PRETREATMENTS TO HASTEN THE DRYING OF NOTHOFAGUS FUSCA

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ABSTRACT

Four different pretreatments were tested to accelerate drying of **Nothofagus fusca** (Hook. f.) Oerst. heartwood – prefreezing, compression rolling, steaming at 100°C, and soaking in hot water. Steaming improved the drying rate, but caused excessive fine internal checking in green wood; its use is restricted to treatment after predrying to about 40% mc. A short period of soaking in hot water at about 70°C reduced the drying time substantially and was the only treatment suitable for green timber. Neither prefreezing nor compression rolling had any effect on drying rate and both caused excessive degrade.

Keywords: drying; prefreezing; compression rolling; steaming; hot-water soaking; collapse; **Nothofagus fusca**.

INTRODUCTION

Timber of *Nothofagus fucsa* has a fine even texture and attractive reddish brown colour, is naturally durable, and has a good reputation for its excellent turning properties and stability.

Despite the presence of a large resource in New Zealand, utilisation of the species to date has been limited by two factors. The frequency of internal decay makes processing as sawn timber unattractive unless there is a facility for utilising defective logs and sawmill residues. The second factor restricting use of *N. fusca* is its refractory drying properties. The wood is so slow drying that 1 year of air drying for every 25-mm thickness is usually recommended, and, despite the lengthy drying period, considerable degrade in the form of collapse and checking still occurs.

Kininmonth (1971) attributed the slow drying of *N. fusca* to the presence of extensive encrustrations of polyphenolic extractives which occlude the cell lumina and pit membranes in the heartwood. In the sapwood, the lumina and pit membranes are rarely affected. Consequently the sapwood has moderate transverse permeability, whereas the heartwood is highly impermeable; this is reflected in the relative drying rates of sapwood and heartwood.

Several workers (e.g., Erickson *et al.* 1966); Erickson 1968; Cooper & Barham 1975) have found that prefreezing the timber of several species (including *Sequoia sempervirens* (D. Don) Endl., *Thuja plicata* D. Don, *Juglans nigra* L., *Eucalyptus regnans*

F. Muell., and *Populus deltoides* Marsh. 'Virginiana') prior to drying has reduced shrinkage and collapse. It was thought that tannins were important in reducing shrinkage after prefreezing because all these species have a high tannin content.

Compression rolling is also claimed to increase the drying rate and reduce the drying degrade of a variety of species of softwoods and hardwoods (Cech & Goulet 1968; Cech 1971). Gunzerodt *et al.* (1986) reported that compression rolling of *N. fusca* improved permeability and subsequent preservation treatment, but that it had no significant effect on drying.

Campbell (1961) reported that short periods of presteaming reduced the initial moisture content and increased the drying rate of three species of ash eucalypts without decreasing quality. Ordinario (1972) found similar results with the presteaming of *Shorea agsaboensis* Stern and the presteaming also reduced drying defects. Presteaming beyond 2 hours had no further effect in reducing drying times.

Although primarily interested in the effect of compression rolling, Gunzerodt *et al.* (1986) also assessed hot-water soaking. They reported that soaking at 90°C for 24 hours modified some of the extractives and this resulted in improved drying rates, particularly in the radial direction.

Considerable research has been carried out into ways of hastening the drying of *N. fusca* heartwood. This paper summarises the results of various pretreatments evaluated at the Forest Research Institute including prefreezing, compression rolling, steaming, and hot-water soaking.

MATERIALS AND METHODS

Work on prefreezing, compression, and some of the steaming was done on test material from the same source and the samples were dried together in one experimental kiln charge. The work on hot-water soaking was done several years later.

Prefreezing

Test material came from the areas designated for *Nothofagus* production in Westland and was obtained as part of a comprehensive sawing and drying study. The test lengths of 150 × 25-mm heartwood were selected at random and three matched series of 0.4-m sample boards were prepared. Two series were frozen, one in dry ice at –78°C and one in a domestic freezer at –5°C. No attempt was made to measure internal temperatures of the samples, but they were left in the "freezers" for 24 hours. To ensure rapid freezing the samples were precooled to 1°C prior to freezing. Shrinkage measurement points were located and measurements of dimension were taken before and after freezing, and after drying and conditioning to 12% mc. The third series of samples was not frozen and was used as a control.

