COMPRESSION ROLLING AND HOT-WATER SOAKING: EFFECTS ON THE DRYING AND TREATABILITY OF NOTHOFAGUS FUSCA HEARTWOOD

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ABSTRACT

Compression rolling improved the permeability of **Nothofagus fusca** (Hook f.) Oerst (red beech) and increased its preservative uptake by up to a factor of six (compared to unrolled controls), without having a substantial effect on the drying rate. Hot-water soaking improved drying, particularly in the radial direction, but had little effect on the permeability. A combination of both treatments conferred no additional benefits over those found for the two individual treatments.

Microscopic observation revealed the probable causes of these results. After compression rolling, the vessel structure (especially tyloses, perforation plates, and vessel to vessel pits) frequently showed deformation, rupture, collapse, and other signs of damage. Thus pathways within the vascular system were reopened for fluid flow. On the other hand, hot-water soaking did not affect the vessel structure substantially, but there was a relocation and partial removal of the extractives encrusting the ray parenchyma cell walls and pit membranes, with a resultant increase in drying rate, which for flat-sawn boards was twice that of unsoaked controls.

Keywords: compression rolling; hot-water soaking; moisture content; timber drying; **Nothofagus fusca**.

INTRODUCTION

Numerous biological, chemical, and mechanical methods have been evaluated in an effort to improve wood permeability and diffusivity. Although many of these processes have had positive results either in drying or treatability, few have found commercial application. Compression rolling has been the subject of study over the last 20 years. With hardwoods (Table 1) it has been claimed that it can reduce the drying time for refractory timbers and/or ameliorate degrade during drying (Goulet & Cech 1967; Cech & Goulet 1968; Goulet 1968; Cech 1971; Cech & Pfaff 1975, 1977). In *Betula alleghaniensis* Britton (yellow birch) this increased drying rate was attributed to splits in the pit membranes of the bordered pits (Cech 1971). With softwoods (Table 2) studies have centred on the use of compression rolling to improve preservative uptake. The results of all these studies are somewhat contradictory and inconclusive (Tables 1 and 2).

Steaming or hot-water soaking has also been used with varying degrees of success to improve both drying and preservative treatment of wood. Steaming of green woods has not proved successful with *Nothofagus fusca* (Kininmonth 1971a; A. N. Haslett & J. A. Kininmonth unpubl. data) where internal checking is a serious problem. However, vats for hot soaking of green sawn *Nothofagus* spp. prior to drying have been installed at one sawmill in North Westland.

Nothofagus spp. forests form the largest indigenous wood resource in New Zealand. However, *N. fusca* forest has not been widely utilised, partly because its timber is notoriously defective and partly because it takes so long to dry. In this study compression rolling and hot-water soaking were evaluated as a pretreatment for the drying and preservative impregnation of *N. fusca*. Because the heartwood has a high natural durability, preservative treatment is only of academic interest. However, part of the confusion in the literature on compression rolling arises from softwood studies being centred on preservative treatment while hardwood studies consider only the problem of drying (Tables 1 and 2).

MATERIAL AND METHODS

The compression rolling device designed for these experiments has been described previously (Günzerodt *et al.* 1984; Günzerodt 1985). The machine has control over those treatment factors which were considered of importance for optimising the process – roller diameter, compression level, and feed speed – and which were incorporated in the statistical analysis.

Two logs (length 5000 mm; diameter (over bark) 870 mm) of mature *N. fusca* were selected from a stand in Maimai State Forest, North Westland. Sixteen baulks (c. 100 × 100 mm in cross-section) were selected from each log, avoiding pith, sapwood, and defective areas (such as decayed tissue, pin-holes, or discoloured wood). From these, 240 specimens were cut (50% quarter-sawn and 50% flat-sawn), planed, and reduced to their final dimension (650 × 100 × 25 mm). The mean basic density was 510 kg/m^3.

Initially 144 specimens were compression rolled in the green condition (moisture saturation level between 80% and 95%). Replication considered both inter- and intra-specific variability with a four-fold replication of each treatment, taking one sample from the top and butt sections of each log. The preparation and allocation of samples to different treatments followed a random selection procedure (Günzerodt 1985). The treatment factors considered were roller diameter (50.6 and 206.8 mm), compression level (7, 10, and 13%), feed speed (800, 1600, and 2400 mm/s), and grain orientation (flat- and quarter-sawn). However, with the original design configura-

