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A SCREENING TO SELECT KILN SCHEDULES

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ABSTRACT - The aim of this was to define a rapid and simple test that would indicate the probable performance of a given wood species in a conventional drying process and the respective kiln schedule. Samples of six known species in relation to their drying characteristics and kiln schedules were dried at 100°C in a laboratory oven. The drying rate (mass/time), frequence of end checks and the remaining mass of water were measured at different moisture intervals, and then correlated with the main parameters of the kiln schedules (initial temperature, final temperature and initial drying potential). Indicated in the literature. The regression analysis gave three equations that permit to set the kiln schedules parameters based on the variables measured during the sample drying at 100°C. This screening was tested with three unknown species (***Erisma uncinatum, Manilkara huberi*** and ***Parapiptadenia rigida***), and the results obtained showed that the selected schedules were adequate to those species.

RESUMO – Este trabalho teve por objetivo definer um teste simples e rápido que possa indicar o provável comportamento de uma determinada madeira durante a sua secagem pelo processo convencional e o respectivo programa de secagem. Amostra de seis espécies conhecidas quanto as suas características e programas de secagem foram secas a 100°C em uma estufa de laboratório. A taxa de secagem (massa/tempo), a freqüência das rachuras de topo e a massa remanescente de água foram medidas a diferentes intervalos de umidade, e então correlacionadas com os parâmetros principais (temperatura inicial, temperatura final e potencial de secagem inicial) dos programas de secagem indicados na literatura. A análise de regressão resultou em três equações que permitem definir os parâmetros do programa de secagem com base nas variáveis medidas durante a secagem das amostras a 100°C. O método foi testado com a madeira de três espécies desconhecidas quanto à secagem (***Erisma uncinatum, Manilkara huberi e Parapiptadenia rígida***), e os resultados obtidos demonstram que os programas de secagem selecionados foram adequados para as espécies em questão.

INTRODUCTION

The wood drying can be defined as a dynamic balance between heat transfer from air stream to the wood, surface evaporation from the wood, diffusion of moisture through the wood and mass flow of free water in the wood (HART, 1966).

The heat transfer and surface evaporation are controlled by the external conditions, and the moisture movement from the interior to wood surface is controlled mainly by wood properties as permeability and specific gravity.

The equilibrium between external and internal factors is attained during kiln drying through the kiln schedule.

However, wood produced from different trees species shows a great variation in it's drying characteristics and lumber of unexperienced species, mainly tropical hardwoods, ins continuously introduced in the market, being necessary to develop adequate kiln schedules.

Schedule development was recommended by the Wood Drying Working Party in 1983 (VERMAAS, 1983) and its is one of the strongest areas of research according the survey issued in 1988 (ROSEN, 1988). The traditional method to develop kiln schecules (trial and error) is slow, and a quick method to predict wood drying characteristics, select kiln schedules or predict severety of drying defects has been carried out around the world (DURAND, 1985; ILIC & HILLIS, 1986; JANKOWSKY, 1988a; TERAZAWA, 1965).

The method based on defects after a drying at 100°C appears to be most simple and effective. Following the same principle, this paper describes the relationship between drying characteristics and kiln schedules, based in the result obtained with small samples quickly dried at 100°C.

METODOLOGY

This investigation follows the work started by TERAZAWA (1965). The principal hypothesis is that when small samples of wood are exposed to a severe drying condition it will show defects in proportional level to the expected was studied to predict the occurrence of collapse in Eucalyptus wood by ILIC & HILLIS (1986) with good results.

For the first step of the experiment, six wood species, well known in rlation to drying characteristics (Table 1), have been selected, with kiln schedule recommendation in literature (GALVÃO & JANKOWSKY, 1985; JANKOWSKY, 1988b).

Five flat-saw boards by species were used, from which five clear samples from each board were cut. The sample dimension was 2 cm thick x 10cm x 20cm, with the length parallel to grain direction.

The 25 samples by species were divided in five groups containing one sample from each original board. Each group was dried at 100°C in a laboratory oven with forced-air circulation.

The samples were weighed and the defects evaluated before and during the drying at 100°C. Measurements were done every 2 hours for the hardwoods and every 1 hour for the softwoods, during the first 12 hours of drying. In the following time intervals between measurements were 3 and 2 hours for hardwoods and softwoods, respectively.

The variables measured before the drying test were the initial moisture content (IM), specific gravity (SG) and initial mass of water (WI). The drying time (T), drying rate ®, end check (E) and surface check (S) were evaluated during the drying at 100°C in the moisture ranges from IM to 5% (1), from IM to 30% (2) and from 30% to 5% (3).

The drying was stopped when moisture content (MC) of samples was 5% or below. Then the samples were half-cutted to expose any collapse (CC) or internal check (IC) and returned to oven until to attain constant mass (oven dry weight) to calculate the mass of water at 30% (W3) and at 5% (W5) moisture content.

A score was attributed to all defects according to the degree of intensity (Table 2). The evaluation of collapse is illustrated in Figure 1.

