4.3 Drying Schedule Tests

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板材の乾燥スケジュール試験

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4.3.1 Purpose

The purpose of this study is to establish the most suitable drying schedule of one inch board for each species of eighteen tropical wood from Togian Island, Sulawesi. Whereas, 100°C-test is carried out as a guide to set up rough drying schedule tests.

4.3.2 Experimental Procedures

Test board sizes were 2.7 cm by 20 cm by 50 cm, in thickness, width, and length respectively. The test boards were made free from visible defects, smooth surface, and also, they were maintained in green condition before running tests by wrapping those boards with polyvinyl sheet and stored in the refrigerator room.

Three flat-grain boards were taken from each species for running test drying schedules, except for *Koordersiodendron sp.* and *Madhuca sp.* which were two flat-grain boards only were available. Each test board was kiln dried with one drying schedule test, so that each species was tried out three times for drying schedule tests, except for those two species which were tried out twice only.

Available edge-grain boards were very short and narrow, and some of them had defects, as knot and split. Only eight species could be made for drying test specimens. But, they were thick enough, so that the thickness of 2.7 cm could be made. For its width and length, they were tried getting maximal sizes and free from visible defects.

Estimating initial moisture content of each test board was done by taking sample-test from each board at both end sides. The initial moisture content was estimated by those average values. From the same sample test, it was observed standard shrinkage for each species, by means of putting the test specimen in room condition, 20°C and depression about 3°C, and then putting in the oven at 60°C, and finally putting in the oven at 105 ± 5°C until reaching oven-dry condition.

Before putting the test board in the kiln, test board was end-sealed at one side by using aluminium foil and glued by synthetic rubber. And then, the weight, the length, the width and the thickness of each board were measured. The weights of aluminium foil and glue were neglected because the weights were so small compared to the test board weight.

The first tested schedule for every species was set-up by means of 100°C-test, as described in the previous chapter (4.1). Those schedules were tried to clarify whether it could be accepted or should be modified.

By running the drying schedules, drying defects and required drying time to reach 10% from green condition were measured. The drying-defects-observed were shrinkage to oven-dry condition and checks. Shrinkage measurement was done when the test board reached oven-dry condition by means of putting the board in the oven at 105 ± 5°C after finished the drying schedule test.

The checks caused by drying was classified to be four grades which is proposed in Table 1.

Table 1. Grade of Check Caused by Drying Schedule.

No.	Description	Grade
1.	Without any checks.	0
2.	Check occurred at end-side only.	1
3.	As number two, but the end-check is extended to the surface and no one of them exceeds to 3 cm length.	2
4.	As number three, but the length of extended-surface-check is more than 3 cm or free surface-check is found.	3

The second schedule was set-up referring to the first drying-schedule result. If the first schedule result was good, so the second schedule could be set-up to be more severe one by rising the initial temperature and/or depression. The grade of defects from 100°C-test can be used as guidance for this purpose. If the grade of initial check is small and required time to reach 1% moisture content is short, so the inital depression of schedule can be set-up at much larger depression than the first one. On the other hand, if the grade of deformation and honey-comb were small, so the drying temperature could be set-up at higher temperature than the first one.

If the check was found in the first drying schedule test, so that the second drying schedule should be milder than the first one. In this case, the initial depression should be reduced regarding to the degree of check. On the other hand, if the shrinkage value caused by drying test is so large and grade of deformation and honey-comb in the 100°C-test result were also large, so that the second drying temperature should be lower than the first one.

The third schedule could be set-up referring to the second and the first schedule results. The modification was done similarly to the above descriptions.

One of the three tested schedules was chosen to be the most suitable schedule which resulting minimal drying defect and the shortest drying time. If no one of the tested schedules was suitable one, so the proposed drying schedule for this species was established by means of modification the mildest schedule to be more safe one.

4.3.3 Results and Discussion

The comparison between inferred- and suitable-drying schedules is shown in Table 2. And the calculation of t-test for the differences between inferred- and suitable-drying schedules is shown in Table 3.

From that Table 2, it could be seen that the inferred drying conditions of some species could match to or were not so different from the suitable drying conditions, as for *Ficus sp.* (2), *Koordersiodendron sp., Dysoxylum sp., Eugenia sp., Podocarpus sp.* (1), and Myristicaceae. Some of the suitable drying conditions were carried out milder than the inferred ones, as for *Pometia sp.* (1), *Madhuca sp.,* and *Heritiera sp.* (2). The other suitable drying conditions were more severe than the inferred ones.