TABLE 1—Compression rolling of timber – hardwoods

Species tested and characteristics	Compression machine: Roller diameter (mm)	Compression machine: Feed speed (mm/s)	Compression machine: Compression (%)	Process	Results and remarks	Source
Acer saccharum Basic density 610 kg/m^3 ?heartwood; permeable; flat-sawn; ?green.	114	254	14	Drying	Moderate improvement in drying characteristcs. 24% strain in surface zone & 5% strain in core. **Three-paragraph summary of unpublished work.**	Grozdits & Chauret (1981)
Betula alleghaniensis Basic density 640 kg/m^3; heartwood; mod. resistant; flat-sawn; green.	127	51–254	5 7.5	Drying	Quality compares to kiln-dried but dried x6 as fast. No micro-checking observed. Most deformation recovered. **First article on compression rolling.**	Cech & Goulet (1968)
	114	254	8.5 12.5	Drying	Possible to HT dry without excessive collapse & checking. Av. 20% increase in radial moisture conductivity at 8.5% compression. SEM photo of ruptured pit membranes. **Mechanical deformation/shear or hydraulic pressure may rupture vessel pit membranes.**	Cech (1971)
Betula papyrifera Basic density 540 kg/m^3; ?heartwood; mod. resistant; flat-sawn; ?green.	114	254	18	Drying	Vessel pits burst "during deformation", due to their small size. As a result, drying time & degrade substantially reduced. 28% strain in surface zone, 10% strain in core. **Deformation more uniform than in other species studied. Confusion as text refers to yellow & white birch.**	Grozdits & Chauret (1981)
Eucalyptus obliqua Basic density 490 kg/m^3; heartwood; v. resistant; ?flat- /quarter-sawn; 110% mc. **Eucalyptus regnans** Basic density 370 kg/m^3; juvenile; v. resistant; ?flat- /quarter-sawn; 190% mc.	50	17	10	Drying	No improvement in drying rate and little effect on shrinkage or checking. **Roller diameter & feed speed unlikely to be optimal, but dynamic compression of highly saturated wood at higher feed speeds is likely to rupture wood tissue.**	A. N. Haslett & J. A. Kininmonth (unpubl. data)
Basic density 700 kg/m^3; heartwood; v. resistant; ?flat- /quarter-sawn; 110% mc.	?	?	?	Drying	No improvement in drying. **Little detail; emphasis on other issues.**	Campbell (1978)
Nothofagus fusca Basic density 530 kg/m^3; mainly heartwood; v. resistant; flat-sawn; 88% mc. **Nothofagus truncata** Basic density 600 kg/m^3; mainly heartwood; v. resistant; ?flat- /quarter-sawn; 85% mc.	50	17	10	Drying	Severe internal checking and shear failure. 25% of **N. fusca** and 75% of **N. truncata** have these defects. **Roller diameter & feed speed unlikely to be optimal, but dynamic compression of highly saturated wood at higher feed speeds is likely to rupture tissue.**	A. N. Haslett & J. A. Kininmonth (unpubl. data)
Populus tremuloides Basic density 450 kg/m^3; ?heartwood; resistant; flat-sawn; ?green.	114	254	18	Drying	No improvement in drying characteristics. Large window-like vessel pit membranes stretched but remain unruptured. 32% strain in surface zone and 3% strain in core. **Three-paragraph summary of unpublished results.**	Grozdits & Chauret (1981)
Quercus rubra Basic density 650 kg/m^3; ?heartwood; resistant; ?flat- /quarter-sawn; 80% mc.	114	254	7.5	Drying	Slight decrease in drying time. Not of economic significance. **Main emphasis on other issues. Lacks detail.**	Cech & Pfaff (1975)

TABLE 2—Compression rolling of timber – softwoods

Species tested and characteristics	Compression machine: Roller diameter (mm)	Feed speed (mm/s)	Compression (%)	Process	Results and remarks	Source
Abies amabilis Basic density 430 kg/m³; heartwood: mod. resistant†; ?flat- /quarter-sawn; ?green.	152	254	10	Creosote CCA	Statistically greater min. & av. face penetration. Best uptake & penetration of six species studied. **Uptake variable, following some annual rings with EW preferred. Low-density wood treats better.**	Cooper (1973)
Picea glauca Basic density 430 kg/m³; heartwood; v. resistant; ?flat- /quarter-sawn; 28–50% mc.	152	254	10–15	Creosote CCA	1–2 mm face penetration at best. Inadequate treatment. **A more severe schedule with creosote induced collapse & improved penetration very little.**	Cooper (1973)
Basic density 430 kg/m³; heartwood; v. resistant; flat-sawn; 20% & 30% mc.	114	254	17.5* at 30% mc 12.5* at 20% mc	CCA	Superior treatment to steaming. 50% increase in uptake & 35% increase in penetration at 20% mc. 10% loss of MOR at most. **Treatment at 20% mc favoured. Would expect greater* uptake & penetration at lower mc (noted in controls).**	Cech & Huffman (1970)
Basic density 430 kg/m³; heartwood; v. resistant; flat-sawn; 33–45% mc.	114	254	15*	Creosote	Uptake & penetration increased 60%. Effective treated zone increased from 1.5 to 5 mm with reasonable creosote loadings. **Greater penetration in rolled face. Tangential penetration on the edge is acceptable even with controls via unaspirated LW pits.**	Cech & Huffman (1972)
Basic density 430 kg/m³; heartwood; v. resistant; flat-sawn; 57, 25, 20, & 17% mc.	114	254	12.5–17.5	CCA	Uptake 40% greater & penetration 30% greater at all mc. Significant interaction between mc & compression. Min. penetration while improved ×4 is shallow – 3.5 mm on face, 2.5 mm on edge. **Uptake & penetration of controls greater than in previous studies by Cech, especially on drying below 20% mc.**	Cech *et al.* (1974)
Basic density 430 kg/m³; heartwood; v. resistant; flat-sawn; green.	114	254	11	Drying	No change in drying rate or degrade. Strain is superficial, c. 19% in surface zone and 2% in core. **Three-paragraph summary of unpublished work.**	Grozdits & Chauret (1981)
Pinus contorta Basic density 400 kg/m³; heartwood; v. resistant; ?flat- /quarter-sawn; 28–50% mc.	152	254	10–15	Creosote CCA	Statistical increase in creosote uptake & min. & av. face penetration, but only 0.4 & 1.1 mm respectively at 10% compression. **Improvement negated by excessive collapse if harsher schedules tried.**	Cooper (1973)
Pinus radiata Basic density 400 kg/m³; sapwood; permeable; flat-sawn; dry/redried.	?	140	10–20	HT drying	Slightly fewer checks when rolled green. Not effective when rolled dry. **Checking on redrying cannot be prevented.**	Berni & Christensen (1979)
Pinus strobus Basic density 380 kg/m³ heartwood; mod. resistant; flat-sawn; green.	114	254	15	Drying	Moderate distribution of deformation, c. 22% in surface zone & 8% strain in core. **Three-paragraph summary of unpublished work.**	Grozdits & Chauret (1981)
Pseudotsuga menziesii Basic density 500 kg/m³; heartwood; v. resistant; ?flat- /quarter-sawn; 28–50% mc.	152	254	15	Creosote CCA	With Interior DF 15% compression only increased min. & av. penetration to 2 & 3 mm. **Severe treatment schedule with creosote induced collapse.**	Cooper (1973)
Basic density 500 kg/m³; heartwood resistant; ?green.	?	?	10	FCAP	Uptake increased ×3.5 in flat-sawn boards & ×1.75 in quarter-sawn boards. Influence of rupture & stretching of pit membranes inferred from these uptakes. **Summary of unpublished work.**	Nicholas (1973)
Tsuga heterophylla Basic density 460 kg/m³; heartwood; mod. resistant; ?flat-sawn; ?green.	152	254	10	Creosote CCA	Initial study showed substantial improvement for both sapwood & heartwood. In this expt. a statistical increase in uptake of creosote by heartwood. **High longitudinal permeability helps get uniform penetration.**	Cooper (1973)