All three series of samples, along with a further series from compression rolling, were kiln dried from fireen in a 2.4-m experimental kiln. Early curtailment of drying meant that some of the slower-drying samples still had a high moisture content, so it was not possible to use drying time to compare treatments – instead final moisture contents were used. The kiln schedule (Table 1) was also used for drying the compressed and some of the steamed samples.

Compression Rolling

Test material came from the same source as for the prefreezing trial, but the test lengths were resawn and planed to 100 × 25 mm. Two sets of matched 0.5-m samples were prepared, one for compression rolling and one as the control.

The simple compression rolling apparatus had limited ability to vary the factors affecting the rolling process. The samples were subjected to 10% compression with a roller diameter of 50 mm and feedspeed of 17 mm/s.

Shrinkage measurement points were located and measurements of dimension were taken before and after compression, and after drying and conditioning to 12% mc.

Both sets of samples were kiln dried from green according to the schedule in Table 1.

TABLE 1—Kiln schedule for combined drying of frozen, compressed, and steamed (Trial 2) 150 × 25-mm samples

Elapsed time (days)	Temperature (°C)	
	Dry bulb	Wet bulb
0	38.0	35.0
3	38.0	34.0
7 until 53	38.0	32.0

Steaming

Evaluation of steaming involved a series of studies. The initial study used 100 × 25-mm boards from the then current production of a Westland sawmill. Matched 0.6-m sample boards were prepared and treated as follows:

Steamed for 2 hours at 100°C
Steamed for 2 hours at 88°–93°C
Steamed for 6 hours at 88°–93°C
Not steamed (controls)

Immediately after green steaming all the flat-sawn boards exhibited extensive surface checking, with those steamed at 100°C being the worst. All the samples were then air dried in a 1.8-m-long stack, before finally being dried to 12% mc in a 1.8-m experimental kiln (Table 2).

Two additional sets of matched sample boards were prepared and placed in the first 1.8-m-long air drying stack. After 35 days of air drying one set was steamed at 100°C for 2 hours and then replaced in the air drying stack. When all the steamed sample boards were below 25% mc they were removed and kiln dried according to the schedule in Table 2. The controls were air dried for 13 months and then also kiln dried on the same schedule, but in a separate charge.

TABLE 2—Kiln schedule for drying of steamed samples (Trial 1)

Steaming treatment	Elapsed time (hours)	Temperature (°C)	
		Dry bulb	Wet bulb
Green steamed	0	60.0	54.4
	24	65.6	54.4
	48	65.6	48.9
	72	65.6	51.7
	96 until dry	65.6	62.8
Steamed after partial drying	0	60.0	54.4
	18	60.0	51.7
	42	65.6	54.4
	63	65.6	51.7
	86 until dry	65.6	62.8

Transmission and scanning electron microscopes were used to determine the effect of steaming on the fine structure of heartwood. End-matched pieces of heartwood obtained from the central North Island were either steamed for 3 hours at 100°C or used as unsteamed controls. Full details of sample preparation and procedure have been given by Kininmonth (1971).

A subsequent steaming trial sought to confirm previous results and also to provide a comparison with prefreezing and compression treatments which were dried in the same charge. From 150 × 25-mm lengths three matched sets of 0.5-m sample boards were prepared. Two sets were steamed for 2.5 hours at 100°C, one green and one after air drying to approximately 40% mc. The third set provided a control. Shrinkage measurement points were located and dimensional measurements taken.

The remaining test material was used to evaluate a proposed multi-stage commercial drying procedure. Two matched sets of 0.6-m sample boards and 2.4-m lengths were prepared and assembled into a small air drying stack. After air drying to approximately 30% mc, one set of sample boards and the 2.4-m lengths were removed and steamed at 100°C for 2.5 hours. After steaming, all the material was then restacked outside and allowed to air dry to approximately 20% mc. The material was then dried in a 2.4-m experimental kiln according to the schedule in Table 3.

TABLE 3—Kiln schedule for multi-stage drying evaluation

Elapsed time (days)	Temperature (°C)	
	Dry bulb	Wet bulb
0	54.0	49.0
1	57.0	49.0
2 until dry	60.0	49.0

Hot-water Soaking

All heartwood test lengths were obtained from the normal cut of a Westland sawmill. A similar procedure was used for all trials in that long lengths were crosscut to yield matched sets of 0.45-m sample boards. After soaking, the samples were end-sealed and shrinkage measurement points located.

