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TREATABILITY AND PENETRATION INDICES OF FOUR LESSER-USED MYANMAR HARDWOODS

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ABSTRACT

Depletion of Myanmar's top commercial timbers has grown the attention towards lesser-used timbers, which present low durability and require protection against biodegradation. This research tested the treatability of four nondurable Myanmar hardwoods: *Bombax ceiba, Bombax insigne, Spondias pinnata* and *Tetrameles nudiflora*. Conditioned heartwood samples were pressure-treated according to standard schedules using a staining solution. Solution uptake, penetration depths, and percent of each cell type penetrated were determined and discussed according to wood anatomical characteristics. *B. ceiba, B. insigne* and *S. pinnata* had high uptakes and good penetration making them promising for protective treatment. *T. nudiflora* was also classified as easy to treat based on its penetration index but as generally difficult to treat according to retention and depth of penetration. This different behavior was attributed to the tyloses occluding its vessels. The results are useful for the development of specific treatment schedules to achieve the retentions and penetration required for the effective protection of these lesser-used hardwoods.

KEYWORDS: Treatability, solution uptake, penetration indices, anatomical characteristics, lesser-used hardwoods.

INTRODUCTION

Myanmar has an extensive forest area of 32 million hectares, which occupies 49 % of the total country area (FAO 2007). Among the many timber species, harvesting has been concentrated only on about 40 species, which has resulted in a decline in their growing stock. On the other hand, the harvesting volume has increased yearly due to the rising demand (Forest Department 2000). These situations have led to the introduction of lesser-used timber species to the market. However, some of these lesser-used timber species are of lower quality and less resistant to biodeterioration when compared to the traditional ones. Extra protection is needed to improve their dimensional stability and durability, especially for outdoor uses.

Solution uptake/gross retention and penetration depth are taken as criteria of effectiveness of impregnation in most studies and standards. However, retention does not represent the penetration of different cell types and ignores micro-distribution aspect (Kumar et al. 1990). The treating solution can be concentrated in certain areas and thus, treatability of timber species determined from these two parameters can be misleading (Kumar and Dobriyal 1993). Inadequately penetrated wood may be subjected to an early failure as untreated areas are potentially susceptible to the effects of wood destroying organisms (Jayanetti 1986). Therefore, distribution should also be used as an indicator of efficacy of treatment. Penetration index determined from the penetration degree of each cell type is more reliable to estimate the treatability because it represents distribution of the solution within wood tissues (Kumar et al. 1990).

No previous research has been done on the treatability of lesser-used timber species growing in Myanmar. However, the utilization potential of these lesser-used species is dependent, among others, on their treatability. Increasing the value of such underutilized species will give forest managers more flexibility to manage forest resources as well as to preserve the commercial timber species (Lebow et al. 2005). This study reports on the treatability and penetration indices of four lesser-used and non-durable hardwood species of Myanmar. The wood anatomical characteristics of each species were studied and their effect on treatability discussed.

MATERIAL AND METHODS

The lesser-used species studied were *Bombax ceiba, Bombax insigne, Spondias pinnata* and *Tetrameles nudiflora*. They are large to very large deciduous trees growing in natural forests, with straight, cylindrical boles. They all produce white to yellowish brown wood. In all species, sapwood cannot be clearly differentiated from heartwood. All are straight-grained except *T. nudiflora*, which possesses interlocked-grained wood in broad bands. They are non-durable and have low commercial value with uses as packaging, boxes, coffins, etc. (Chudnoff 1984).

Air-dried wood planks from the heartwood of all species with dimensions 100 x 50 x 750 mm (radial x tangential x longitudinal) were conditioned at 65 % RH and 20 °C for two weeks and used as material for the preparation of specimens.

Wood anatomy and density

For the description of wood anatomy of the species, microscopic slides were prepared in accordance with the usual methods of softening, sectioning, staining and mounting, and observed under a light microscope. Special attention was given to the presence of tyloses and deposits. The dimensions of wood anatomical characteristics were reviewed from the literature.