* Optimal compression
† Permeability

tion of the compression rolling machine the 25-kW drive motor was unable to achieve the feed speeds desired and a single feed speed of 1000 mm/s was used instead.

In addition 32 samples were soaked for 20 hours in hot water at 90°C. Twenty-four of these boards were compression rolled while hot and immediately wrapped in polyethylene together with the other eight which were soaked in hot water but not rolled. Subsequently all samples were dried under controlled conditions. The hot-water soaking treatment was a separate experiment and was not included in the multi-factorial experiment just described.

Sixteen flat-sawn boards from the original two logs of *N. fusca* were air dried and conditioned to 20% moisture content (mc). Twelve of these flat-sawn replicates were compression rolled to establish the effects this had on timber dried to below fibre saturation, four at each of the compression levels 7%, 10%, and 13%, and the other four samples were kept as unrolled controls.

Drying

All replicates were endcoated with a two-component epoxy resin adhesive and randomly stacked to a height of 500 mm using 20 × 20-mm fillets, in a controlled climate room (*see* Table 3 for drying schedule).

To ensure even drying, the sequence of the boards in each stack was altered and the stacks themselves were rotated round the room to selected positions every second day during the first 7 weeks and every 3 days thereafter, following a predetermined statistically randomised procedure. Replicates were weighed every 2 days during the first 48 days and at 3-day intervals thereafter.

Preservative Treatment

After drying the replicates were cross-cut into three pieces – two short boards and one central cross-section; the latter was oven dried to estimate the moisture content of the original board. The two remaining "halves" were endsealed with two coats of epoxy resin and eight replicates for each rolling treatment were subsequently impregnated with copper-chrome-arsenate (CCA) salts. The NZ Timber Preservation Authority's schedule (TPA 1986) for the Bethell (full cell) process was used, but with the final vacuum omitted: thus the timber was subjected to an initial vacuum of –85 kPa for a period of 30 min and then immersed in preservative and pressure-treated for 2 hours at 1385 kPa. After treatment the samples were allowed to stand for a few minutes to dry superficially before final weighing to determine the uptake of CCA solution. Subsequently each sample was cut in two and a spot-test for the presence of copper (chrome-azurol S test – TPA 1986) was used to differentiate the preservative-penetrated areas in the cross-section from unpenetrated areas. Measurements at four fixed points on both top and bottom surfaces of each board were used to determine the average depth of preservative penetration. This method was chosen after establishing that preservative penetration was uniform enough to be represented by such measurements. Edge penetration was negligible and unaffected by compression rolling (Fig. 1) and was not determined.

TABLE 3—Drying schedule for the controlled-climate room

Treatments	Dry bulb (°C)	Wet bulb (°C)	Relative humidity (%)
Day 1-4	19.0	18.5	95-100
Day 4-28	24.0	23.0	90
Day 28-49	25.0	22.5	84
Day 49-60	26.0	23.0	78
Day 60-68	27.0	23.0	74
Day 68-72	29.0	25.0	68