Madhuca sp. had special characteristics, it was high density wood, 0.93 gr/cm^3, easy getting check and cell-collapse, slow drying rate and drying stress reversal at low moisture content. This species needed special drying treatment, very mildest one with initial dry bulb temperature of

Table 2. Comparison Between Inferred- and Suitable-Drying Schedule.

No.	Wood Species	Density[1)] (gr/cm³)	Initial Moisture Content (%)	Inferred Drying Condition			Drying Time Estimation for 2.7 cm Board (day)	Suitable Drying Condition			Suitable Drying Time (day)
				Initial DBT (°C)	Initial DBT-WBT (°C)	Final DBT (°C)		Initial DBT (°C)	Initial DBT-WBT (°C)	Final DBT (°C)	
2.	*Koordersiodendron sp.*	0.66	76	45	2.5	70	15.3	40	3.0	60	19.0
14.	*Lophopetalum sp.*	0.38	97	60	3.6	85	6.3	70	6.0	80	1.8
18.	*Terminalia sp.* (4)	0.54	41	65	5.5	90	6.0	70	7.0	80	2.0
23.	*Octomeles sp.*	0.29	97	50	3.8	77	7.3	55	6.0	70	6.6
28.	*Gonystylus sp.*	0.46	67	53	3.0	82	7.7	60	3.0	70	4.0
29.	*Calophyllum sp.* (1)	0.43	70	58	4.7	83	6.0	55	8.0	70	2.5
33.	*Litsea sp.* (3)	0.47	140	60	4.3	85	8.6	70	6.0	80	4.6
39.	*Dysoxylum sp.*	0.48	81	54	4.0	80	9.8	55	5.0	70	6.0
42.	*Artocarpus sp.*	0.24	260	50	3.6	77	7.0	50	8.0	70	2.1
44.	*Ficus sp.* (2)	0.39	114	50	3.0	77	6.9	50	3.0	70	8.0
45.	(*Myristicaceae*) (1)	0.42	105	50	3.8	77	5.8	50	3.0	70	3.5
47.	*Eugenia sp.*	0.61	95	47	2.0	71	17.2	40	2.0	60	14.4
49.	*Podocarpus sp.* (1)	0.42	53	55	3.6	83	5.7	50	3.0	70	7.5
53.	*Pometia sp.* (1)	0.59	70	53	3.0	80	10.8	40	1.5	60	12.5
55.	*Madhuca sp.*	0.93	41	45	2.0	70	18.3	37	1.5	60	21.0
57.	*Paláquium sp.* (2)	0.51	63	49	3.3	73	10.0	55	6.0	70	8.3
62.	*Ailanthus sp.* (2)	0.37	102	60	4.3	85	5.3	70	8.0	80	1.3
68.	*Heritiera sp.* (2)	0.50	63	55	3.6	83	8.3	45	1.5	60	8.3

Note: 1) Based on green volume and oven-dry weight.

37°C and initial depression of 1.5°C.

Heritiera sp. (2) and *Pometia sp.* had drying stress reversal at low moisture content and high grade of initial check in 100°C-test, so those species were very easy getting check but the check was difficult to close back. Furthermore, referring to the 100°C-test also, *Pometia sp.* (1) had large variation of deformation, one to four, so a mild drying schedule was better to be applied.

The average suitable initial dry bulb temperature of eighteen tested species was 53.4°C with standard deviation of 11.1°C. The lowest initial dry bulb temperature was for *Madhuca sp.*, 37°C, and the highest ones were for *Lophopetalum sp., Terminalia sp.* (4), *Litsea sp.*, and *Ailanthus sp.* (2) with initial dry bulb temperature of 70°C.

According to t-test calculation, see Table 3, there was no difference statistically between the inferred and the suitable- initial drying temperature. In other words, the inferred drying temperature from 100°C-test results could be applied for practical purpose directly. In some cases, the inferred initial dry bulb temperature could be raised a little bit if the species was not cell-collapse susceptible which was indicated by the low grades of deformation and honey-comb in 100°C-test results, as for *Lophopetalum sp., Litsea sp.* (3), and *Ailanthus sp.* (2). And conversely, it was better to be lowered a little bit if the species was susceptible to cell-collapse, as for *Koordersiodendron sp., Pometia sp.* (1), and *Madhuca sp.*

The suitable initial depression, the difference between dry- and wet-bulb temperatures, was varied from 1.5°C, as applied for *Madhuca sp.*, to 8.0°C, as for *Ailanthus sp.* (2). The average depression was 4.5°C, and standard deviation was 2.4°C.