Air-dry density was measured after conditioning small orthogonal specimens of each species at 65 % RH and 20 °C for two weeks. The air-dry volume was determined by measuring the dimensions of specimens.

Lateral and longitudinal penetration

Twenty sound and straight-grained specimens per species of size 40 x 40 x 40 mm were prepared and used for a lateral penetration test. A longitudinal penetration test was carried out with specimens of two sizes: 20 x 20 x 200 mm (twenty specimens per species) and 40 x 40 x 400 mm (ten specimens per species). The specimens for the lateral penetration test were sealed with oilborne epoxy on end surfaces. In the small-sized specimens for the longitudinal test, five surfaces (two radial, two tangential and one end) were sealed with the epoxy. In the large-sized specimens, only one end surface was sealed to observe differences in solution uptake, penetration depth and flow pattern of the solution from small-sized specimens. Three to five layers of the epoxy were applied to all specimens depending on the absorbing ability of species. To ensure that the coating material is well dried and stabilized, the specimens were air-dried for 24 hours after each coating. The specimens were weighed before impregnation.

For impregnation, a full cell process was applied in accordance with CEN/TC 38/WC 26 but for a shorter duration, with the process parameters of 50 mbar held for 45 minutes (vacuum) and of 8 bars for 90 minutes (pressure). For a better traceability, a brilliant blue Ramazol 1 % solution was employed as a staining agent. After impregnation, the specimens were removed from the solution, wiped with paper to remove excess solution from the surfaces and weighed to calculate the solution uptake. Specimens were then conditioned at 65 % RH and 20 °C for two weeks. Lateral penetration test specimens were cut cross-wise and longitudinal penetration test specimens were cut length-wise in the middle to expose a fresh cross section. The fresh exposed surfaces were scanned with an Epson Expression 10000 XL scanner, and penetration depth and penetrated area were determined from the scanned photos with the help of ImageJ software.

Penetration indices and treatability

Six specimens of 10 x 10 x 10 mm were prepared for each species, conditioned at 65 % RH and 20 °C for two weeks and vacuum-impregnated with 5 % Ramazol solution for 120 minutes under 26 mbar. The impregnated blocks were sectioned in their transverse, tangential and radial planes at 20-40 μm thickness using a sliding microtome. The sections were temporarily mounted in glycerol and examined under a light microscope. Each section was observed at five random locations and the degree of penetration (P) of each cell type was determined in percentage. More than 60 % penetration of cells represents 3, 30-60 % represents 2, 10-30 % represents 1, and less than 10 % represents 0 (Kumar and Dobriyal 1993). A weight factor (W) of each cell was assigned according to their ease of treatability and their importance as structural members: vessels = 3, fibres = 3, rays = 2 and parenchyma =1. Penetration index (PI) for each species was calculated as follows (Kumar and Dobriyal 1993):

$$PI = \sum_{i=1}^{4} WiPi \,/27$$

where: PI = penetration index, W = weight factor (1-3) and P = degree of penetration (0-3).

A treatability class was assigned for each species according to their penetration indices (Kumar and Dobriyal 1993). The treatability of the species was also evaluated according to three standards (BS EN 350-2, CEN/TC 38/WG 26, BS EN 351-1) and two methods proposed by Rapp and Peek (1994) and by Kakaras and Philippou (1996). Their classification was based on the results from the lateral and longitudinal penetration tests.

RESULTS AND DISCUSSION

Wood characteristics

As shown in Tab. 1, the species studied are low to very low in weight. According to the classification system proposed by Negi (1997), *B. ceiba, S. pinnata* and *T. nudiflora* were classed into the "very light" group and *B. insigne* into the "light" group.