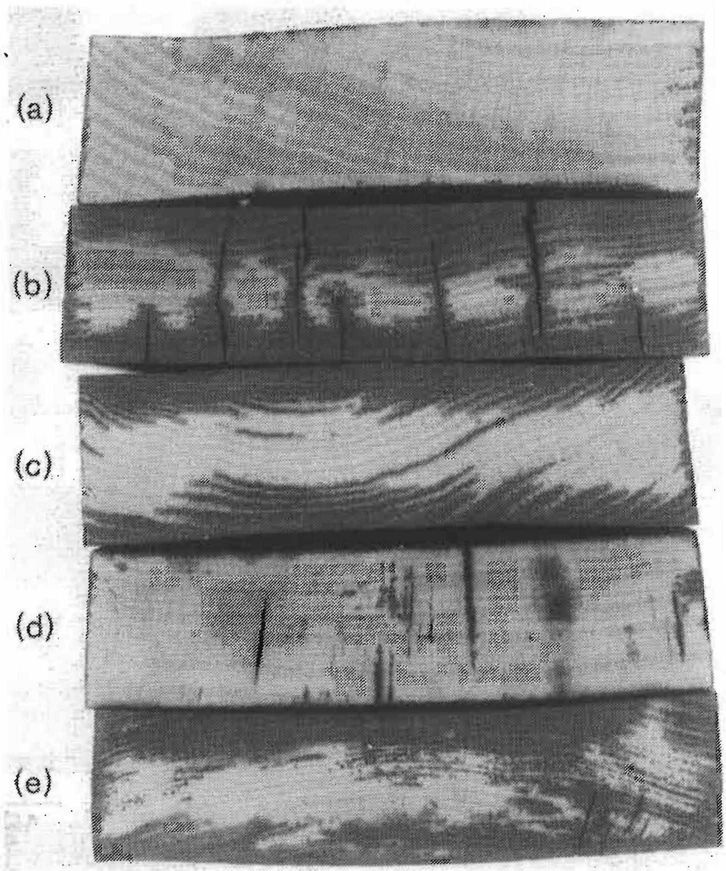

FIG. 1—Preservative penetration of flat-sawn **N. fusca**.

(a) Control, showing little face or edge penetration by CCA preservative.
(b) Green wood (c. 120% mc) rolled between 206.8-mm-diameter rollers at 1000 mm/s with 13% compression. Significant face penetration.
(c) Rolled as in (b) but at 20% mc. Penetration is comparable but with little macroscopic wood failure.
(d) Hot soaked, giving uptake comparable to that for (a). Lateral penetration from checks is not great (compare (d) and (b)).
(e) Hot soaked and rolled (conditions as for (b)). Uptake is comparable to (b) but with fewer checks.

RESULTS

Drying

Differences in the drying rate of flat- and quarter-sawn boards after various pre-treatments were assessed by comparing the slope of the drying curves for the individual boards, and establishing a relationship between moisture content and time. The following equation was used to describe the drying curve above fibre-saturation point.

$$\mathrm{Ln}\ (Y) = \mathrm{Ln}\ (A) + t\ \mathrm{Ln}\ (C)$$

where Y represents percentage moisture content and t the drying time in weeks. A corresponds to the original moisture content which was approximately 120% in all boards. Ln (C) characterises the drying slope, and is used as the indicator for the drying rate in the analysis of variance (Table 4).

TABLE 4—Effect of compression rolling of green **N. fusca** (c. 120% mc) on drying and preservative treatment (feed speed 1000 mm/s)

Treatments	Variables					
	Drying rate (°C)		Preservative uptake (%) (wt/wt basis)		Preservative penetration (mm)	
Control						
Quarter-sawn†	-0.13		7.8		1.9	
Flat-sawn†	-0.12		6.2		1.5	
Roller diameter (mm)	50.6	206.8	50.6	206.8	50.6	206.8
Compression 7%						
Quarter-sawn	-0.13	-0.13	20	26	5.2	6.4
Flat-sawn	-0.15	-0.15	17	21	4.5	5.2
Compression 10%						
Quarter-sawn	-0.15	-0.15	27	32	6.8	7.8
Flat-sawn	-0.16	-0.16	23	29	5.8	7.0
Compression 13%						
Quarter-sawn	-0.15	-0.16	31	39	7.6	9.5
Flat-sawn	-0.16	-0.18	32	38	7.9	9.4
Significance arising from analysis of variance						
Roller diameter	*		***		***	
Compression	***		***		***	
Grain orientation	***		***		***	
2-way interactions:						
Diameter/compression	*		ns		*	
Diameter/orientation	ns		ns		ns	
Compression/orientation	ns		**		**	
3-way interaction	ns		ns		ns	

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
† = grain orientation

Statistically significant increases in drying rate were noted with increasing compression levels (Table 4) but this was accompanied by severe macroscopic damage, especially at the higher compression levels (*see* "Ultrastructural Changes"). In contrast, the hot soaking pretreatment resulted in significantly faster drying compared to the controls (Table 5) without showing macroscopic damage. Compression rolling after the hot soaking pretreatment led to little further increase in drying rate and induced

TABLE 5—Effect of hot-water soaking† and compression rolling of **N. fusca** (c. 120% mc) on drying and preservative treatment (roller diameter 206.8 mm; feed speed 1000 mm/s)