TABLE 1. Species selected according drying characteristics and kiln schedule.

Common Name	Scientific Name	Drying Classification	Recommended Schedule (*)
Pine	***Pinus caribaea***	Easy	10
Cedro	***Cedrela fissilis***	Easy	8
Parana pine	***Araucária angustifolia***	Moderate	6
Grapia	***Apuleia leiocarpa***	Moderate	4
Jatobá	***Hymenaea counbaril***	Difficult	3
Eucalypt	***Eucalyptus saligna***	Difficult	2
(*) See Appendix 1.			

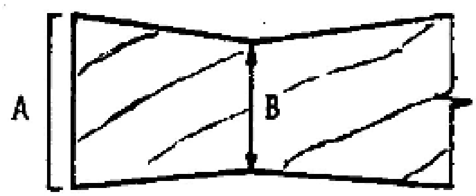
TABLE 2. Score attributed to drying defects according its intensity

SCORE	KIND OF DEFECT			
	END CHECK	SURFACE CHECK	INTERNAL CHECK	COLLAPSE (*)
1	No Checks	No Checks	No Checks	A – B < 0.5mm
2	Small Checks L < 10.0mm W < 0.8 mm	Small Checks L < 50.0mm W < 0.5mm	Small Checks L < 5.0mm W < 1.0mm	A – B > 0.5mm and A – B < 1.0mm
3	Small Checks L > 10.0mm W < 0.8mm	Small to Medium Checks L < 100.0mm L>5.0mm W < 1.0mm W > 1.0mm	Medium to Big Checks	A – B > 1.0mm and A – B < 1.5mm
4	Medium Checks L < 10.0mm W > 0.8mm W < 1.5mm	Medium to Big Checks L < 150.0mm W < 1.5mm	—	A – B > 1.5mm
5	Medium to Big Checks L > 10.0mm W > 0.8mm W < 1.5mm	Big Checks L > 150.0mm W > 1.5mm	—	—
6	Big Checks L > 10.0mm W > 1.5mm	—	—	—

(*) See Figure 1.

L = Check length, measure with pachymeter

W = Check width, measure with feeler gauge



A – B = COLLAPSE SCORE (mm)

FIGURE 1. Diagram showing collapse measurement.

The measured variables were correlated with the parameters of recommended kiln drying schedules through a multiple regression analysis using the stepwise method. The schedule parameters studied were initial temperature (IT), final temperature (FT), initial drying potential (IP) and constant drying potential (DP).

RESULTS

The regression analysis confirmed the relationship between schedule parameters and variables measured in the drying at 100^{o}C, mainly end check, drying rate and remaining mass of water. Those correlations are showed in Table 3.

Aiming to test the method effectiveness, samples of there lesser-known species in relation to its drying characteristics were submitted to drying at 100^{o}C, the schedule parameters calculated according equations from Table 3 and the suggested kiln schedules.

One charge from each of these three species was dried following the kiln schedule suggested by the screening application, using a Hildebrand dried model HD4004, with capacity for 0.1m^3 of saw wood, semi-automatic control and air velocity of 1.5m/s.

Each charge had 20 boards of 2.5cm x 10.0cm x 50.0cm. The board ends were coated with a paraffin emulsion to avoid excessive drying by the ends. The periodic measurements of moisture content loss was done with four kiln samples, using the weighing method described by RASMUSSEN (1979), and a resistance-type electric moisture meter.

TABLE 3 – Relationship between schedules parameters and variables of drying at 100^oC.

SCHEDULE PAREMETER	CORRELATED VARIABLES	EQUATION	r^2
IT	E1, R2, R1, E2	IT = 50.21 - 0.502 (E1) + + 3.628 (R2) – 0.910 (R1) - - 1.215 (E2)	0.917(***)
FT	E1, W5, R2	FT = 77.85 – 2.364 (E1) – - 0,580 (WS) + 1.184 (R2)	0.942(***)
IP	W3, R2, R1	IP = 4.71 – 0.009 (W3) + + 0.205 (R2) – 0.064 (R1) - - 0.224 (E3)	0.905(***)
(***) = Significant at the 0.1% level			

TABLE 4 – Drying variables, schedule parameters and kiln schedules suggested according to the screening.

Variables and Paremeters		Species		
		Quarubarana (*Erisma uncinalum*)	Angico (*Parapiptadenia rigida*)	Maçaranduba (*Manilkara huberi*)
Specific Gravity (g/cm^3)		0.46	0.71	0.83
Mass of Water (g)	W3	57.5	91.2	106.8
	W5	9.6	15.3	17.2
Drying Rate (g/h)	R1	13.2	12.6	8.7
	R2	4.7	3.5	2.4
End Checks	E1	5.0	3.0	2.3
	E2	5.0	3.0	4.5
	E3	5.0	3.0	4.5
Schedule Parameters	IT	46.7	46.3	44.4
	FT	66.0	66.0	65.3
	IP	3.1	3.2	2.6
Schedule Suggested (*)		6	6	3
(*) See Appendix 1				

TABLE 5. Drying results of the lesser-known species.