Tab. 1: Equilibrium moisture content (EMC), air-dry density and weight class of the four Myanmar hardwoods[1]

Species	Number of specimens	EMC2	Air-dry density[2]	Weight class[3]
Bombax ceiba	20	11.2 (0.4)	0.27 (0.02)	Very light
Bombax insigne	20	11.6 (0.2)	0.50 (0.02)	Light
Spondias pinnata	20	11.4 (0.2)	0.32 (0.01)	Very light
Tetrameles nudiflora	20	12.1 (0.2)	0.31 (0.01)	Very light

[1] mean values and standard deviations in parenthesis
[2] at 65 % RH and 20 °C
[3] according to Negi (1997)

Information on the wood anatomy of the species is given in Tab. 2 and Fig. 1. *B. ceiba* has vessels with the widest diameter and the shortest length. The number of vessels per square millimeter is the highest in *S. pinnata* while no major differences exist among the other species. Weak tyloses are present in all species, with greater abundance in *T. nudiflora*. The shortest fibres were found in *T. nudiflora*. Fibre pits are numerous in *S. pinnata* and *T. nudiflora*, while sparsely distributed in *B. ceiba* and *B. insigne*. Fibre tracheids exist only in *S. pinnata* and have numerous pits on the walls. Axial parenchyma with plentiful starch grains comprises an appreciable volume of wood in *B. ceiba* and *B. insigne*. The size and amount of parenchyma is much smaller in *S. pinnata* and *T. nudiblora*. Rays are relatively conspicuous, 1-6 seriate and heterogeneous in *T. nudiflora* while visible to naked eyes, 1-7 seriate and heterogeneous occasionally with horizontal gum canals in *S. pinnata*. They are very large and plainly visible to the naked eyes, 1-7 seriate and heterogeneous in *B. ceiba* and *B. insigne*.

Tab. 2: Dimensions of wood anatomical characteristics of the four Myanmar hardwoods[1]

Species	Vessel members, mm		Vessels, number per (mm^2)	Fibre length (µm)	Fibre wall thickness (µm)	Diameter of axial parenchyma cells (µm)	Rays (µm)	
	L	D					W	H
B. ceiba	390	390	0-9	2.200*	4	90	135	3.900
B. insigne	490	330	0-7	2.060*	4	60	235	3.500
S. pinnata	525	315	4-17	950	3	30	100	1.485
T. nudiflora	1.100	260	2-9	420	3	40	86	875

[1] taken from Pearson and Brown (1932) except for data marked with * taken from Mohiuddin (1990)
L: length, D: diameter, W: width, H: height

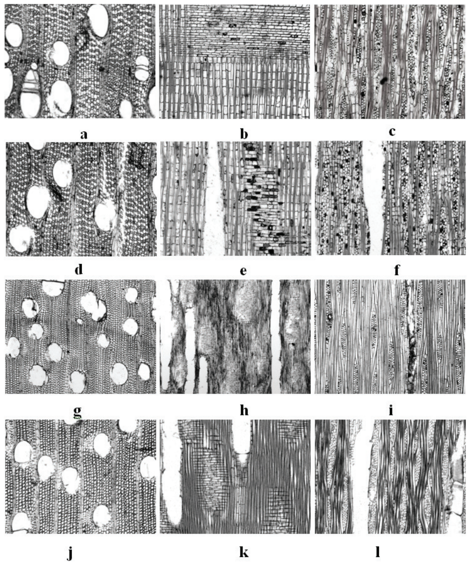

Fig. 1: Tranverse, radial and tangential view of B. ceiba (a-c), B. insigne (d-f), S. pinnata (g-i) and T. nudiflora (j-l). Micrographs were taken at 40x magnification

