EFFECT OF TIMBER DRYING TEMPERATURE ON SUBSEQUENT MOISTURE AND DIMENSIONAL CHANGES

J. A. KININMONTH
(Forest Research Institute, New Zealand Forest Service, Rotorua)

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ABSTRACT

Sawn timber of radiata pine (**Pinus radiata**) and also tawa (**Beilschmiedia tawa**) was kiln dried at varying temperatures up to 115°C or was air dried. It was then assessed for rate of moisture uptake and swelling when exposed to high humidity in the laboratory or to fluctuating humidity outside under cover.

There is a progressive reduction in both moisture uptake and swelling as drying temperature is increased but, under commercial conditions, high-temperature drying at 115°C for less than 1 day will lead to only slightly greater stability than drying at 77°C for 3 days. Timber dried at either temperature is substantially less responsive to high humidity after drying than air-dried timber, with reduction in swelling of 12-35 percent.

INTRODUCTION

Information is available on the equilibrium moisture content (e.m.c.) of the more important New Zealand timbers in different parts of the country (Orman, 1955) and on the relative dimensional stability and related properties of most of our indigenous and exotic timbers (Harris, 1961). Of these studies, the former was carried out on air-dried timber and the other did not specify the seasoning method.

When industrial uses require precisely defined properties, timber is usually kiln dried at temperatures up to 80°C in conventional kilns, or to 40°C in low-temperature driers (Kininmonth, 1975). There is also a resurgence of interest in high-temperature drying, i.e., at temperatures of 115°C or higher, and this process is used widely to dry radiata pine (*Pinus radiata* D. Don) in Australia. This paper reports isolated studies carried out over a period of several years on the effects of these drying methods on e.m.c., rate of moisture movement, and dimensional changes for radiata pine and, to a lesser extent, for tawa (*Beilschmiedia tawa* (A. Cunn.) Benth. et Hook.f. ex Kirk).

Most previous work was concerned with the effect of heat treatment on dried wood rather than with the temperature used during drying or with the effect of temperatures above 100°C. Spiller (1948) showed that increasing temperature within the range 86-150°C caused progressive reduction of e.m.c. in radiata pine and in two indigenous timbers previously air dried. Orman (1955) confirmed these results and included tawa in his study on the effect of heat treatment. Spiller also referred to earlier work of Stamm, Burr, and Kline (1946) who exposed wood to temperatures of up to 320°C in absence of air. Kollmann and Schneider (1963) exposed oven-dried wood at temperatures of 70-200°C in air for varying periods. Increase in temperature and time of exposure reduced moisture sorption.

Kozlik (1973) dried Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg) from the green state to two moisture content (m.c.) levels at temperatures in the range 32°-100°C, and also studied the effect of an extended drying period. He concluded that increasing temperature had the greatest effect in lowering e.m.c. and reducing subsequent shrinkage and swelling. Prior to this, Kininmonth and Williams (1972) showed that e.m.c. and rate of moisture change in radiata pine reduced progressively as drying temperature increased in the range 25-88°C. This preliminary work was extended to provide the information presented in this paper.

MATERIAL AND METHODS

Kininmonth and Williams (1972) exposed rough-sawn radiata pine outside under cover so, in case the observed differences due to drying temperatures were a surface phenomenon, this work was duplicated using material machined to 19 mm thick from the nominally 100 × 25-mm size. Five boards of green radiata pine sapwood were selected from Rotorua material and five matched clear lengths were prepared from each. These provided material for five drying treatments, air drying or kiln drying at one of four temperatures in the range up to 93°C. Details are shown in Table 1 (series 1). Specimens were sealed on the ends to minimise end drying. Kiln drying was carried out in a small laboratory kiln, and air drying in the laboratory. After drying, the test material was conditioned for several months in a cabinet running at approximately 12% e.m.c. and at a temperature of 25°C or less. It was machined, then stacked outside under cover and completely protected from direct wetting by rain, in such a way that all specimens were fully exposed to the surrounding atmosphere. The pieces were weighed at the beginning, after 1, 4, and 7 days, and then weekly for a year. After this they were oven dried to calculate moisture contents corresponding to periodic weighings.

