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Araucaria Sector Research – 3-Year Program

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Queensland **the Smart State**

FWPRDC Project PN01.1901
Araucaria Sector Research – 3-Year Program

Final Report

Summaries for-

- **Kiln stain**
- **Brownstained heartwood**
- **Colour matching**
- **Reduced rotation length**
- **Araucaria wood characteristics**
- **Araucaria logging practices**
- **Technology transfer**

Compiled by Department of Primary Industries and Fisheries

November 19, 2004

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Queensland Government Department of Primary Industries and Fisheries

Timber Queensland

Australian Government Forest and Wood Products Research and Development Corporation

HameyVision

Swinburne University of Technology

The Department of Primary Industries and Fisheries (DPI&F) seeks a better quality of life for all Queenslanders – a quality of life supported by innovative world-class food and fibre industries, by responsible and ecologically sustainable use of natural resources and by capable and self-reliant rural communities. Our business is about:

- Innovative science and commercial uptake of new technology by food and fibre industries.
- Sustainable use of natural resources
- Food safety and protection against imported pests and diseases
- Market-driven and ethical food and fibre production and
- Capable rural communities achieving prosperity and self reliance through successful rural businesses

This publication is designed to offer a summary of quality research outcomes to the Araucaria industry and the Forest and Wood Products Research & Development Corporation for improved processing and utilisation of *Araucaria cunninghamii* (hoop pine).

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Market repositioning of hoop pine
(Three-year program projects)

Final report prepared for the

Forest & Wood Products
Research & Development Corporation

by

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19 November 2004

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Introduction

During the late 1990s, the Araucaria industry sector established a joint industry/government working group to promote and reposition plantation-grown *Araucaria cunninghamii* in both domestic and export markets. The initial program of R&D, known as the 'two-year project' (Forest & Wood Products Research & Development Corporation FWPRDC PN00.1900) was managed by the Queensland Forestry Research Institute (QFRI) during the period January 2000 to July 2002. Timber Queensland managed a second program of R&D activities, funded through the FWPRDC and Department of Primary Industries Forestry and known as the 'three-year' project (FWPRDC PN01.1901). Work on the three-year projects commenced in June 2001 and concluded in 2004.

An industry forum was held in Brisbane in July 2002 to inform interested parties of the results determined during the two-year project and included presentations on preliminary results from the three-year projects. A second Araucaria R&D Forum was held in Brisbane in September 2004 to enable presentations and discussions on the final results of the three-year program activities.

This document provides summaries for components of the research presented at the second Araucaria R&D Forum held in Brisbane in September 2004. This summary report includes a CD with copies of the full milestone reports as distributed to stakeholders during the term of the program.

1. Kiln stain research

1.1 Mechanism of Araucaria kiln stain

(see MS4 Jul 03 on CD for further detail)

by Michael J Kennedy and Tony Treloar DPI&F

Summary

Experimental preliminary irrigation of freshly-felled *Araucaria cunninghamii* (hoop pine) logs, with water or dilute aqueous solutions of sodium metabisulphite or formaldehyde, produced significant variation in the incidence of kilnstain developing during subsequent drying of boards cut from the logs. Although hot water removed large quantities of sugars and nitrogen-containing compounds from the log, significant quantities remained and unacceptable levels of kilnstain developed in the boards. However, logs irrigated cold with aqueous solutions of the test chemicals, which would be expected to retain even greater concentrations of sugars and nitrogen compounds in the wood, developed significantly less kilnstain. While the test chemical sodium metabisulphite was considered likely to inhibit kilnstain whether caused by Maillard or oxidative browning mechanisms, the inhibition associated with the formaldehyde treatment was considered likely to be possible only if a Maillard mechanism was involved. It was therefore concluded that a Maillard mechanism (involving sugars and nitrogen compounds) is responsible for kilnstain in this species, and that the test chemicals possess the ability to suppress this reaction in timber of this species.

Introduction

Kilnstain research within the previous project, PN00.1900 *Market Repositioning of Hoop Pine* (previously reported[1]) included much work on extractive compounds present in Araucaria, but did not clearly establish the chemical reaction responsible for kilnstain in this species. The experiment now described was designed to establish the mechanism by a thorough search for sources of nitrogen and sugars in the timber, a study of their mobility during log irrigation, and correlation of their presence, mobility and inhibition with the development of kilnstain. It was proposed that, if sources of Maillard reactants were located in sufficient quantity, and their removal correlated with reduced kilnstain development, and if the introduction of a Maillard inhibitor into wood still containing the reactants further reduced kilnstain development, we would conclude that the mechanism is Maillard. If not, we would conclude that it is non-Maillard, without defining further.

[1] Kennedy, MJ (2002) Research Progress Summary: Hoop Pine Kiln Stain Chemistry – July 18, 2002 report within PN00.1900

Materials and methods

A freshly-felled *Araucaria cunninghamii* (Araucaria or hoop pine) log, 4.8 m x 30-35 cm diameter with well-attached intact bark was cut into four equal length billets. While the control billet A was not irrigated, billets B, C and D were subjected to an irrigation treatment as previously described[1] (Figure 1.1).