Solution uptake

The solution uptake calculated from the lateral and longitudinal penetration tests varies greatly among the species (Tab. 3). B. ceiba absorbs the highest amount of solution in both lateral and longitudinal tests, while *T. nudiflora* absorbs the smallest amount of solution. In *B. ceiba*, the enhanced solution flow can be attributed to the wide vessels, very large and wide rays, great quantity of large diameter axial parenchyma cells and to the numerous and slit-like intervessel pits. The greater presence of weak tyloses contributed in the lowest solution uptake in *T. nudiflora*. *B. insigne* absorbs higher amount of solution than *S. pinnata* in lateral penetration test, and this could be attributed to its numerous slit-like intervessel pits, very large vessel-parenchyma pits, and ray-vessel pits with wide mouth and narrow border. Gum canals and infiltration and deposits in rays of *S. pinnata* might be responsible for the lower solution uptake in the lateral penetration test. On the other hand, *S. pinnata* absorbs more solution in the longitudinal direction probably due to the presence of fibre tracheids, which simulate vessels and are better adapted for conduction (Côte 1963).

Tab. 3: Solution uptake (mean values and standard deviations in parenthesis) in lateral and longitudinal penetration tests of the four Myanmar hardwoods

Species	Solution uptake ($kg.m^{-3}$)		
	Lateral penetration test	Longitudinal penetration test	
		Small-sized specimens	Large-sized specimens
Bombax ceiba	848 (5)	756 (10)	790 (24)
Bombax insigne	484 (57)	604 (57)	611 (18)
Spondias pinnata	394 (22)	749 (38)	787 (3)
Tetrameles nudiflora	136 (26)	354 (113)	358 (98)

Lateral penetration depth and penetrated area

As shown in Tab. 4, the highest penetration depths were observed in B. *ceiba* (> 20 mm in radial and tangential direction), they were almost the same in *B. insigne* and *S. pinnata* and very low in *T. nudiflora*. As lateral transport of fluids is accomplished mainly through the radially oriented ray cells, the differences in the relative dimensions of rays (Tab. 2) played a major role. *B. insigne* and *S. pinnata* presented noticeable differences between the two different directions (radial, tangential), indicating the relative importance of ray cells to the treatability in these timbers. The ratio of radial to tangential permeability was 1.3 in *B. insigne* and 2.0 in *S. pinnata*. A typical star-shaped pattern of impregnation in the cross section was observed in these two species as a result of fairly rapid radial penetration along the rays. Species with highest solution uptake were found to have the highest penetrated area and penetration depths.

Tab. 4: Penetration depth and penetrated area as determined by the laterapenetration test in the four Myanmar hardwoods (mean values and standard deviations in parenthesis)

Species	Lateral penetration depth (mm)							Penetrated area (%)
	Average			Minimum		Maximum		
	R	T	R/T	R	T	R	T	
Bombax ceiba	>20 (0)	>20 (0)	1.0	>20 (0)	>20 (0)	>20 (0)	>20 (0)	100 (0)
Bombax insigne	12 (2)	9 (2)	1.3	8 (3)	6 (2)	16 (2)	11 (2)	80 (9)
Spondias pinnata	12 (1)	6 (1)	2.0	8 (3)	5 (2)	15 (8)	8 (1)	74 (3)
Tetrameles nudiflora	2 (1)	3 (1)	0.7	1 (0)	1 (1)	5 (2)	6 (2)	26 (6)

R: radial direction, T: tangential direction

Longitudinal penetration depth

B. ceiba and *S. pinnata* were completely penetrated in both longitudinal penetration tests (Tab. 5). Although *B. insigne* was completely penetrated in the large-sized specimens test, it was not in the small-sized. Since the lateral surfaces (radial, tangential) of small-sized surfaces were sealed but they were not in the case of large-sized specimens, this difference highlights the relatively significant role of lateral penetration in this species, which has relatively high volume of broad ray cells (Tab. 2) and numerous slit-like intervessel and vessel-parenchyma pits. *T. nudiflora* presented a noticeable difference and was found more resistant to solution flow than the other species due to the weak tyloses occluded in vessels. Maturbongs and Schneider (1996) also reported the resistance of this species to impregnation.