A second set of five matched series of specimens was dried and conditioned with the first set and used to prepare specimens of a size similar to those used by Harris (1961). For this reason, five boards of air-dried rimu (*Dacrydium cupressinum* Lamb.) were included as a basis for comparison. From each test piece dried as a 450-mm length, a flat-sawn strip 32 mm wide and 8 mm thick was sawn with all faces at least 2 mm from an original rough-sawn surface. A pair of specimens 100 mm long was sawn from each strip and these pieces were sealed on the ends with nitro-cellulose lacquer. After further conditioning in the 12% e.m.c. cabinet, the widths of the test pieces were measured at marked points near the mid point, weights were recorded, and the specimens were exposed for 24 h in a cabinet over water at a temperature of 22°C ± 1°C. This cabinet was a converted incubator with a small fan and external motor to provide air circulation. With prolonged exposure it was possible to reach 26-28% m.c., equivalent to a relative humidity (r.h.) in excess of 95%.

The purpose of this experiment was to determine the comparative moisture uptake and dimensional change in matched pieces from different treatments, so special care was taken to place matched groups of specimens together on small racks made of material that did not pick up moisture. After the exposure period, specimens were weighed and remeasured. The cycle was repeated after putting the test pieces back in the 12% e.m.c. cabinet until the original weight was attained.

Similar information was obtained for tawa, but the test material was dried as 38-mm squares sawn from a single log (Table 1, series 3). Further series of radiata pine (series 4 and 5) were prepared and exposed according to the above general procedure to determine the comparative responsiveness after air drying, kiln drying at 77°C (commercial kiln schedules recommended by Kininmonth and Williams, 1974), or kiln drying at 115°C (high-temperature drying schedule). Included in series 5 was matched material kiln dried at 77°C for periods of 1 day, 3 days (normal time for boards 25 mm thick), and 6 days. All material was then conditioned to as near as possible the same moisture content, before moisture uptake was tested.

TABLE 1—Test material and drying temperature ranges

Series	Material	Drying temperature	Remarks
1 & 2	Ten boards of 100 × 25-mm radiata pine sapwood, each providing 5 matched 450-mm length for drying. Material for all series was freshly sawn and in green condition.	(1) Air dried (2) 43°C* (3) 60°C (4) 77°C (5) 93°C	Temperature less than 25°C Dried for 7 days at 12% e.m.c. Dried for 6 days at 12% e.m.c. Dried for 4 days at 12% e.m.c. Dried for 3 days at 12% e.m.c.
3	Five lengths of whitewood of tawa prepared as 38-mm square cross-sections from one log. Each length provided 5 matched specimens for drying.	Temperature ranges for series 1 and 2	All kiln drying was carried out for 10 days at 12% e.m.c., the time needed for the slowest drying (i.e, at lowest temperature).
4	Five boards of 150 × 25-mm radiata pine sapwood, each providing 3 test specimens.	(1) Air dried (2) 77°C (3) 115°C	 Dried for 3 days at 8% e.m.c. Dried for 16 h at very low e.m.c. (wet-bulb temperature 70°C).
5	Five boards of 150 × 25 mm radiata pine sapwood, each providing 5 test specimens.	(1) Air dried (2) 77°C (3) 77°C (4) 77°C (5) 115°C	 Dried for 1 day at 8% e.m.c.† Dried for 3 days at 8% e.m.c. Dried for 6 days at 8% e.m.c. As for series 4.

* Originally set on the Fahrenheit scale

† Treatments 2, 3 and 4 were conditioned together after drying.

RESULTS

Results covering the year of exposure of radiata pine outside under cover are summarised in Table 2. There is a progressive decrease in e.m.c. and a reduction in rate of moisture change with increasing drying temperature, and the latter is confirmed by the results from the cycling of small specimens under laboratory conditions (Table 3). The figures given are the means for five specimens per treatment, and an analysis of variance showed the drying temperature effect to be highly significant ($F = 18.79$, significant at the 0.1% level for 4,40 degrees of freedom).

