemeana, Bambusa sp., D. longispathus, D. strictus, T. oliveri*, *T. siamensis,* and *G. albociliata*.

2) Density and specific gravity

The average mean of density was found to range from 728 to 944 kg/m^3 and specific gravity from 0.65 to 0.81. *T. oliveri* and *D. longispathus* exhibited the highest and second highest density and specific gravity respectively.

3) Shrinkage

a. Core diameter shrinkage

The culm of *B. bambos* showed the highest core diameter shrinkage, while the lowest ones were found in the samples of *T. oliveri* and *T. siamensis*.

b. Thickness wall shrinkage

The highest thickness wall shrinkage was found in *G. albociliata* followed by *D. strictus*, while *B. bambos* exhibited the lowest one.

c. Culm length shrinkage

The culm *B. bambos* showed the highest culm length shrinkage and the lowest one appeared in *D. asper.*

4) Fiber saturation point (FSP)

Of five bamboo species, the highest FSP was found in *T. oliveri*, followed by *B. bambos,* while *T. siamensis* exhibited the lowest FSP.

In case of physical properties of three parts of culm of ten bamboo species, there were no differences in correlations on specific gravity and density. High specific gravity or high density means high hardness on the surface of culm, while low shrinkage indicates high stability of woods or bamboo dimension under green to dry conditions.

Mechanical properties

The mechanical properties of different parts of culms of ten bamboo species, are presented in Table 4 and Table 5.

1) Modulus of rupture (MOR)

Among ten bamboo species, the highest MOR at air dry condition was found in *B. bambos* followed by *T. siamensis*, *T. oliveri, G. albociliata*, *D. longispathus, D. hamiltonii, B. bluemeana, D. asper, D. strictus,* and *Bambusa sp.*

The results from the comparison of MOR between ten species of bamboo and RFD hardwood standard such as *Hopea odorata* Robx. were as follows.

a. Among five bamboo species, *D. hamiltonii, B. bambos, T. oliveri, T. siamensis*, and *D. longispathus* under the Project PD372/05 Rev.1 (F) and *G. albociliata* of the Project PD 56/99 Rev.1 (I), the MOR were at the same level of RFD hardwood, *i.e.* 100 MPa or higher at 12% moisture content.

b. The MOR of *D. asper, B. bluemeana, D. strictus* and *Bambusa sp.* under the Project PD 56/99 Rev.1 (I) were at the same level of those of intermediate hard wood, *i.e.* 60-100 MPa at 12% moisture content.

It can be noticed that the green bamboo culm demonstrated lower MOR than that of the air-dried culm (Table 4).

2) Stress at proportional limit

Among five bamboo species, *D. longispathus* demonstrated highest stress at proportional limit at air dry condition followed by *B. bambos, T. oliveri, T. siamensis*, and *D. hamiltonii*.

Table 5 presents the stresses at proportional limit of green and air- dried bamboo culms. It can be noticed that the green culms exhibited lower SPL as compared with that of the air-dried ones. The conditions, green or air-dried, or moisture content of the culms posed the results on MOR and SPL values.

3) Modulus of elasticity (MOE)

Of ten bamboo species, the highest MOE at air dry condition was found in *D. asper* followed by *B. bluemeana, B. bambos, G. albociliata*, *Bambusa sp., T. oliveri, D. longispathus, D. strictus, T. siamensis*, and *D. hamiltonii*. It should be kept in mind that the MOE in bamboo is generally higher than that of hardwood, but it is easy to break when applied with high load.

4) Compression

Among ten bamboo species, *D. asper* exhibited the highest compression at air dry condition followed by *Bambusa sp., B. bluemeana, D. longispathus, T. oliveri, D. strictus, T. siamensis*, *B. bambos, D. hamiltonii, and G. albociliata*.

There were no significant differences on the compression among ten bamboo species.

The results presented in Table 5 indicate that, among five bamboo species, air-dried culms exhibited higher compression than that of the green culms, except in case of *D. hamiltonii*.

5) Shear stress

a. Shearing of internodes

The highest shearing of internodes at air dry condition among ten bamboo species was found in *D. strictus.* This bamboo species also exhibited the highest shearing followed by *Bambusa sp., B. bluemeana, G. albociliata*, *D. asper, B. bambos, D. hamiltonii, D. longispathus, T. siamensis*, and *T. oliveri*.

b. Shearing of nodes

Among ten bamboo species, the highest shearing of nodes at air dry condition was found in *D. strictus,* which also exhibited the highest shearing followed by *Bambusa sp., B. bluemeana, D. asper, G. albociliata*, *B. bambos, D. hamiltonii, T. oliveri*, *D. longispathus,* and *T. siamensis*.