The soaking was done in a stainless steel bath with two heater-stirrer units giving temperature control of ±1°C. Initial tests involved preheating the water to the required temperature and then plunging each complete set of cold boards into the hot water for the prescribed soaking period. To aid heat transfer the samples were filleted before soaking. After soaking the heaters were switched off but the stirrers left on and the water was allowed to cool to below 50°C before the samples were removed. Slow cooling was employed to minimise thermal shock and possible degrade.

For each soaking trial all the samples were dried in a forced-air dryer, stacked in such a manner as to balance positional differences between the soaking pretreatments. Initially the dryer was unheated but once all the samples were below approximately 40% mc electric heating was used to raise the temperature by approximately 10°C above ambient. As the dryer conditions did not approximate recommended commercial schedules it is relative and not absolute drying times and degrade which are of importance.

The initial trial involved 150 × 25-mm, 100 × 50-mm, and 75 × 75-mm material, at soaking temperatures ranging from 80° to 100°C. Since the main objective was to quantify the effect of hot-water soaking on drying timber of different sizes, only minor emphasis was given to identifying optimum soaking temperature and duration.

The second trial used only 100 × 25-mm samples which were soaked at temperatures ranging from 50° to 80°C for either 1 or 6 hours. This trial was undertaken to identify the minimum conditions (soaking temperature and duration) necessary to increase drying.

RESULTS

As many of the prefrozen, compressed, and steamed samples dried in the 2.4-m kiln did not dry below 30% mc, it was not possible to use drying times for comparison, and so final moisture contents after 53 days' kiln drying were used for the comparisons. Compared to the controls, prefreezing or compression had no significant effect on final moisture content (drying rate) or shrinkage (Table 4). Only steaming significantly reduced final moisture content, which confirms the initial results for steaming (Table 5).

Additionally, prefreezing and compression rolling were found to cause the development of internal checking in boards which had over 90% moisture saturation. Typically, the checks were numerous and fine; however, in the compressed samples they were often in the form of complete ring delaminations, as reported by Gunzerodt *et al.* (1986). Neither prefreezing nor compression rolling therefore appear to offer any advantages in the drying of *N. fusca.*

All the green steaming treatments reduced drying times, with steaming at 100°C generally giving the biggest response and the least variation (Table 5). Unfortunately, all the green steamed samples had either internal or surface checking, making this procedure commercially unacceptable. Steaming after partial drying reduced drying times but still caused the development of internal checking in four of the 10 samples, compared to none in the controls. Results of the later trials confirmed both the reduced drying times (Table 4) and the unacceptable checking after green steaming. However, steaming at 40% mc gave a positive response in drying rate with an acceptable level of checking.

TABLE 4—Final moisture content and average shrinkage to 12% mc of **N. fusca** sample boards (16 sample boards per treatment)

Treatment	Final mc (%)			Comparative F or t value	Shrinkage to 12% mc (%)		Comparative F or t value	
	Average	Min.	Max.		Thickness	Width	Thickness	Width
Prefreeze								
Dry ice	21.6	12.3	40.3		10.8	5.5		
Freezer	19.8	12.4	29.7	3.11 ns	11.7	5.5	0.87 ns	0.12 ns
Control	21.3	12.5	34.9		10.9	5.6		
Compression								
Compressed	17.3	12.8	27.1		11.8	5.4		
Control	19.1	12.4	38.2	1.56 ns	11.3	5.9	0.57 ns	2.82 ns
Steamed								
Steam green	13.7	10.4	20.3		11.7	6.4		
Steam 40%	15.5	12.3	32.1	24.72**	10.2	5.4	2.78 ns	1.77 ns
Control	23.3	13.6	49.4		11.1	5.7		

** significant difference at $p<0.01$
ns no significant difference

TABLE 5—Drying after steaming

Steaming treatment	Air drying			Kiln drying		
	Average initial mc (%)	Average time to 25% mc (days)	CV%	Average initial mc (%)	Average time to 14% mc (hours)	CV%
Steam green						
2 h at 100°C	108	108	16	14.7	5	52
2 h at 88°–93°C	106	113	23	14.7	6	68
6 h at 88°–93°C	104	119	28	15.4	10	76
Control	118	303	36	20.8	57	68
Steam after partial drying						
2 h at 100°C	114	114	11	20	58	62
Control	115	265	28	23	74	40

The initial hot-water soaking trial at temperatures of 80°–100°C showed favourable response with all treatments reducing drying times by at least one-third; actual temperature or duration had little effect. However, drying degrade was increased by more severe soaking conditions. Soaking at 100°C caused a similar pattern of internal checking to that of green steaming, and also some surface checking.