Tab. 5: Penetration depth as determined by the longitudinal penetration test in the four Myanmar hardwoods (mean values and standard deviations in parenthesis)

Species	Longitudinal penetration depth (mm)					
	Small-sized specimens			Large-sized specimen		
	D100	D50	D0	D100	D50	D0
Bombax ceiba	>200 (0)	>200 (0)	>200 (0)	>400 (0)	>400 (0)	>400 (0)
Bombax insigne	163 (29)	186 (19)	>200 (0)	>400 (0)	>400 (0)	>400 (0)
Spondias pinnata	>200 (0)	>200 (0)	>200 (0)	>400 (0)	>400 (0)	>400 (0)
Tetrameles nudiflora	123 (48)	157 (49)	>200 (0)	359 (62)	398 (18)	>400 (0)

D100: minimum depth (distance from the unsealed end of specimen where solution entered to the point to which the area was completely penetrated), D50: average depth (distance to the point where half of the area was penetrated), D0: maximum depth (distance to the point beyond which no penetration occurred)

Penetration indices

All cell types were almost completely penetrated in *B. ceiba*, *B. insigne* and *S. pinnata*, thus their treatability indices were 1.0 (Tab. 6). The lower penetration index of *T. nudiflora* (0.70) compared to the other species was mainly due to the lower degree of penetration of most of the cell types. The primary flow routes, vessels, were not well penetrated because of the presence of tyloses and this was the reason of the very low penetration of fibres despite the abundant fibre-fibre pitting in *T. nudiflora.* Poor penetration of rays in this species also leads to the same conclusion, as the rays were free from any deposits but well-connected to the vessels. The lower penetration of rays explains the lower lateral penetration of the species (Tab. 4) while the lower longitudinal penetration (Tab. 5) can be attributed to the lower penetration of fibres and to the greater presence of weak tyloses. Accordingly, solution uptake was the lowest in this species (Tab. 3).

Tab. 6: Penetration indices of the four Myanmar hardwoods[1]

Species	Cell type	Degree of penetration[2]	Penetration factor	Penetration index
Bombax ceiba	Vessels	+++	3*3 = 9	1.0
	Fibres	+++	3*3 = 9	
	Rays	+++	2*3 = 6	
	Parenchyma	+++	1*3 = 3	
Bombax insigne	Vessels	+++	3*3 = 9	1.0
	Fibres	+++	3*3 = 9	
	Rays	+++	2*3 = 6	
	Parenchyma	+++	1*3 = 3	
Spondias pinnata	Vessels	+++	3*3 = 9	1.0
	Fibres	+++	3*3 = 9	
	Rays	+++	2*3 = 6	
	Parenchyma	+++	1*3 = 3	
Tetrameles nudiflora	Vessels	++	3*2 = 6	0.70
	Fibres	++	3*2 = 6	
	Rays	++	2*2 = 4	
	Parenchyma	+++	1*3 = 3	

[1] according to Kumar and Dobriyal (1993)

[2] +++: more than 60 % penetration of cells, ++: 30-60 % penetration of cells

Classification of treatability

The classification of treatability refers to two approaches: according to penetration indices and according to penetration depth/solution uptake (Tab. 7).

The classification according to penetration indices (Kumar and Dobriyal 1993) consists of four groups: “a” (easily treatable if penetration index > 0.66) to “d” (refractory to treat if penetration index < 0.1). All species were classified into group “a” (Tab. 7).

According to BS EN 350-2 standard, *B. ceiba* was grouped into treatability class 1 (easy to treat) because it was completely penetrated. *B. insigne* and *S. pinnata* were grouped into class 2 (moderately easy to treat) because lateral penetration was more than 6 mm. *T. nudiflora* was grouped into class 4 (extremely difficult to treat) as it absorbed little solution and the lateral penetration was less than 3 mm. In fact, the BS EN 350-2 classification system has many disadvantages, the impregnation parameters (vacuum, pressure, time) are not mentioned, the size of specimens is not clearly defined and it does not recognize the longitudinal penetration depth.