According to t-test calculation, see Table 3, the suitable initial depression was significantly different from that inferred one with 5 % confidence level. It was 1.0°C larger than the inferred one. For some species, the initial depression was set-up larger than that the inferred one and maintained it until lost moisture content was more than one-third of its initial, as for *Lophopetalum sp., Gonystylus sp., Litsea sp.* (3), *Artocarpus sp., Ficus sp.* (2), Myristicaceae (1), and *Podocarpus sp.* (1).

Lophopetalum sp., Gonystylus sp. and *Podocarpus sp.* (1) had drying stress reversal at low moisture content, i.e. 15 %, 15 %, and 11 % respectively. The other species had high initial

Table 3. Calculation of t-test for the Difference Between Inferred- and Suitable-Drying Schedules.

Source	Initial DBT (°C)	Initial Depression (°C)	Final DBT (°C)	Drying Time (hr)
$\bar{X}$	0.16	–0.99	9.89	1.61
σ_{n-1}	7.18	1.85	5.16	2.78
$S_{\bar{X}}$	1.69	0.44	1.22	0.65
t	0.10	2.12*)	8.14**)	3.08**)

Notes: *) Significant at 5% level.
**) Highly significant at 1% level.

moisture content, so that a lot of free water in the wood should be moved before applying the more severe drying condition.

If changing condition was done just after one-third moisture content was lost so the initial depression should be set-up a smaller one that of the recommended or proposed drying schedule. In the large scale of drying factory, this method would be better because drying condition was usually changed in a milder condition. In this experiment, the changing condition could be done suddenly and the next drying condition could be reached soon because the used kiln was small capacity and the load was one to two test specimens only.

The average final dry bulb temperature was 69.4°C with standard deviation of 7.3°C. The lowest final dry bulb temperature was 60°C, as for *Koordersiodendron sp.*, *Eugenia sp.*, *Pometia sp.* (1), *Madhuca sp.*, and *Heritiera sp.* (2). And the highest one was 80°C, as for *Lophopetalum sp.*, *Terminalia sp.* (4), *Litsea sp.* (3), and *Ailanthus sp.* (2). The depression was usually set-up at 25°C to 30°C in the last step of the kiln drying process.

According to t-test calculation, see Table 3, the suitable final drying temperature was with high significance different from that inferred one. In this experiment, the final drying temperature was ignored because it could be set-up to any level after passing the danger point. As cited by Brown et al. (1952) when the wet core is dried beyond the danger point at which collapse may occur, the temperature can be raised to any level and humidity lowered to any degree, without injury the wood.

From those suitable drying conditions discussed above, the mildest drying schedule was for *Madhuca sp.* with initial dry bulb temperature of 37°C and initial depression of 1.5°C. And also, very mild ones were for *Pometia sp.* (1) with initial dry bulb temperature of 40°C and initial depression of 1.5°C, and *Eugenia sp.* with initial dry bulb temperature of 40°C and initial depression of 2.0°C.

The most severe drying schedule was for *Ailanthus sp.* (2) with initial dry bulb temperature of 70°C and initial depression of 8.0°C. And also, very severe one was for *Terminalia sp.* (4) with 70°C and 7.0°C in initial dry bulb temperature and initial depression respectively.

The average required suitable drying time was 7.4 days with standard deviation of 5.9 days. The shortest suitable drying time was 1.3 days, as for *Ailanthus sp.* (2), and the longest one was 21 days, as for *Madhuca sp.* The shortest one was carried out with the most severe drying schedule, and the longest one was applied with the mildest drying schedule.

Regarding to the relation between wood density and drying rate, the high and moderately high density woods took long time to kiln dry and needed a mild drying condition because water in wood moved very slow. And conversely, low density woods took short time to kiln dry and severe drying condition could be applied, but sometimes it had exceptions because of the other wood properties regarding to drying, see Table 2.

From that Table 2, *Ficus sp.* (2) took drying time of 8.0 days or 0.6 days longer than that average required drying time from green condition to 10 % moisture content. In this case, this species had special characteristics, easy getting check and cell-collapse, and the wood properties variation was very large as indicated by the grade of initial check in 100°C-test results. So that initial high drying temperature and large initial depression could not be applied.

On t-test calculation for difference in inferred and suitable drying conditions in Table 2, required drying time under suitable drying schedule was high significance different from its estimation at 1 % level (Table 3). This case was caused by the different drying condition of both systems. As stated by Bramhall (1976), various drying schedules have the same drying effort, but different dry- and wet-bulb settings and different duration may be devised.

Furthermore the comparison of required drying time between edge- and flat-grain boards of eight species is shown in Table 4. Those required drying times were calculated from average moisture content at green condition to 10 % moisture content.