For 150 × 25-mm and 100 × 50-mm samples the lowest temperatures gave the least checking, but it was still worse than in the controls. In contrast, none of the 75 × 75-mm samples which were soaked at 80°C showed internal checking, whereas 33% of the control samples did (Table 6). It is likely that soaking increases the permeability of the heartwood, thereby reducing the stress differential throughout the thick cross-section and giving reduced drying degrade.

TABLE 6—Drying of samples after hot-water soaking

Sizes/ soaking treatment	Average drying time to 20% mc (weeks)	Average thickness shrinkage to 12% mc (%)	Number samples checked		Collapse
			Surface	Internal	
150 × 25 mm (12 samples)					
Control	11.4	4.8	1	0	Absent
80°C 12 h	7.0	6.4	4	0	Slight
90°C 12 h	7.1	7.8	6	4	Moderate
100°C 4 h	7.2	7.8	6	6	Moderate
100 × 50 mm (12 samples)					
Control	24.0	9.2	0	0	Slight
80°C 18 h	16.6	8.9	2	2	Slight
90°C 18 h	16.5	11.3	7	1	Moderate
100°C 8 h	15.5	17.8	7	6	Moderate
75 × 75 mm (9 samples)					
Control	48.2	7.1	0	3	Moderate
80°C 24 h	33.2	8.4	1	0	Slight
90°C 12 h	33.8	7.8	0	3	Slight

It seems that 25-mm-thick boards must be soaked at 70°C for 1 hour before a full response in drying rate is obtained (Table 7). Soaking at 50°C gave no significant reduction in drying time, and soaking at 60°C gave results intermediate to those at 50° and 70°C. No additional benefit was obtained from extending the soaking period beyond 1 hour. Soaking at 50°C gave the least degrade (but no reduction in drying time) but there were indications that low temperatures (70°C) or placing boards in cold water then heating both to 80°C gave less degrade than plunging the cold boards into hot water.

TABLE 7—Hot-water soaking of 100 × 25-mm material (15 sample boards per treatment)

Soaking treatment		Mean days drying to 15% mc*	Mean percentage shrinkage to 12% mc*	Number samples checked	
				Surface	Internal
50°C	1 h	80.9a	7.8b	0	1
50°C	6 h	76.2a	7.8b	2	3
60°C	6 h	50.8b	10.8a	7	6
70°C	1 h	38.3c	10.9a	7	4
70°C	6 h	34.5c	11.2a	6	3
80°C	1 h	33.7c	10.6a	7	6
80°C	6 h	33.9c	9.9a	6	4
Cold to 80°C†	6 h	36.0c	6.1b	4	2

* Means followed by the same letter are not significantly different at $p < 0.05$.
† Boards placed in cold water then both treated to 80°C.

DISCUSSION

Despite having appreciable concentrations of ellagitannins (Hillis & Orman 1962), which Cooper & Barham (1975) hypothesised were important preconditioners in the reduction of shrinkage and collapse after prefreezing, there was no improvement in the drying behaviour of *N. fusca.* Prefreezing neither increased drying rate nor reduced shrinkage.

Similarly, compression rolling of *N. fusca* had no significant effect on drying or shrinkage. These results plus the increased incidence of internal checking were confirmed by Gunzerodt *et al.* (1986), who found that, whereas compression rolling increased permeability and thus preservative uptake, it had no significant effect on drying.

There can be no doubt that steaming increases the drying rate of *N. fusca* but unfortunately the full benefits of presteaming cannot be obtained because green steaming causes excessive checking and therefore material must be dried to below 40% mc before steaming. As well as reducing over-all drying times, steaming has the added advantage of reducing the variability of drying rate, an important point in commercial drying. Whilst steaming at 88°–93°C gave reductions in drying time, there was considerably more variation than for material steamed at 100°C – hence the commercial recommendation for steaming at 100°C. Electron microscopy observations (Kininmonth 1971) showed the polyphenolic extractives which line the cell lumina and pit areas were blistered and often discontinuous after steaming and this is considered to explain the improved drying rate after steaming.