Treatments	Variables					
	Drying rate (°C)		Preservative uptake (%) (wt/wt basis)		Preservative penetration (mm)	
Hot soaked	No	Yes	No	Yes	No	Yes
Control						
Quarter-sawn‡	-0.12	-0.21	7.7	9.3	1.7	2.3
Flat-sawn‡	-0.13	-0.26	7.1	7.0	1.8	1.8
Compression 7%						
Quarter-sawn	-0.13	-0.23	26	12	6.3	3.0
Flat-sawn	-0.15	-0.25	23	13	5.6	3.2
Compression 10%						
Quarter-sawn	-0.15	-0.24	34	20	8.4	5.0
Flat-sawn	-0.16	-0.22	28	15	6.8	3.8
Compression 13%						
Quarter-sawn	-0.15	-0.20	37	29	9.0	7.3
Flat-sawn	-0.17	-0.25	38	25	9.5	6.1
Significance arising from analysis of variance of hot soaking						
Hot soak	***		ns		ns	
Grain orientation	***		ns		ns	
2-way interaction	**		ns		ns	
Significance arising from analysis of variance of hot soaking and compression						
Hot soak	***		***		***	
Compression	ns		***		***	
Grain orientation	**		***		***	
2-way interactions:						
Soak/compression	*		ns		ns	
Soak orientation	ns		ns		ns	
Compression/orientation	*		*		**	
3-way interaction	ns		**		**	

ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
† = Hot soaked boards were rolled hot
‡ = Grain orientation

similar but less severe damage to that observed in the unsoaked boards (Table 5). Consequently, compression rolling does not offer any prospect for enhanced drying of *N. fusca* heartwood. Haslett & Kininmonth (1986) reached similar conclusions, but under very different rolling conditions.

Permeability

A considerable improvement in permeability of *N. fusca* can be achieved by compression rolling under all treatment conditions (Table 4). A six-fold increase in both preservative uptake and penetration was noted when flat-sawn boards were subjected to 13% compression between 206.8-mm-diameter rollers.

Some macroscopic damage in the form of tangential and radial splits was observed. Surprisingly, these did not contribute substantially to further penetration and uptake of preservatives as little lateral movement of preservative from the immediate vicinity of the cracks was detected (Günzerodt *et al.* 1984; Günzerodt 1985). This observation was substantiated in an additional experiment, in which a small number of flat-sawn boards at 20% mc were compression rolled and then pressure treated. At the 13% compression level (roller size 206.8 mm; feed speed 1000 mm/s) preservative uptake increased six-fold on a weight to weight basis, i.e., 63.9% wt/wt against 10.5% wt/wt in controls. Again, the improvement in preservative uptake was substantial although these samples suffered no visual damage at even the highest compression level (cf. Fig. 1(a), (b), (c)). good penetration and uptake were not dependent on macroscopic failures.

The combination of hot-water soaking and rolling of green wood at all three levels of compression increased preservative uptake and penetration significantly, although to a lesser extent than compression rolling of unsoaked boards (Table 5). Macroscopic damage was still noticeable, especially at the higher compression levels, but it was less severe and with fewer checks which was presumably a function of rolling while the wood was still hot (Fig. 1(b), (d), (e)). Hot-water soaking alone increased preservative uptake and penetration in quarter-sawn boards slightly in comparison to unsoaked controls and had no effect on flat-sawn boards.

Ultrastructural Changes

The effects of compression rolling on the ultrastructure of *N. fusca* were dependent on the level of saturation at the time of rolling. High levels of saturation (around 90%) led to extensive macroscopic failure, particularly in the earlywood (Fig. 2). Damage was concentrated in the first place on radial vessel-to-vessel walls which in extreme examples induced a complete delamination between individual growth rings. Occasionally splits also extended across growth rings, mainly following the ray parenchyma. Rolling at the lower saturation level did not damage the wood to the same degree (Fig. 3).

Microscopic examination of compression-rolled boards at both saturation levels partially confirmed observations reported by Cech (1971) and Grozdits & Chauret (1981) since some pit membranes in the vessels were damaged. However, this should not be attributed solely to the rolling process because artefacts may be induced during drying and specimen preparation. More pronounced was the rupture of terminal ray cell walls and their pits, and the extensive damage to tyloses (Fig. 2, 3, 4).

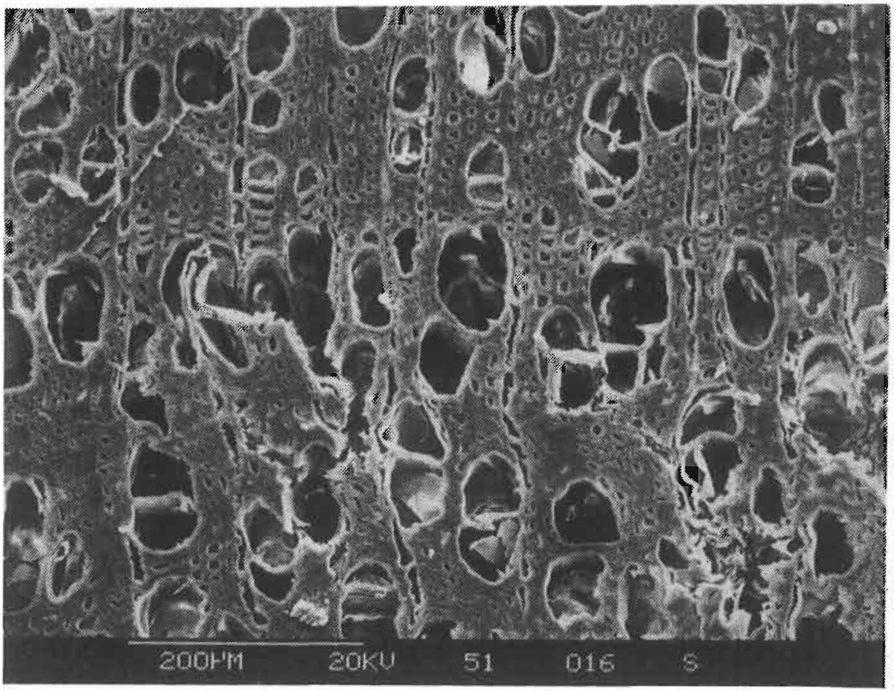

FIG. 2—**Nothofagus fusca** with severely damaged earlywood vessels as a result of rolling green wood (c. 120% mc) between 206.8-mm-diameter rollers at 1000 mm/s with 10% compression.