Tab. 7: Classification of treatability of the four Myanmar hardwoods

Species	Classification system					
	Penetration indices	Penetration depth/area and retention				
	Kumar and Dobriyal (1993)	BS EN 350-2	CEN/TC 38/WG 26	BS EN 351-1	Rapp and Peek (1994)*	Kakaras and Philippou (1996)
B. ceiba	a	1	1	P9	>35	1
B. insigne	a	2	2*	P9	25	3
S. pinnata	a	2	2*	P9	24	3
T. nudiflora	a	4	4	P1	15	5

* penetration indices calculated by the formula (t50 + r50)/2 + (DA100) x 0.05, where t50 is the average tangential penetration depth, and r50 the average radial penetration depth. DA100 was obtained by averaging the two D100s determined from small-sized and large-sized specimens (see Tab. 5). The larger the penetration index, the more easily treatable the species is

In accordance with CEN/TC 38/WG 26 classification system, *B. ceiba* was grouped into class 1 (easy to treat). *B. insigne* and *S. pinnata* were grouped into class 2* (easier to treat than those in class 2 but not as easy as those in class 1), because they were penetrated more than 6 mm laterally and more than 300 mm longitudinally. *T. nudiflora* was grouped into class 4 (extremely difficult to treat) as the minimum lateral penetration is less than 1 mm. Although the two systems, BS EN 350-2 and CEN/TC 38/WG 26, differ in the classification of treatability, they both use average lateral penetration in common and the class boundaries are also the same, resulting in almost the same classification of the species studied.

BS EN 351-1 standard classifies the penetration depth into 9 groups from P1 to P9 and specifies a required penetration depth for each group. The minimum requirement for class P9 is complete penetration of sapwood and 6 mm penetration of heartwood. *B. ceiba*, *B. insigne* and *S. pinnata* met this requirement for heartwood while *T. nudiflora* failed. *T. nudiflora* was grouped into class P1 because it was penetrated less than 3 mm laterally.

According to the method developed by Rapp and Peek (1994), *B. ceiba* was the most easily treatable (with a penetration index of > 35), followed by *B. insigne* (25), *S. pinnata* (24) and *T. nudiflora* (15).

Following the classification by Kakaras and Philippou (1996), *B. ceiba* was grouped into class 1 (very permeable), *B. insigne* and *S. pinnata* into class 3 (moderately permeable) and *T. nudiflora* into class 5 (very resistant).

It should be noted that the results of classification according to the penetration indices were in agreement with the other classification systems based on penetration depths/area and retention for all species except *T. nudiflora*. *T. nudiflora* was classified as easy to treat based on its penetration index but as generally difficult to treat according to the other systems. A high penetration index with low penetration of vessels, fibres and rays (Tab. 6) seems to overstate the treatability of *T. nudiflora*. Such a feature of good treatability of wood with poor penetration of important cell types might be a potential shortcoming of using this classification alone (Maturbongs and Schneider 1996). On the other hand, the treatability of this very light species can possibly be improved by blowing out the weak tyloses with the use of high pressure or prolonged pressure periods or both.

CONLUSIONS

The study reported on the treatability of lesser-used and less durable hardwood species of Myanmar as it is affected by their wood anatomical characteristics. *B. ceiba*, *B. insigne* and *S. pinnata* were classified as easily treated according to the most commonly used standards and methods and, therefore, appear promising for protective treatment. *T. nudiflora* proved difficult to treat due to the greater presence of tyloses which block the vessels and control the fluid flow to the other structural components. Application of treatment schedules based on the penetration index of this very light species might be needed to ensure adequate levels of protective treatment. The overall results can be used for establishing treatment practices of commercial-sized lumber.

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