There were no significant differencesin the shearing of nodes and internodes among ten species. However, there were some differences in the shearing values between green and air-dried samples.

The results of the study presented in Tables 4 and 5 indicated that shearing values of green and air-dried nodes and internodes were at the same level.

6) Tension

The highest tension of nodes at air dry condition was found in *G. albociliata* which also exhibited the highest tension followed by *Bambusa sp., B. bluemeana, D. strictus, B. bambos, D. asper,* and *D. hamiltonii*.

The results of the study presented in Table 4 indicate that the tension of internodes is higher than that of the nodes, since their grain directions are of regulative arrangement.

Mechanical properties of the culm were determined by the specific gravity and by the structure such as fiber length and vascular bundle number. Nodes played a great influence on mechanical strength of the culms.

The advantage and disadvantage of tested bamboo species with reference to their properties are presented in Table 6.

As far as physical and mechanical properties are concerned, bamboos can be inferred to have potential as the construction materials depending on their length, size, shape and thickness of the culm.

CONCLUSION

There were some differences in physical and mechanical properties among ten bamboo species. However, these bamboos exhibited a good potential to be used for bamboo housing compared to some important hard wood such as *Hopea odorata.*

ACKKNOWLEDGEMENT

The authors wish to express their sincere thanks to ITTO and the Royal Forest Department for the support and contributions throughout the study under the Project PD 372/05 Rev.1 (F). Special thanks are given to the Faculty of Engineering of Kasetsart University for cooperation on laboratory works. This project was also made possible through the cooperation of RFD officers in Maehongson and Kanchanaburi Provinces and Forest Research and Development Bureau.

Table 2 Physical properties of bamboos under Project PD 56/99 Rev.1 (I).

Bamboo species	Culm part	Culm diameter (mm)	Thickness wall (mm)	Moisture content of sampling at test (%)	Specific gravity	Density (kg/m^3)	Shrinkage (%)		
							Core diameter	Thickness wall	Culm length
Dendrocalamus asper	bottom	102.10	14.80	12.00	0.67	748	4.30	4.50	0.10
	middle	97.50	10.80	11.00	0.69	773	5.40	6.50	0.00
	top	77.90	7.80	11.00	0.70	779	3.90	2.20	0.00
	Average	92.50	11.13	11.33	0.69	766.67	4.53	4.40	0.03
Bambusa blumeana	bottom	91.40	9.20	11.00	0.71	784	5.80	5.10	0.20
	middle	78.60	7.90	10.00	0.85	935	4.50	4.40	0.20
	top	55.40	6.70	11.00	0.75	837	4.20	3.80	0.00
	Average	75.13	7.93	10.67	0.77	852.00	4.83	4.43	0.13
Dendrocalamus strictus	bottom	48.30	11.70	12.00	0.72	806	5.20	7.40	0.90
	middle	45.30	7.30	11.00	0.75	843	3.60	3.20	0.30
	top	39.60	6.20	10.00	0.75	833	4.70	3.80	0.00
	Average	44.40	8.40	11.00	0.74	827.33	4.50	4.80	0.40

Table 2 (continued)

Bamboo species	Culm part	Culm diameter (mm)	Thickness wall (mm)	Moisture content of sampling at test (%)	Specific gravity	Density (kg/m^3)	Shrinkage (%)		
							Core diameter	Thickness wall	Culm length
Gigantochloa albociliata	bottom	29.30	12.40	11.00	0.62	697	6.30	5.60	0.10
	middle	28.80	8.00	11.00	0.68	750	3.50	4.20	0.20
	top	26.10	6.20	12.00	0.66	737	4.70	5.60	0.30
	Average	28.07	8.87	11.33	0.65	728.00	4.83	5.13	0.20
Bambusa sp.	bottom	59.60	12.30	12.00	0.75	848	4.10	2.90	0.10
	middle	54.00	6.60	12.00	0.73	820	3.60	4.20	0.00
	top	43.80	5.40	11.00	0.67	744	5.00	3.30	0.10
	Average	52.47	8.10	11.67	0.72	804.00	4.23	3.47	0.07

Source: Thaipetch (2004)

Table 3 Physical properties of bamboos under Project PD372/05 Rev.1 (F).