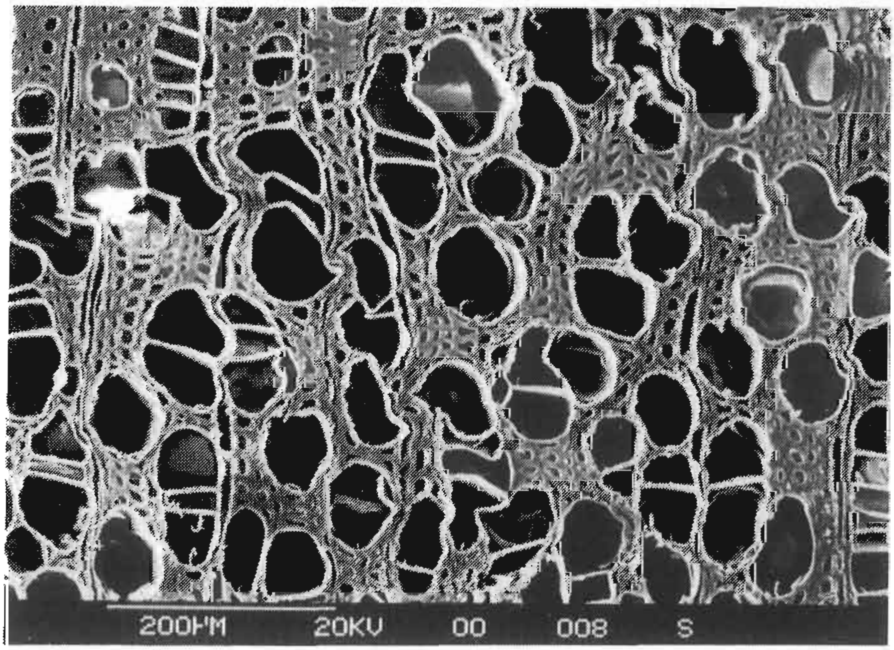

FIG. 3—**Nothofagus fusca** after compression rolling at 20% mc under the same conditions as in Fig. 2.

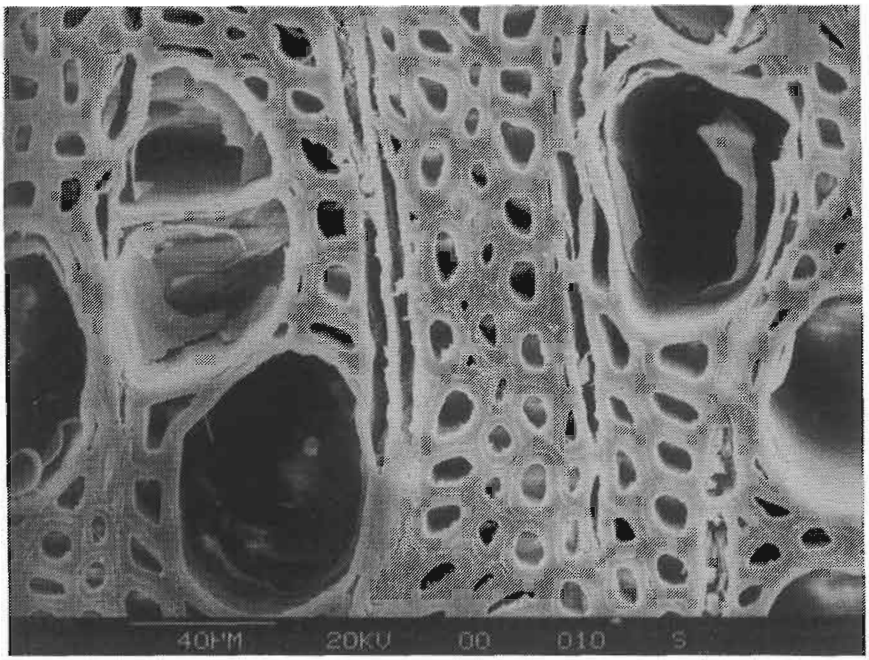

FIG. 4—Ruptured tyloses in **N. fusca** (rolling conditions as in Fig. 2).

The microscopic fracture pattern and the deformation of vessels were greater in the earlywood (Fig. 2) indicating that compressive strain and the pressures induced by displacing fluids were somewhat unevenly distributed during rolling. A grid pattern of overlapping circles printed on the edge of the green boards and photographed while passing through the rollers revealed that the deformation was extensive near the rolled surfaces of the boards and in localised zones which correspond to earlywood of low compressive strength. In the latter there can be localised collapse (Fig. 5). Although wood was subject to dynamic compressions as high as 13%, less than 1% was permanent.

