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Laboratory test for grouping tropical species for kiln drying

A. de Souza Mendes, W. T. Simpson, S. P. Verrill

Summary A system was developed for grouping tropical wood species for kiln drying based on similar estimated drying times. Six tropical species were subjected to drying and water soaking tests; variables were test temperature and specimen thickness. Soaking time, specimen thickness, and test temperature were used in an empirical model to predict drying times. The capability of the model to predict drying times was considered acceptable based on an adjusted coefficient of determination equal to 0.929 and an average error of 14 percent. The overall capability of the method proposed for grouping tropical hardwoods for drying is considered promising and worthy of further investigation.

Introduction

Deforestation in the tropics, especially in the Amazonian region, has become a worldwide concern. The tropical forests of the world cover about 1.2 billion hectares, and more than 17 million hectares are destroyed every year (Reis 1990). Slash and burn agriculture and fuelwood account for 65 percent of tropical forest destruction (Lindell 1991). Increasing the economic value of the hundreds of species in the Amazonian forest could create an incentive for sustainable forest management. Improved drying can contribute to this goal by making lesser-used species more suitable for industrial processing.

Industrial wood drying presently requires a large amount of wood of the same species to be practical. The heterogeneity of the Amazonian forest makes it almost impossible to continuously supply the amount of wood required for kiln drying with just one species. Use of such a heterogeneous wood supply requires a grouping system by which different species can be dried at the same time under the same drying schedule.

The objective of this research was to develop a laboratory test for grouping tropical hardwoods for drying, based on similar drying times.

Background

Considerable attention has recently been given to the drying characteristics of tropical timbers. Many kiln schedules have been developed for tropical wood species (IBDF/DPq-LPF 1988, Longwood 1961). Nevertheless, little information is available on kiln drying of mixed tropical hardwood species (Simpson and Baah 1989).

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A. de Souza Mendes
Instituto National de Pesquisas de Amazonia Manaus, Brazil

W. T. Simpson, S. P. Verrill
Forest Products Laboratory, USDA Forest Service, Madison, Wisconsin

Table 1. Test species

Common and scientific names	Species code	Number of trees	Samples per tree	Specific gravity[a]
Angelin amargo (*Enterolobium* sp.)	AG	5	2	0.73
Cedro (*Cedrella odorata*)	CN	5	2	0.40
Cedrorana (*Cedrelinga catenaiformis*)	CED	5	2	0.47
Cerejeira (*Amburana guianensis*)	CE	4	2	0.48
Copaibarana	CO	5	2	0.50
Peroba d'agua (*Aspidosperma* sp.)	PE	5	2	0.56

[a] Average basic specific gravity

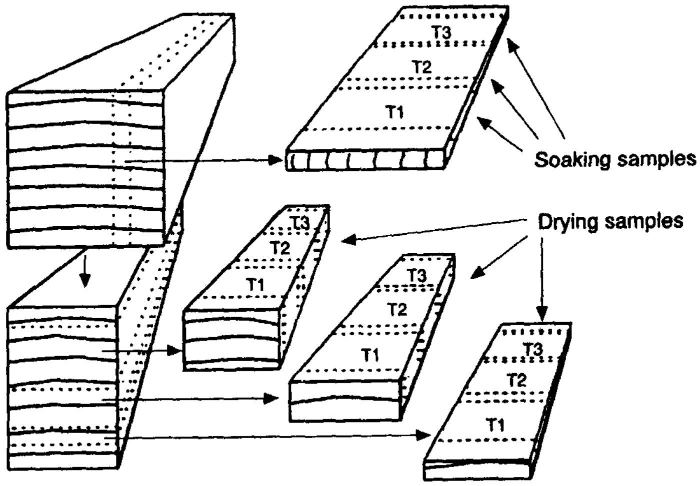

Fig. 1. Samples for drying and soaking tests. T_1, T_2, and T_3 are test temperature levels

Many studies on drying mixtures of species have been based on prior knowledge of the drying properties of the different species in the mixture, including initial and final moisture content, kiln drying temperature and time, and drying defects (Bello 1966, Keenan and Tejada 1984, Ma 1975). This approach is limited because it cannot be applied to species for which there is no information on drying properties. Other attempts to group species have been based on mathematical or statistical models that establish correlations between drying time and properties such as density, initial moisture content, temperature, relative humidity, and shrinkage (Ali and others 1968, Hisada and Sato 1980, Simpson and Baah 1989, Simpson and Sagoe 1991).