TABLE 2—Equilibrium moisture content (e.m.c.) of radiata pine after drying at various temperatures (mean of 5 specimens)

Drying temperature °C	Effects on e.m.c. (%) of exposure, outside but under cover, for 12 months commencing January					
	Initial m.c.	Mean of weekly change	Relative change	Highest*	Lowest†	Range
Air dried‡	12.0	1.24	100	22.2	15.2	7.0
43	12.3	1.24	100	22.1	15.1	7.0
60	12.2	1.14	92	21.3	14.9	6.4
77	11.9	1.00	81	19.2	14.2	5.0
93	11.2	0.92	74	18.4	13.5	4.9

* 14 July
† Excluding the first 2 weeks of exposure, 22 December.
‡ Temperature not exceeding 25°C.

TABLE 3—Effects of drying temperature on rate of moisture uptake and swelling of radiata pine sapwood (mean of 5 specimens)

Adsorption cycle	Species and drying temperature	Moisture content (%)	After 24 h at 95% r.h.			
			Increase in m.c. (%)	Weight increase (g)	Swelling (%)	Relative stability
1	Rimu air dried	13.2	10.2	1.43	3.23	100
	Pine air dried	12.8	11.3	1.51	3.05	94
	43°C	12.6	11.0	1.46	2.82	87
	60°C	12.5	10.3	1.37	2.84	88
	77°C	12.3	10.1	1.28	2.43	75
	93°C	12.4	8.1	1.12	2.13	66
2	Rimu air dried	13.1	9.9	1.38	3.05	100
	Pine air dried	12.5	10.7	1.42	2.80	92
	43°C	12.4	10.1	1.34	2.68	88
	60°C	12.2	9.9	1.30	2.60	85
	77°C	12.1	9.2	1.22	2.45	80
	93°C	12.1	8.0	1.09	2.23	73

Similar drying temperature effects were found with tawa, as shown in Table 4. The tawa specimens were all dried for the same time, but evidence in Table 5 indicates that temperature is more important than time in its effect on the stability of radiata pine, although the two probably interact. In this respect, high-temperature drying for 16 h at 115°C led to only slightly greater stability than drying at 77°C for 3 days, the normal commercial drying period for 25-mm boards. The difference between these two treatments (Table 5) was not significant overall (F = 3.02 for 1,22 degrees of freedom).

DISCUSSION

This study has shown radiata pine kiln-dried at normal commercial schedules (77°C) to swell 12-35% less than air-dried material in different runs under the same exposure conditions. After high-temperature drying at 115°C, material swelled 17-28% less than after air drying. Matched material dried at 77° and 115°C behaved similarly, indicating that these effects are time- as well as temperature-dependent, although extending the drying period at 77°C from 3 to 6 days (Table 5) did not cause any reduction in subsequent swelling. These results indicate that kiln drying can ensure maximum stability in service not only because it is possible to dry to the correct moisture for any particular end use, but also because kiln-dried timber will absorb moisture from a damp atmosphere more slowly than air dried timber. This difference between kiln- and air-dried timber might represent a width difference of less than 1 mm in a constructional situation. However, in practical terms, any reduction in the rate or range of dimensional change is beneficial in helping to reduce the inherent instability of wood in fluctuating conditions of exposure.

It is obvious from the results in Tables 2-5 that any prediction of the e.m.c. or relative stability of a timber should specify the history of the material, in particular the temperature at which it was dried. If the final column of Table 3 is compared with the short-term stability figures presented by Harris (1961), the two are similar only if the air-dried figures of Table 3 are used. Kiln-dried radiata pine sapwood (77°C) has a short-term stability factor (percentage swelling compared with that of sap rimu in the tangential grain direction over the same period) of 75-80, similar to figures for heartwood of radiata pine or rimu in Harris's table.

The limited data in Table 4 indicate that whitewood of tawa (containing sapwood and heartwood) shows the same tendency as radiata pine for stability to increase with increasing drying temperature. The tawa was more stable than radiata pine at the highest temperatures (77° and 93°C) compared with air-dried material. This might have been due to the combination of temperature and extended drying period used for this series. Kozlick (1973) showed that the heartwood of Douglas fir and western hemlock were affected in the same way by increasing drying temperature, but the effect on the latter species was not obvious at temperatures below 70°C.