Hot-water soaking by itself, and when applied to boards which were subsequently compression rolled hot, partially or completely cleared extractives from the surfaces of cell walls and pit membranes particularly within the ray parenchyma. The observations are similar to those described by Kininmonth (1971a) after steaming of *N. fusca* heartwood ". . . the uniform lining of the cell cavity in the natural condition was modified by steaming, forming discontinuous rounded bodies . . .", except that during hot soaking material is also leached from the wood.

DISCUSSION

The effect of compression rolling on wood structure, and any resulting structural damage, has received limited attention (Cech 1971; Grozdits & Chauret 1981). Thus the original findings of Goulet (1968) are still not fully explained or confirmed. Goulet (1986) claimed in his patent that savings of the order of 60% in drying time could

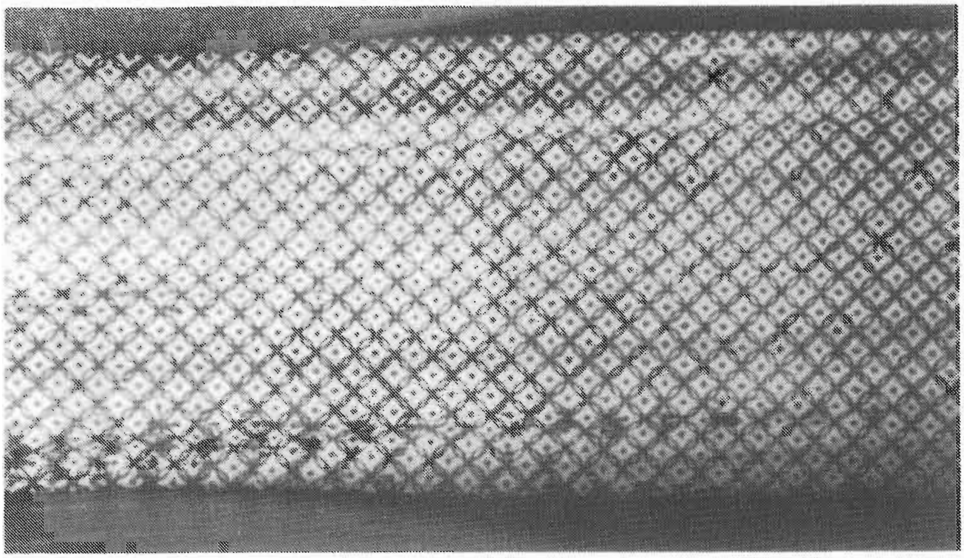

FIG. 5—Deformation of the grid pattern (printed on the edge of a flat-sawn board) while passing out from between the rollers (rolling conditions as in Fig. 3). The compression of the wood is not uniform but is concentrated in the region adjacent to the rollers, where there is extensive localised collapse associated with earlywood of low compressive strength.

be achieved after compression rolling of *Betula alleghaniensis.* Subsequent application of the process to several slow-drying hardwoods (Table 1) did not produce the expected improvement in drying behaviour. Two observations from the experiments with *N. fusca* help explain some of the apparent contradictions in the literature.

Firstly, anatomical alterations in both flat- and quarter-sawn boards during compression rolling were confined to the axial sap-conducting tissue (primarily vessel walls, perforation plates, and tyloses), while damage to transverse pathways (ray-to-ray walls, ray-to-ray pits, and fibre-to-fibre pits) was limited to areas adjacent to vessels.

Secondly, despite the small differences between earlywood and latewood in diffuse porous *N. fusca,* damage was more pronounced in the former, especially when compression rolled at high saturation levels (Fig. 2). This implies that the strain during rolling was unevenly distributed, and a homogeneous alteration to the microstructure cannot be presumed (Fig. 5). Thus the earlywood bands in Fig. 2 and 3 may well have been subject to a localised dynamic strain of 30–50% although they now show little permanent strain. Much of the dynamic deformation was confined to the surface regions (Fig. 5). Grozdits & Chauret (1981) observed considerable variation in the depth of deformation – very shallow for *Populus tremuloides* (Michx. (c. 32% strain in the outer zone and c. 2% strain in the central 50% of the board) and far more homogeneous for *Pinus strobus* L. (c. 22% strain in surface and c. 8% strain in the core). Wood density wood density variation across the annual ring, and orientation of the wood rings with respect to the rollers are the obvious wood characteristics which will determine the distribution of the strain and the effectiveness of compression rolling.

Compression rolling demonstrated that structure and condition of the vessels play an important role in the preservative treatment of hardwoods. Thomson & Koch (1981), who worked on the treatability of *Fagus, Quercus,* and *Carya* spp., and Juacida (1978) with *Nothofagus coiqüe* (Chilean beech) have related the low permeability of these timbers to the presence of occlusions in their vessels. *Nothofagus fusca* clearly belongs to the same grouping of impermeable woods. Kininmonth (1971b) and Thomson & Koch (1981) suggested that an improvement in axial permeability is possible if the thin-walled tyloses could be ruptured or removed. This was confirmed in this study. The rupture of many tyloses during compression rolling resulted in a substantial improvement in preservative uptake and penetration in axial and tangential directions, primarily in the earlywood but more irregularly in the latewood, as well as some limited preservative penetration of ray parenchyma and fibres which was mainly restricted to zones adjacent to vessels.