Species	Culm part	Outer diameter (mm)	Inner diameter (mm)	Thickness (mm)	FSP	Specific gravity	Density (kg/m^3)	Shrinkage (%)			
								Core diameter	Thickness wall	Culm length	Volume diameter
Dendrocalamus hamiltonii	bottom	155	121	16.8	17	0.56	608.00	2.82	0.35	4.19	8.57
	middle	120	103	8.61	18	0.74	808.00	3.91	0.09	4.46	9.38
	top	95.6	81.8	6.92	21	0.88	961.00	2.81	0.12	4.06	7.86
	Average	123.53	101.93	10.78	18.67	0.72	792.33	3.18	0.19	4.24	8.60
Bambusa bambos	bottom	86.4	61.3	12.54	18	0.74	856.00	7.61	0.14	8.45	15.70
	middle	81.7	67.2	7.25	29	0.72	799.00	7.03	0.15	7.66	14.32
	top	68.1	54.8	6.66	22	0.71	804.00	5.79	0.20	6.02	11.65
	Average	78.73	61.10	8.82	23.00	0.73	819.67	6.81	0.16	7.38	13.89
Thyrsostachys oliveri	all	42.4	19.9	11.24	24	0.81	944.00	2.12	0.22	2.37	5.38
Thyrsostachys siamensis	all	35.1	17.3	8.89	16	0.73	845.00	2.12	0.24	2.42	3.52
Dendrocalamus longispathus	all	49.9	24.4	12.74	19	0.79	935.00	2.56	0.20	2.58	5.19

Table 4 Mechanical properties of bamboos under Project PD 56/99 Rev.1 (I).

Bamboo species	Culm part	Modulus of Rupture (MOR) (MPa)	Modulus of Elasticity (MOE) (×100 MPa)	Compression (MPa)	Shearing (MPa)		Tension (MPa)	
					internode	node	internode	node
Hopea odorata Roxb*		115	117.9	51	-	-	-	
Dendrocalamus asper	bottom	92	702	66.0	9.7	11.1	385	87
	middle	59	564	70.0	10	8.4	348	101
	top	100	520	70.0	8.4	9.9	342	100
	Average	83.67	595.33	68.67	9.37	9.80	358.33	96.00
Bambusa blumeana	bottom	93	634	66.5	11.1	11.4	421	103
	middle	104	878	68.0	12.2	12.3	353	134
	top	79	221	65.0	13.5	12.7	389	123
	Average	92.00	577.67	66.50	12.27	12.13	387.67	120.00
Dendrocalamus strictus	bottom	81	191	54.5	12.8	12	394	142
	middle	78	177	57.5	15.1	13	322	124
	top	90	197	56.0	11.5	13.4	331	53
	Average	83.00	188.33	56.00	13.13	12.80	349.00	106.33

Table 4 (continued)

Bamboo species	Culm part	Modulus of Rupture (MOR) (MPa)	Modulus of Elasticity (MOE) (×100 MPa)	Compression (MPa)	Shearing (MPa)		Tension (MPa)	
					internode	node	internode	node
Gigantohloa albociliata	bottom	130	280	42.0	10.1	9.4	358	164
	middle	114	264	53.0	9.8	10.3	447	168
	top	108	381	41.0	8.9	9.2	438	199
	Average	117.33	308.33	45.33	9.60	9.63	414.33	177.00
Bambusa sp.	bottom	71	224	62.5	11.5	11.4	271	127
	middle	79	210	68.5	13.1	12.7	-	-
	top	94	257	72.5	13.6	13.6	-	-
	Average	81.33	230.33	67.83	12.73	12.57	271.00	127.00

Source: Thaipetch (2004)
* Forest Production Development Division (2005)

Table 5 Mechanical properties of bamboos under Project PD372/05 Rev.1 (F).

Bamboo species	Culm pa	Modulus of rupture (MOR) (MPa)		Stress at proportional limit (MPa)		Modulus of elasticity (MOE) (x100 MPa)	
		green	air dry	green	air dry	green	air dry
*Hopea odorata**	-	-	115.0	-	-	-	117.90
Dendrocalamus hamiltonii	bottom	85.3	104	38.4	53.4	58.5	86.3
	middle	73.6	99.8	46.3	44	143	114
	top	85.3	113	53.9	46.9	146	223
	Average	81.40	105.60	46.20	48.10	115.83	141.10
Bambusa bambos	bottom	116	156	37.9	83.1	347	301
	middle	131	162	47.6	69.7	353	326
	top	182	175	98.4	91.8	371	370
	Average	143.0	164.3	61.3	81.5	357.0	332.3
Thyrsostachys oliveri	all	106	120	75.5	81.3	161	197
Thyrsostachys siamensis	all	130	131	69	75.9	206	177
Dendrocalamus longispathus	all	117	117	74.4	84.1	253	190

Source: * Forest Production Development Division (2005)

Table 5 (continued)