The average ratio was 1.22 with standard deviation of 0.19 and varied from 0.92 to 1.54. The smallest ratio was for *Ailanthus sp.* (2), and the biggest one was for *Calophyllum sp.* (1).

If the ratio was equal to one, so that the edge- and flat-grain boards could be kiln dried together without any trouble and resulting in the same required drying time, as for *Ficus sp.* (2), *Podocarpus sp.* (1), and *Ailanthus sp.* (2). But in some cases, both kinds of board could be kiln dried together whereas the edge-grain board should be finished later.

Table 4. Required Drying Times of Edge- and Flat-Grain Boards of Eight Species.

No.	Species	Green to 10 % MC		Ratio of Edge/Flat
		Edge (hr)	Flat (hr)	
1.	*Lophopetalum sp.*	55.7	41.0	1.36
2.	*Terminalia sp.* (4)	61.6	47.7	1.29
3.	*Gonystylus sp.*	111.7	94.8	1.18
4.	*Calophyllum sp.* (1)	92.4	60.0	1.54
5.	*Ficus sp.* (2)	197.2	190.5	1.04
6.	Myristicaceae (1)	107.1	82.1	1.30
7.	*Podocarpus sp.* (1)	145.8	132.0	1.10
8.	*Ailanthus sp.* (1)	28.7	29.8	0.92

Note: The applied drying schedules of edge-grain boards were the third running test of flat-grain boards, except for Myristicaceae which was the second one.

Referring to the 100°C-test results, the inferred schedule could be modified regarding to the wood properties, as drying rate, and susceptibilities to check and cell-collapse. If the wood was easy to check and cell-collapse so it was suggested that the schedule might be a little bit milder than that inferred one, as for *Pometia sp.* (1), *Madhuca sp.*, and *Heritiera sp.* (2). Conversely, if the wood was susceptible to check and cell-collapse so the schedule could be carried out more severe than that inferred one, as for *Litsea sp.* (3) and *Ailanthus sp.* (2).

If the drying rate was high so the drying condition could be set-up at a severe one, but the susceptibilities to check and cell-collapse should be considered, otherwise those drying defects would be occurred. Conversely, if it was low so that a mild drying schedule should be applied. To accelerate drying rate, steaming might be suitable to be treated especially for the species which was not easy getting check and cell-collapse (Mackay, 1971, and Simpson, 1975).

Mixed species in one run could be carried out if the woods had similarity in drying properties. Grouping could be done based on 100°C-test results or the other properties, as density and color. Referring to the 100°C-test results, the considerable grouping factors were drying rate, initial moisture content, susceptibility to check and cell-collapse. By those considerations, the load consisting of some species could be kiln dried as well as drying each species separately.

The most suitable or proposed drying schedule of each species is listed in Table 5.

4.3.4 Conclusion

From sixteen species which were investigated on drying schedules for one inch board, it can be concluded:

1. For the species that have large variation in wood properties the mildest drying schedule should be chosen, as for *Ficus sp.* (2) and *Pometia sp.* (1).
2. Drying schedule can be set-up more severe than the inferred one if the wood is insusceptible to check and cell-collapse, as for *Ailanthus sp.* (2) and *Litsea sp.* (3). Conversely, it must be carried out at a milder one if the wood is very susceptible to check and cell-collapse, as for *Madhuca sp.*
3. Moisture content at drying stress reversal apparently relates to the changing drying conditions. If it is low, below 20 %, initial drying condition must be maintained until more than one-third of moisture content is lost, or applied a milder one if changing condition is done after one-third of moisture content is lost.
4. There is no difference statistically between the inferred and suitable drying temperatures, so that the inferred one can be applied for practical purpose directly.
5. Average initial depression was 1.0°C larger than the inferred one, because many species were insusceptible to check so the initial depression could be set-up at a larger one.
6. Average final drying temperature was 9.9°C lower than the inferred one. The final drying temperature was ignored in this experiment because setting it up to any level is possible after passing the danger point.
7. Average drying time was 1.6 days shorter than the inferred one, because the tested schedules were carried out more severe than the inferred one.
8. Mixed species in one run can be carried out if the woods have similarity in drying properties. Grouping can be done based on 100°C-test results or the other wood properties, as density and color.

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Table 5. Recommended or Proposed Drying Schedule of Each Species.