Since impermeable timbers lack paths for mass flow, their drying involves bound water diffusion across cell walls even at high levels of saturation. A major improvement in moisture movement can be achieved only by creating continuous pathways in the transverse plane. This was not accomplished by the compression rolling of *N. fusca.* On the other hand, the separate hot-water soaking treatment modified the lining within the ray parenchyma and removed some of the extractives, which resulted in an improved drying rate particularly in the radial direction (Table 5).

The importance of vessels as pathways for preservative penetration is further demonstrated in the hot-water soaking treatment; as with steaming, hot-water soaking does not re-open void spaces through either de-aspiration or rupture of pit membranes or the destruction of tyloses (Kininmonth 1971a). Thus hot soaking does not enhance penetration of the vessel tissue. The ray parenchyma in hardwoods, on the other hand, is generally not penetrated during pressure treatment (Thompson & Koch 1981), so that alterations to the parenchymous tissue during hot soaking have little influence on the over-all uptake.

It remains to be tested whether the results of this study can be applied to similarly structured timbers to improve their treatability. Research could then concentrate on species of greater commercial interest which often cannot be treated to an acceptable standard (for example, *Populus* spp. and *Fagus sylvatica* L.).

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REFERENCES

BERNI, C. A.; CHRISTENSEN, F. J. 1979: Influence of dynamic transverse compression and redrying conditions on internal checking in 45 mm thick CCA treated radiata pine. 19th Forest Products Research Conference (topic 4A/9), CSIRO, Highett, Australia.

CAMPBELL, G. S. 1978: The drying of ash-type eucalypts. **Australian Forest Industries Journal 44(7):** 29–36.

CECH, M. Y. 1971: Dynamic transverse compression treatment to improve drying behaviour of yellow birch. **Forest Products Journal 21(2):** 41–50.

CECH, M. Y.; GOULET, M. 1968: Transverse compression treatment of wood to improve its drying behaviour. **Forest Products Journal 18(5):** 90–1.

CECH, M. Y.; HUFFMAN, D. R. 1970: Dynamic transverse compression treatment of spruce to improve intake of preservatives. **Forest Products Journal 20(3):** 47–52.

——— 1972: Dynamic transverse compression results in greatly increased creosote retention in spruce heartwood. **Forest Products Journal 22(4):** 21–5.

CECH, M. Y.; PFAFF, F. 1975: Kiln-drying of 1-inch red oak. **Forest Products Journal 25(8):** 30–7.

——— 1977: Dynamic transverse compression. Kiln operators manual for Eastern Canada. **Eastern Forest Products Laboratory, Ottawa, Report OPX 192E.**

CECH, M. Y.; PFAFF, F.; HUFFMAN, D. R. 1974: CCA-Retention and disproportioning in white spruce. **Forest Products Journal 24(7):** 26–32.

COOPER, P. A. 1973: Effects of species, precompression and seasoning on heartwood preservative treatability of six western conifers. **Forest Products Journal 23(7):** 51–9.

GOULET, M. 1968: Methode de séchage des bois massifs. Canadian Patent, No. 790832.

GOULET, M.; CECH, M. 1967: Traitement de compression transversale des bois en vue de faciliter leur séchage – Essais préliminaires. **Note Technique: Department d'Exploitation et Utilisation des Bois, Université Laval.**

GROZDITS, G.; CHAURET, G. 1981: Influence of wood-structure on seasoning and gluing: Application of wood anatomy in research and development. **Forest Products Journal 31(2):** 28–33.

GÜNZERODT, H. 1985: The effects of compression rolling on sawn timber. Ph.D. thesis, University of Canterbury, Christchurch, N.Z.

GÜNZERODT, H.; JOHNSTON, G.; WHYBREW, K.; WALKER, J. C. F. 1984: Compression rolling of **Nothofagus fusca. Proceedings of the Pacific Timber Engineering Conference, Auckland, New Zealand, 2:** 675–82.

HASLETT, A. N.; KININMONTH, J. A. 1986: Pretreatments to hasten the drying of **Nothofagus fusca. New Zealand Journal of Forestry Science 16:** 237–46.

JUACIDA, L. R. 1978: Untersuchungen über die anatomische Struktur,natürliche Dauerhaftigkeit und Imprägnierbarkeit von 4 chilenischen Laubhölzern. Ph.D. thesis, University of Hamburg.

KININMONTH, J. A. 1971(a): Effect of steaming on the fine structure of **Nothofagus fusca. New Zealand Journal of Forestry Science 1(2):** 129–39.

——— 1971(b): Permeability and fine structure of certain hardwoods and effects on drying: Transverse permeability of wood to micro-filtered water. **Holzforschung 25(4):** 127–33.

NICHOLAS, D. D. 1973: Experimental determination of the effect of dynamic transverse compression on Douglas fir heartwood. **Quoted in** "Wood Deterioration and its Prevention by Preservative Treatments" Vol. 2, p. 331. Syracuse Wood Science Series No. 5 Wilfried Côté, Syracuse University Press, New York.

THOMPSON, W. S.; KOCH, P. 1981: Preservative treatment of hardwoods: A review. **USDA Forest Service, General Technical Report SO-35.**

TPA 1986: "Timber Preservation in New Zealand: Specifications." Timber Preservation Authority, Wellington.