Bamboo species	Culm part	Compression (MPa)		Shearing (MPa)				Tension (MPa)	
		internode		internode		node		node	
		green	air dry	green	air dry	green	air dry	green	air dry
Dendrocalamus hamiltonii	bottom	42	31.1	6.19	5.96	4.73	4.94	58	96.3
	middle	46.8	50.9	7.47	8.52	7.51	8.36	52.7	75.7
	top	63.7	58.2	8.89	8.91	9.39	8.18	65.4	76.2
	Average	50.83	46.73	7.52	7.80	7.21	7.16	58.70	82.73
Bambusa bambos	bottom	40.6	49	6.42	8.69	5.93	8.28	142	103
	middle	51.7	56.3	6.37	9.85	6.31	8.79	117	103
	top	44.5	57.4	6.29	8.9	6.99	9.59	135	98.4
	Average	45.60	54.23	6.36	9.15	6.41	8.89	131.33	101.47
Thyrsostachys oliveri	all	49.7	57	3.77	4.3	5.18	7.03	*	*
Thyrsostachys siamensis	all	41.6	54.3	4.62	5.16	6.28	4.79	*	*
Dendrocalamus longispathus	all	50.3	57.8	4.09	7.16	4.72	6.94	*	*

Table 6 Advantages and disadvantages of bamboos by their properties.

Species	Advantage	Disadvantage
Pai Hok (*Dendrocalamus hamiltonii* Nees et Arn. Ex. Munro)	• very large culm size • straight culm shape • high mechanical properties	• rather high shrinkage • only limited distribution to the natural forest in mountainous area • not commonly planted
Pai Pa (*Bambusa bambos* (L) Voss)	• large culm size • very high mechanical properties	• very high shrinkage • mainly distribution to the natural forest • not commonly planted • many branches and thorns in the culm
Pai Ruak Dam (*Thyrsostachys oliveri* Gamble)	• high mechanical properties • low shrinkage • has been planted though out the country	• small culm size
Pai Ruak (*Thyrsostachys siamensis* Gamble)	• as same as *T. oliveri*	• small culm size
Pai Lammalok (*Dendrocalamus longispathus* Kurz)	• high mechanical properties • low shrinkage	• medium to large culm size • mainly distribution to the natural forest
Pai Liang (*Bambusa sp.*)	• high mechanical properties • has been planted though out the country	• medium to large culm size • rather high shrinkage
Pai See Suk (*Bambusa blumeana* Schultes)	• large culm size • high mechanical properties • has been planted though out the country	• high shrinkage • many branches and thorns in the culm

Table 6 (continued)

Species	Advantage	Disadvantage
Pai Tong (*Dendrocalamus asper* Backer)	• large culm size • has been planted though out the country • high mechanical properties	• high shrinkage • rough grain
Pai Sang (*Dendrocalamus strictus* Nees)	• high mechanical properties as same as *D. asper*	• high shrinkage • small culm size • mainly distribution to the central and north region
Pai Rai (*Gigantochloa albacilliata* Munro)	• high tension tolerance and high flexibility • has been planted though out the country	• small culm size

REFERENCES

Boonkerd, S. 1985. **Some Bamboo Species in Thailand.** Technical report. Faculty of Forestry, Kasetsart University.198 pp.

Chuenwarin, W. 1977.**Physical Properties of Three Thai Bamboos.** Forest Research. Bulletin No. 48, Faculty of Forestry, Kasetsart University

Forest Product Development Division, 2005. **The Thai Hardwood.** Forest Research Bureau, Royal Forest Department.111 p.

Janssen, J.J.A. 2000.**An International Model Building Code for Bamboo**. INBAR

Limaye, V.D. 1952. **Strength of Bamboo**. Indian Forester, vol 78 No.1 (1952) pp.558 – 575

Pattanavibool R., Phuriyakorn B., and Sathitvibool W., 2002.**Bamboo in Thailand.** Forest Research Bureau, Royal Forest Department.120 p.

Sekhar A.C., B.S. Rawat and R.K. Bhatari, 1962.**Strength of Bamboos: Bambusanatans,** Indian Forester, vol. 88 No. 1. pp. 67-73

Thaipetch, S. 2004. **Physical and Mechanical Properties of Five Bamboo Species in Thailand**, *In*: Final Technical Report, Project: PD 56/99 Rev.1(I) Promotion of the Utilization of Bamboo from Sustainable Sources in Thailand, Royal Forest Department and International Tropical Timber Organization. pp. 41-45.

AKSORNSIAM PRINTING 16 Bangwak 2 Junction 4, Charunsanitwong13, Pasicharoen, Bangkok 10160

Tel. 0-2410-7813, 0-2410-8795-6 E-mail : aksornsiam@yahoo.co.th