Mathematical and numerical models were successfully developed for adsorption and resorption of liquid water (Mounji and others 1991, Kouali and Vergnaud 1991).

However, there is no information in the literature on the correlation between drying time and uptake time of liquid water into wood. For the hydroscopic range of wood, a reasonable hypothesis is that every barrier to water flow, such as extratives, tyloses, and wood anisotropic properties, affects both absorption and desorption. Therefore, the time required for water to migrate from one position to another in drying may correlate with the time required for liquid water to migrate the same distance in absorption.

The main objective of this study was to develop a laboratory test based on a correlation between the absorption time of liquid water and drying time that will allow the grouping of tropical species for drying. To implement this method, we gathered the following information: (1) absorption time of liquid water into six tropical hardwood species, (2) drying time at the same conditions as absorption, (3) appropriate statistical analysis that correlates drying time with absorption time and other relevant variables such as drying temperature, initial moisture content, thickness, and specific gravity, and (4) grouping criteria that allow different wood species to be dried with the same drying schedule. The advantage of the proposed method compared to direct drying tests is that it does not depend on the availability of fresh, green wood to estimate drying times.

The grouping criteria based on similar estimated drying times do not address susceptibility to drying defects such as collapse, surface checking, honeycomb, or warp. However, these defects are difficult to describe in a way that can be included in a quantitative grouping system. In the absence of any specific information on drying characteristics, estimated drying times provide a good first estimate to group species for drying by a conservative kiln schedule.

Materials and methods

The classification process involved five steps: sampling, electric moisture meter calibration, drying tests, liquid water soaking tests, and development of a grouping system.

Sampling

Materials were collected according to the direct random sampling system (Bendtsen and others 1970, Noack 1970, COP ANT 1972). Six species were selected with basic specific gravity ranging from 0.44 to 0.78 (Table 1). An 8- by 8-cm cross-section of heartwood was taken from each selected trunk along its length; a 34-cm-long section was cut from this cross-section. The sections were marked, wrapped in plastic bags, and kept at 2°C until use. Samples from each 8- by 8-cm piece were prepared for soaking and drying tests, as shown in Fig. 1. Samples for the soaking test were oriented radially along their length; samples for the drying test were flat sawn.

Soaking test

For the soaking test, specimens (0.5 by 5 cm in cross-section) with an initial moisture content of 10 percent were inserted in a reservoir such that one end of the specimen touched the water level (Fig. 2). The moisture flow was oriented in the radial direction. The water reservoir held 10 specimens at a time. It was equipped with a device that kept a constant water level in the tray, with a maximum variation of 1.5 mm. The outer surfaces of the specimens, except for the ends, were waterproofed. Surfaces were sealed with a double coating of aluminum paint, followed by one coat of epoxy polymer and a final layer of silicon rubber. One electrode was inserted in each side of the specimen, 1 cm from the bottom (Fig. 3). The distance between the electrode tips was 2.5 cm. Moisture content readings were taken every day with a moisture meter, using a wood clamp to ensure electrical contact (Fig. 4).