The success of a delayed steaming treatment led to recommendation of a multi-stage drying procedure for *N. fusca.* This process is broadly similar to that already used in Australia for drying ash eucalypt species. If predryer facilities (a large-volume low-temperature dryer) are available, steaming should be done after air drying to 40% mc; after steaming the material should be predried at up to 40°C until the moisture content is under 20% (wettest piece less than 25%). Material should be finally dried in a conventional kiln. Alternatively, where no predrying facilities are available, the initial period of air drying should be extended until the material is under 30% mc, after which steaming should be done. Material may then be finally kiln dried, albeit at slightly less severe conditions and for a longer period than if it had been in a predryer.

The four-stage drying process has not been adopted commercially in this country. The repeated handling of material requires well-planned facilities and the provision of a predryer, steaming chamber, and kilns necessitates a substantial capital commitment. As yet only one processor of *N. fusca* has installed a steaming chamber. It should be noted that not only does steaming after partial drying increase subsequent drying rate and reduce variability, it also significantly reduces collapse which can occur even in preliminary air drying. Thus steam reconditioning can improve sawmill conversions.

Like steaming, hot-water soaking substantially reduced the drying time of *N. fusca.* Hot-water soaking at 100°C causes a similar pattern of degrade to that incurred by steaming green material, but fortunately a similar improvement in drying time can be obtained by soaking at lower temperature – as low as 70°C. Soaking at below 100°C decreases drying degrade and, unlike steaming at below 100°C, does not result in increased variability of drying times. Heating the boards and water together causes less degrade than plunging cold boards into preheated water.

Research has shown that a short period of soaking is effective. The first commercial application of soaking of 25-mm-thick material used 12- to 24-hour soaking periods, but the later trial has shown that there is no benefit in soaking for more than 1 hour from the time the wood is heated to the specified temperature. Temperature measurements using thermocouples (later confirmed by theoretical calculations) showed that filleted green 25-mm-thick boards were heated to 70°C through the entire cross-section in approximately 30 minutes. This shows that the beneficial effects of heat treatment are obtained in a shorter time and at a lower temperature than previously realised.

Thus, to obtain full response to soaking, the water temperature need not be over 70°C and the duration need not be much more than the time required to heat the entire cross-section to this temperature. Even when the severity of soaking conditions is minimised as recommended, hot-water soaking is generally accompanied by a slight increase in degrade. The one exception to this is for 75 × 75-mm material, which in the past has proved to be virtually impossible to dry without severe internal checking (of the type that develops late in drying). After soaking this material can be dried without substantial degrade.

Collapse is a feature of *N. fusca,* no matter how it is dried. Hot-water soaking tends to increase collapse, depending on the soaking temperature, so it does not dispense with the need to steam to recover this loss of dimension. To maximise conversion of logs to sawn timber, the hot-water soaking facility should also have a steam reconditioner to recover collapse, thereby avoiding the need to saw over size.

To date work on steaming, and particularly hot-water soaking, has concentrated on determining whether these pretreatments improve the drying of *N. fusca.* Additional work can now be initiated to quantify the effect of these treatments on properties such as dimensional stability, strength, and machining. Adoption of hot-water soaking also requires the development of kiln schedules for drying after soaking.

CONCLUSIONS

Neither prefreezing or compression rolling has favourably affected the drying of *N. fusca* heartwood and it is unlikely that these pretreatments warrant further investigation.

Both steaming and hot-water soaking cause partial relocation of polyphenols resulting in substantial improvements in drying times. Degrade in green material after steaming at 100°C is severe enough to preclude its use; material must first be air dried to below 40% mc if degrade is to be minimised. Commercial drying procedures including steaming after partial drying have been recommended.

The advantage of soaking over steaming is that an improvement in drying rate can be obtained from the commencement of drying without excessive degrade. Recommendations on commercial operating procedures for hot-water soaking have been published (Haslett 1986). Improvements in drying attributable to soaking could provide the impetus necessary to initiate further specialist use of the large *Nothofagus* resource available in New Zealand.

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