The results in Table 2 are very similar to those reported for material exposed in the rough-sawn condition (Kininmonth and Williams, 1972). Thus the reductions in e.m.c. and the decreased rate of moisture uptake are not surface phenomena but involve the wood as a whole. Kozlik (1973) did not present any evidence as to the cause of these changes in properties, but obviously heartwood is affected as well as sapwood. Any

TABLE 4—Effect of drying temperature on rate of moisture uptake and swelling of tawa whitewood (mean of 5 specimens)

			After 24 h at 95% r.h.			
Adsorption cycle	Drying temperature °C	Moisture content (%)	Increase in m.c. (%)	Weight increase (g)	Swelling (%)	Relative stability
1	Air dried	12.5	7.1	1.81	2.5	100
	43	12.5	7.0	1.82	2.4	96
	60	12.0	6.3	1.66	2.1	84
	77	11.4	5.1	1.40	1.7	68
	93	10.9	3.9	1.02	1.4	56
2	Air dried	12.6	7.2	1.83	2.6	100
	43	12.9	6.8	1.83	2.3	88
	60	12.1	6.6	1.67	2.3	88
	77	11.6	5.5	1.41	1.7	65
	93	11.0	3.8	1.03	1.4	54

TABLE 5—Uptake of moisture after kiln drying at 77°C and 115°C (mean of 5 specimens per treatment)

A. Series 4

			After 24 h at 95% r.h.			
Adsorption cycle	Drying temperature °C	Moisture content (%)	Increase in m.c. (%)	Weight increase (g)	Swelling (%)	Relative Stability
1	Air dried	12.5	12.1	1.49	3.5	100
	77	12.1	9.1	1.21	2.9	83
	115	9.4	8.5	1.31	2.9	83
2	Air dried	12.5	12.4	1.53	3.5	100
	77	12.1	10.3	1.36	2.9	83
	115	11.2	9.9	1.31	2.7	77

B.Series 5

			After 24 h at 90 or 95% r.h.*			
Adsorption cycle	Drying temperature and times °C/days	Moisture content (%)	Increase in m.c. (%)	Weight increase (g)	Swelling (%)	Relative Stability
1	Air dried	12.9	12.2	1.83	3.6	100
	77/1	12.8	10.5	1.57	2.7	75
	77/3	11.9	9.6	1.42	2.6	72
	77/6	11.7	9.7	1.41	2.6	72
	115/†	11.1	9.4	1.37	2.3	64
2	Air dried	12.7	7.2	1.06	2.0	100
	77/1	12.3	6.9	1.03	2.0	100
	77/3	12.0	6.1	0.92	1.7	85
	77/6	11.7	6.3	0.91	1.7	85
	115/†	11.4	5.9	0.86	1.6	80

* The second cycle was carried out at 90% r.h. using a saturated solution of zinc sulphate.
† Drying time of 16 h

drying temperature effect is seen as a reduction in both moisture uptake and rate of swelling, and can therefore be explained as a reduction in hygroscopicity. It is not an anti-swelling effect because total swelling back to the saturated condition is unaffected. Neither is it simply a hysteresis effect because it persists for two cycles and even longer (Kininmonth, unpublished data) and can be regarded as a permanent effect as far as cycling within the hygroscopic moisture range is concerned. Birt (pers. comm.) has studied the rain-wetting of air-dried and kiln-dried radiata pine and found no difference in rate of water absorption.

The reduction in hygroscopicity caused by kiln-drying from the green state may be due to slight chemical changes occuring during the period, from less than one day (at 115°C) to several days, when the wood is subject to elevated temperatures while retaining high humidity internally. If this is so, kiln drying at high humidity should reduce hygroscopicity more than drying at lower humidity; Kozlik (1973) found this to be so. This may also account for the appreciable reduction in swelling after drying at 77°, 93°, and 115°C when other workers (e.g., Stamm *et al.,* 1946) required much higher temperatures to achieve similar results on dry wood. Stamm (1964) explained the latter effect: "the initial thermal degradation of wood results in furfural polymers of breakdown sugars that are less hygroscopic than the hemicelluloses from which they are formed". It still remains to be discovered why kiln-drying temperature affects the hygroscopicity of the wood.

CONCLUSIONS

(1) The rate of moisture uptake and swelling of radiata pine and tawa after drying decreases progressively as the drying temperature is increased from ambient to 93°C.

(2) Kiln drying of radiata pine for 3 days at 77°C, or for 16 h at 115°C, have similar effects on rate of moisture movement.

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