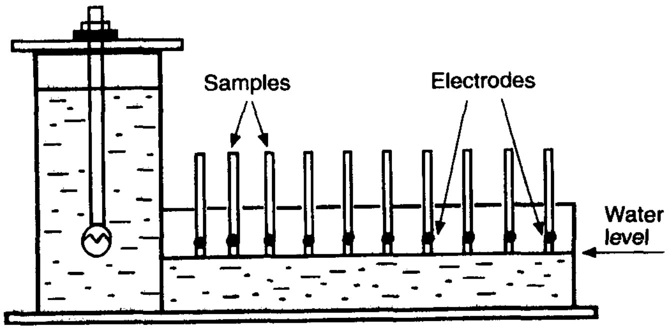

Fig. 2. Soaking test device

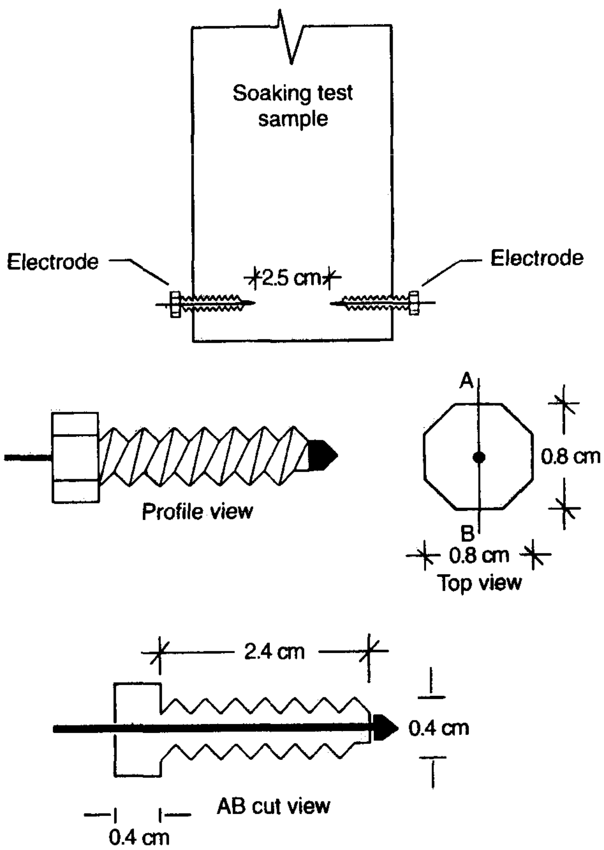

Fig. 3. Electrode design and placement for soaking test

Soaking time was determined as approximate time required for a specimen to adsorb from 10 percent moisture content to 90 percent of its equilibrium moisture content. The test was performed at three temperatures: 27°C, 40°C, and 60°C. One specimen per tree, per temperature level, and per species was used.

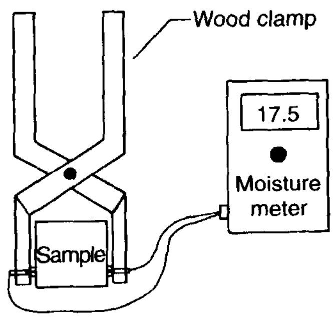

Fig. 4. Method used to take moisture content readings

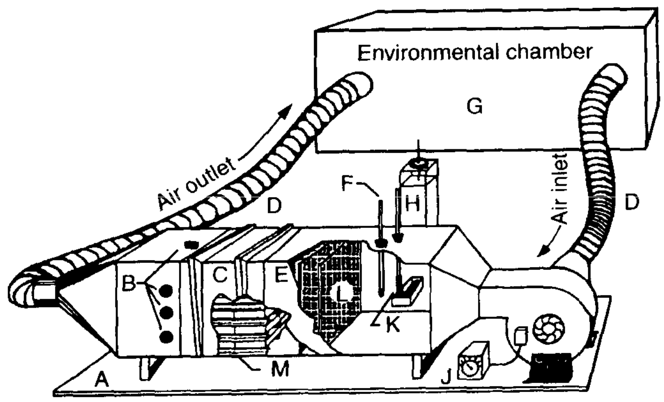

Fig. 5. Kiln test dryer. A, base; B, rubber stoppers; C, door; D, flexible pipes; E, plywood duct; F, dry-bulb thermometer; G, environmental chamber; H, water reservoir; I, fan; J, speed controller; K, wet-bulb thermometer L, perforated plates; and M, load

Drying test

Drying rates of the six species were determined through a test conducted at 10 percent equilibrium moisture content and three temperatures (27°C, 40°C, and 60°C), using specimens of varying thickness (0.5, 1.0, and 2.0 cm). Air velocity was 1.6 m/s. Green wood specimens were end- and edge-coated with epoxy polymer to restrict drying to the radial direction. One sample per tree was used for each temperature level and thickness (Fig. 1). The kiln test dryer is shown in Fig. 5.

Drying was monitored by weighing each specimen every few hours initially, and then weighing at longer time intervals. Results were analyzed by plotting the moisture content-time curves for each thickness and temperature. The following empirical equation was used to fit each set of drying curves, using the least squares method:

$$W = a + b\exp(-kt) \tag{1}$$

where W is moisture content (percent) at time t (h), and a, b, and k are coefficients determined by the least squares method.

For this study, drying time was defined as the time required for a specimen to dry from 30 percent moisture content to a moisture content within 10 percent of its equilibrium value; that is, the time for 90 percent of the total possible drying to occur. This drying time refers to a change in moisture content approximately within the hydroscopic range of wood. This condition was pre-established because we

Table 2. Coefficients of Eq. (3) for predicting drying time from soaking time, specimen thickness, and drying temperature

Temperature (°C)	ln A	B	C	D
27	31.6	0.828	1.60	5.63
40	31.9	0.935	1.60	5.63
60	33.4	0.756	1.60	5.63