Results		Species Quarubarana	Angico	Maçaranduba
Moisture Content (%)	Initial	97.6	53.5	33.5
	Final	7.4	7.0	10.6
Drying Time (h)		160	285	480
Drying Rate ($g/h.cm^2$)	Above FSP	0.0337	0.0283	0.0058
	Below FSP	0.0238	0.0106	0.0047
	Mean	0.0309	0.0165	0.0049
Drying Defects (%)	Cup	20	20	15
	Twist	15	35	30
	End Check	5	NO	10
	Surface Check	NO	NO	10

Although the schedule suggested for wood of Quarubarana and Angico was the same, the drying rate is different (Table 5). This difference can be attributed to the distinct physical properties of these species.

In the green condition, Quarubarana wood ahd more capillary water (320 kg/m^3 and hygroscopic water (128 kg/m^3) than Angico wood (181 kg/m^3 and 199 kg/m^3, respectively). Since Quarubarana wood is more permeable and less dense, its drying rate is greater in both capillary and hygroscopic moisture ranges.

With respect to quality of dried lumber, warping (cup and twist) was present in all species tested (Table 5). The occurrence of this defect in high percentage can be explained by the small dimension of the boards and because no mechanical restraint was applied on the lumber pile. Application of external restraint appears to be at present the more effective method in warping reduction, according STOHR (1983). Probably the use of a restraint device will reduce warping incidence in industrial drying.

In relation to other drying defects, only a small percentage of end and surface checks was observed without any incidence of collapse, honeycomb or case hardening confirming that kiln schedules using the proposed methodology were adequate to the tested wood.

CONCLUSIONS

The screening methodology presented in this paper appears to be suitable to select kiln schedules for lesser known wood in relation to drying behaviour.

Aiming to get safety in applying this screening to any kind of wood, it is recommendable to use a schedule just anterior to the initially selected, until further experience could be accumulated.

APPENDIX 1

GENERAL KILN DRYING SCHEDULES (6)

Moisture Content (%)	SCHEDULE NUMBER														
	1			2			3			4			5		
	Ts	Tu	P	Ts	Tu	P	Ts	Tu	P	Ts	Tu	P	Ts	Tu	P
> 50	35.0	34.0	-	40.0	38.5	-	40.0	38.5	-	40.0	38.5	-	40.0	38.0	-
50	35.0	34.0	2.3	40.0	38.5	2.5	40.0	37.5	2.9	40.0	38.0	2.7	40.0	37.0	3.1
40	35.0	33.5	2.0	40.0	38.0	2.2	40.0	37.5	2.5	40.0	37.0	2.5	40.0	35.0	3.1
30	35.0	33.0	1.6	45.0	42.0	1.8	45.0	41.0	2.1	45.0	39.5	2.5	45.0	37.0	3.1
25	40.0	37.0	1.5	50.0	46.5	1.7	55.0	49.0	2.2	55.0	47.5	2.5	55.0	45.0	3.1
20	50.0	45.5	1.5	60.0	54.5	1.7	65.0	56.5	2.2	65.0	54.5	2.5	65.0	51.0	3.0
15	50.0	42.0	1.5	60.0	51.0	1.7	65.0	51.5	2.2	70.0	54.0	2.5	70.0	50.0	3.0
10	50.0	36.0	1.5	60.0	44.0	1.7	65.0	43.0	2.2	70.0	48.0	2.5	70.0	42.0	3.0
	6			7			8			9			10		
	Ts	Tu	P	Ts	Tu	P	Ts	Tu	P	Ts	Tu	P	Ts	Tu	P
> 50	50.0	48.0	-	50.0	48.0	-	50.0	47.0	-	50.0	46.5	-	60.0	56.0	-
50	50.0	47.0	3.2	50.0	46.5	3.4	50.0	45.5	3.8	50.0	45.5	3.8	60.0	55.0	4.0
40	50.0	46.0	2.9	50.0	44.5	3.3	50.0	43.5	3.6	50.0	44.0	3.5	60.0	54.0	3.6
30	55.0	49.5	2.6	55.0	47.0	3.1	55.0	45.5	3.5	55.0	47.0	3.1	65.0	56.0	3.4
25	65.0	58.0	2.5	65.0	55.0	3.0	65.0	52.5	3.5	60.0	50.0	3.0	70.0	57.0	3.5
20	70.0	59.0	2.5	70.0	56.0	3.0	75.0	58.0	3.5	70.0	56.0	3.0	75.0	58.0	3.4
15	70.0	54.0	2.5	70.0	50.0	3.0	75.0	51.0	3.5	80.0	60.0	3.0	80.0	56.0	3.6
10	70.0	46.0	2.5	70.0	42.0	3.0	75.0	44.0	3.5	80.0	51.0	3.0	80.0	50.0	3.2

Where: Ts = Dry bulb temperature (^{o}C)
Tu = Wet bulb temperature (^{o}C)
P = Drying potential

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