Number of Species	DBT	WBT	Drying Time**) (day)
2[X]	40 45 50 60	37 36 34 31 32 37 30	19
14[X]	70 75 80	64 61 57 50	1.8
18	70 75 80	63 65 60 50	2.0
23	55 60 70	49 47 43 37 35 40	6.7
28	60 65 70	57 60 62 58	4.0
29	55 60 65 70	47 43 37 40	2.5
33[X]	70 75 80	64 62 58 55 45 50	4.6
39	55 60 70	50 48 45 40	6.0
42[X]	50 55 60 65 70	42 38 33 30 35 40	2.1
44[X]	50 55 60	47 46 49 52	8.0
45	50 55 60 70	47 46 44 40 32 30 40	3.4
47	40 45 50 55 60	38 37 36 39 41 40 35	14.4
49[X]	50 55 60 70	47 50 52 58	7.5
53[X]	40 45 50 55 60	38.5 43 47 50	12.5
55[X]	37 42 45 55	35.5 40 38 40 45	21
57[X]	55 60 70	49 47 43 37 35 40	8.3
62	70 75 80	62 58 52 45 40 45 50	1.2
68[X]	45 50 55 60	43.5 42.8 41.5 44 45 30	8.3

Moisture Content (%): 300, 100, 80, 60, 40, 20, 10

Notes:

DBT = Dry bulb temperature (°C)
WBT = Wet bulb temperature (°C)
----- = Average Initial Moisture Content (%)

**) Estimated from average initial moisture content to 10% moisture content.

Number of Species

2 = *Koordersiodendron sp.*
14 = *Lophopetalum sp.*
18 = *Terminalia sp.* (4)
23 = *Octomeles sp.*
28 = *Gonystylus sp.*
29 = *Calophyllum sp.* (1)
33 = *Litsea sp.* (3)
39 = *Dysoxylum sp.*
42 = *Artocarpus sp.*
44 = *Ficus sp.* (2)
45 = *Myristicaceae* (1)
47 = *Eugenia sp.*
49 = *Podocarpus sp.* (1)
53 = *Pometia sp.* (1)
55 = *Madhuca sp.*
57 = *Palaquium sp.* (2)
62 = *Ailanthus sp.* (2)
68 = *Heritiera sp.* (2)

X No running test with this schedule, but it was suggested that it would be suitable regarding to the results of the other running tests. (proposed drying schedule).

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4・3・5　概　要

板材の乾燥スケジュール試験

具体的な1インチ材の乾燥スケジュールを作る事がこの試験の目的で，その予備試験として先の100℃のスケジュール推定試験を行ない，この結果にもとづいて，第1回目のスケジュール試験を実施し，その状態をみて次回のスケジュール試験の条件を決定し，大略一樹種3回の試験を行ない，適切なスケジュールを定めた。

供試材は18種類18属で，試験材は板目心材が主であるが，乾燥時間の比較のためにまさ目材を最後の乾燥試験の時に板目材と一緒に乾燥したものもある。試験結果のうち，1インチ材の乾燥初期の温湿度ならびに乾燥末期の温度などにつき，100℃のスケジュール推定試験の結果と，板材のスケジュール試験の結果とをTable 2に一緒に比較して示す。

また，それぞれの樹種の最も適した乾燥スケジュールの含水率と乾湿球温湿度との関係をTable 5に示す。なおTable 5のスケジュールではOctomeles sp.とPaluquium sp. (*2*)両樹種で同一であった。いづれのスケジュールも板目材をコントロールサンプルとしている。

試験材のうちAilanthus sp. (*2*)が乾燥時間が最も短く1.3日であり，Madhuca sp.が21日を要して最長である。

まさ目材の乾燥時間と板目材の乾燥時間をTable 4に示す。この結果は最終的に良好と考えられたスケジュール試験の際に板目材と一緒にまさ目材を乾燥した時のものである。大略平均値でまさ目材は1.2倍乾燥時間が板目材より長くかかる。

1インチ材の乾燥スケジュール試験の結果と100℃のスケジュール推定試験とが乾燥温度，乾湿球温度差，乾燥時間の3者ともに極めてよく合ったものはFicus sp. (*2*)で，Koordersiodendron, Dysoxylum, Eugenia, Podocarpus (*1*), Myristicaceae (*1*)などが比較的近似した値を示している。

一般に乾湿球温度差が推定値より小さく出されており，そのために推定の乾燥時間が長く計算されているものが多い。これに含まれる樹種は比重が小さいか，100℃のスケジュール推定試験で含水率1％になるまでの乾燥時間の比較的短いものに多い。

逆に，推定の条件より温度を低く乾湿球温度差を小さくしなければならなく，従って推定値より乾燥時間の延長されたものはPometia sp. (*1*), Madhuca, Heritiera (*2*)である。