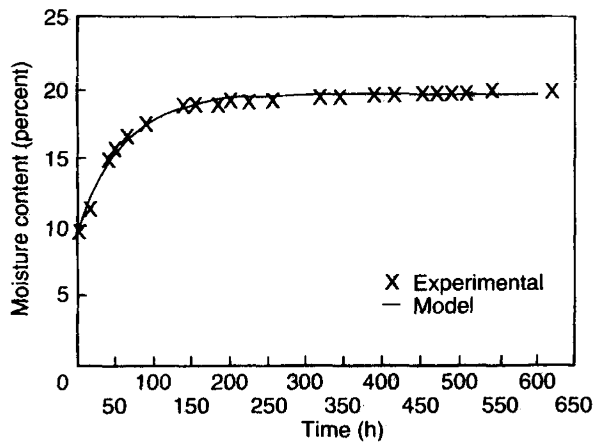

Fig. *6*. Experimental data for soaking test for species PE (Peroba d'agua) at 27°C fitted by Eq. (1)

hypothesized that the moisture movement in the soaking test is controlled by diffusion rather than by capillary flow.

As a general rule, drying time increases with specific gravity (Tschernitz and Simpson 1977). However, a comparison of the specific gravity data in Table 1 and the drying times in Table 2 show one significant deviation from this general rule. Cedro has the lowest specific gravity but by far the longest drying time. Factors other than specific gravity may be involved in determining drying time. Cedro is known to contain oils and gums, which could be responsible for reducing drying rates. Cedro is also known to be extremely resistant to preservative treatment (Chudnoff 1984).

Moisture meter calibration

Electric moisture meter readings were calibrated to moisture content determined by the ovendry method so that moisture content of the specimens in the soaking test could be monitored continuously. The same specimens used for the soaking test were used for calibration, which ensured uniform initial moisture content. Readings were calibrated at three temperatures (27°C, 40°C, and 60°C) and four equilibrium moisture content conditions (18, 16, 12, and 10 percent), Radially, oriented, 7- by 2- by 0.5-cm samples were prepared as shown in Fig. 1. At the end of each equilibrium condition, moisture meter readings were taken using. electrodes and probes as shown in Fig. 3. Ovendry weight was measured at the end of the soaking test.

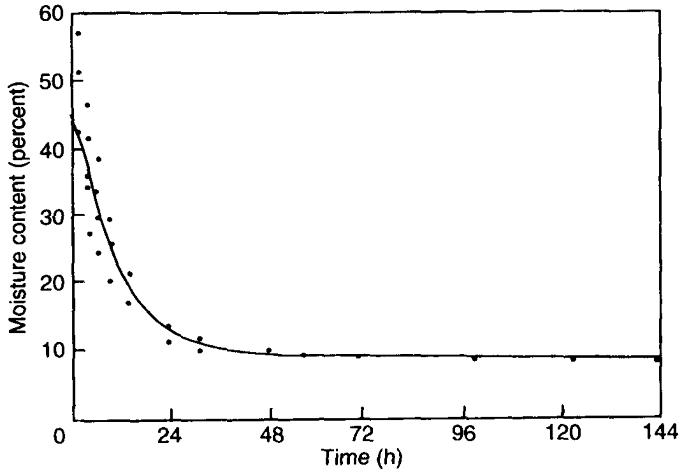

Fig. *7*. Drying curve for species AG (angelin amargo), 1 cm thick, 40°C, fit by regression model from Eq. (1). Data from five trees

Results

The results of this study were analyzed in four steps. The first and second steps addressed the drying and soaking tests. The third step focused on development of a statistical model. Based on the results of these steps, the final step was development of criteria for grouping different species under the same drying schedule.

Soaking test

The moisture content values, as determined by the moisture meter calibration curve for 27°C, were plotted against the soaking time for each species. Figure 6 shows a 27°C soaking test plot of moisture content as a function of soaking time for a single angelin amargo sample; the curve was fitted by Eq. (1). The analysis of soaking test curves was based on the same approach used to analyze drying test curves. Eq. (1) was used to fit the data for all soaking tests.

Drying test

Figure 7 shows a drying curve representing five angelin amargo specimens fit by the average model statistics for five trees.

Empirical correlation

Analysis of the results was based on the predictive ability of an empirical equation of the form

$$t_d = A\left[(t_s)^B d^C\right] / T^D \tag{2}$$

where t_d is drying time (h), t_s soaking time (h), d thickness (cm), and T temperature in kelvin. A, B, C, and D are coefficients to be estimated. The linearized model is written as

$$\mathrm{Ln}(t_d) = \mathrm{Ln}(A) + B\,\mathrm{Ln}(t_s) + C\,\mathrm{Ln}(d) - D\,\mathrm{Ln}(T) \tag{3}$$

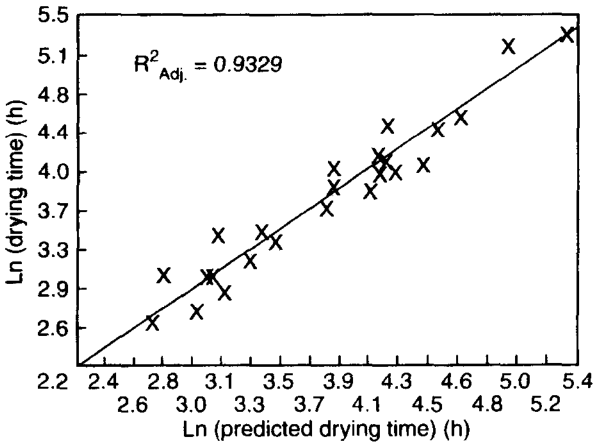

Fig. 8. Scattered plot of predicted drying time compared to observed drying time using soaking time at 60°C, specimen thickness, and test temperature as predictors

Figure 8 shows predicted drying time compared to observed drying time when soaking time at 60°C was used as a predictor in Eq. (3). Table 2 presents the coefficient values of Eq. (3) determined by regression analysis.

The value of 1.60 for the coefficient C is in the range of 1.5 to 1.7, as mentioned by Hildebrand (1970). The average percentage of error in predicting drying time is 14.4 percent. McMillen and Boone (1974) found that 15.8 percent of the drying time is required for equalizing and conditioning some tropical hardwoods. Therefore, the margin of error of 14.4 percent for the drying time prediction is within the normal requirements for equalizing and conditioning wood after drying any differences in final moisture contents would be minimized in these steps.

Grouping of species

The drying times can be used as a criterion for grouping species. To test this criterion, we compared group members selected by actual drying times with group members selected by drying times predicted with Eq. (3). Actual and predicted drying times of the six species, and two possible ways of grouping the species are shown in Table 3. One way is to place the species into three groups: the three shortest drying times, the next two longer drying times, and the longest drying time (singled out because this time was considerably longer than any other drying times) (Table 3). Using the grouping on actual drying time as the standard, the predicted drying time correctly placed two of three species in the shortest drying time group, one of two species in the intermediate drying time group, and one species in the longest drying time group.

Species could also be divided into two groups: the three species with the shortest drying times and the three species with the longest drying times (Table 3). In this case, two of three species are correctly placed in each group.

For both grouping methods, the overall success rate of grouping by drying time was 67 percent (four of six species). The failure to correctly place all species could be explained by the lack of a large difference in drying times of the species (except for species CE). The system may not be sensitive enough to make fine distinctions, but it was able to single out CE because of its distinct drying time. The strength of the system may be its use as a first approximation for separating species with large differences in

Table 3. Actual and predicted drying times for specimens and grouping based on drying times

Species code	Drying time (h) of specimens[a]			
	2-cm-thick specimens		1-cm-thick specimens	
	Actual	Predicted	Actual	Predicted
AG	84.8	90.8	32.8	30.2
CE	212	201	62.0	66.4
CED	86.9	67.1	31.2	22.2
CN	96.5	98.3	28.0	32.5
CO	57.1	62.9	21.6	20.8
PE	63.3	83.1	24.1	27.5
Drying time	Classification into three groups[b]			
Shortest	CO	CO	CO	CO
	PE	PE	PE	PE
	AG	CED	CN	CED
Intermediate	CN	CN	AG	AG
	CED	AG	CED	CN
Longest	CE	CE	CE	CE
Drying time	Classification into two groups[b]			
Shortest	CO	CO	CO	CO
	PE	PE	PE	PE
	AG	CED	CN	CED
Longest	CE	CE	CE	CE
	CN	CN	AG	AG
	CED	AG	CED	CN

[a]Specimens dried at 40°C
[b]Species groups correspond to specimen thickness and drying times in same column

drying times. One recommendation for further research is to design a similar study using a larger number of species that includes species with large differences in drying times.

Conclusions

For diverse species, average drying times in the hydroscopic range can be predicted from soaking times, specimen thickness, and drying temperature through an empirical model. Drying curves in the hydroscopic range and soaking curves were well defined by an empirical equation. Soaking time was a strong predictor of drying time. Predicted drying time shows promise as a basis for grouping species for drying. Sixty-seven percent of the species studied could be correctly grouped by predicted drying time. Although this success rate is not as great as desired, it does justify further research to improve our understanding of the worth and limitations of this grouping system.

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