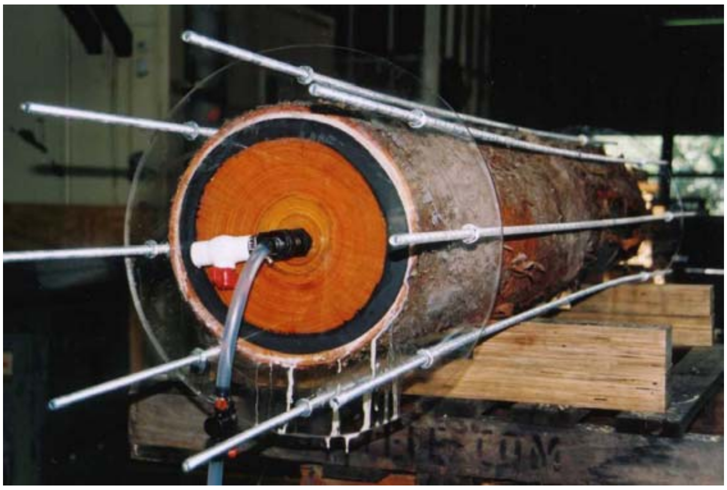

Figure 1.1. Irrigation of billet.

Water or dilute aqueous solution of test chemicals was introduced to the butt end under about 30 kPa pressure. Irrigation effluent which began immediately to emerge from the opposite end of the billet was collected in a series of 20 L polyethylene containers and stored at 4°C for up to one week before freeze-drying for analysis. Irrigation details of the 24-48 hr processes are in Table 1.1:

Table 1.1 Irrigation fluids and conditions.

Billet	Irrigation fluid	Irrigation conditions
B	Water	100L at ambient temp, then 120L at 90°C
C	3% aqueous formaldehyde solution	120L at ambient temperature
D	1% aqueous sodium metabisulphite solution	120L at ambient temperature

A cross-sectional disc was removed from the outlet end of each billet for analysis, and the remainder of each billet was sawn into 25 mm thick bark-to-bark slabs. Slabs from one side of each billet were air dried, while the matching slabs from the other side of the billet were kiln dried under kilnstain-producing conditions. After drying, each air-dried and each kiln-dried slab were progressively dressed and assessed for kilnstain severity at 1 mm, 2 mm, and 3 mm from the rough surface. The sapwood from each disc removed from billets after irrigation was analysed as in Table 1.2:

Table 1.2 Analysis of irrigated wood.

Test Method	Analytes	Significance
TAPPI T207	Solubility in cold water Solubility in hot water	Sugars and gums Sugars, gums and starches
TAPPI T212	Solubility in 1% aq. sodium hydroxide	Sugars, gums, starches, total hemicellulose
TAPPI T223	Total pentosans	Hemicellulose fraction containing C_5 sugars
Kjeldahl N	Total nitrogen	Total nitrogen (amino acids, proteins, ++)

Freeze-dried irrigation effluent samples from the B treatment were analysed for total reducing sugars and individual mono- and di-saccharides (AOAC Method 982.14)[2], and also for total nitrogen using a combustion-based CHN microanalysis system.

Results and discussion

Kilnstain developed in the slabs to varying extents. Table 1.3 gives the mean scores for each treatment. These scores represent aggregate scores over the whole dressed surface of each slab. The development of stain in the air-dried slabs from the B treatment was unusual, but probably can be attributed to the heating involved during that treatment. In the case of kiln-dried slabs from the C and D treatments, the kilnstain giving rise to the scores was not evenly distributed over the entire surface – significant patches of kilnstain were associated with knots, while the remainder of the surface was quite clean (Figure 1.2). We suggest that zones of wood near knots were poorly swept by the irrigation fluid, and that ignoring the knot areas when assessing the surfaces for kilnstain would give reduced scores, more representative of the visual effect of the treatments easily seen in Figure 1.2.

Table 1.3 Kilnstain scores.

Kiln dried	Kilnstain assessment score - mean of slabs of each treatment			
Depth assessed	**A**	**B**	**C**	**D**
1mm	7.0	4.8	3.8	2.0
2mm	7.0	4.3	2.5	2.3
3mm	7.0	3.0	1.8	1.5
Air dried	Kilnstain assessment score - mean of slabs of each treatment			
Depth assessed	**A**	**B**	**C**	**D**
1mm	1.0	2.3	1.2	2.0
2mm	1.0	1.0	1.0	1.0
3mm	1.0	1.0	1.0	1.0

[2] Association of Official Analytical Chemists (2000) Method 982.14 Sugars

Treatment A **B** **C** **D**

Figure 1.2 Kilnstain in kiln dried boards at 3 mm depth, after treatments A, B, C & D.

Results of analysis of irrigated wood and irrigation effluent solutions are given in Tables 1.4 & 1.5.

Table 1.4 Analysis of irrigated wood.

Billet:	A	B	C	D
Cold water soluble %	5.1	2.4	5.9	7.2
Hot water soluble %	9.6	6.5	9.6	9.1
1% NaOH soluble %	17.2	18.3	18.4	18.6
Pentosans %	6.3	6.2	7.2	4.6
Total N %	0.063	0.054	0.056	0.052

Table 1.5 Analysis of effluent after irrigation treatment B.

Fraction	Total solids (%m/v)	Total N (g/20L)	Total sugars (mM/L)	Glucose:Fructose ratio	Sorbose present?	Xylose present?	Arabinose present?
Cold 0-20	0.04	0.00					
20-40	0.00	0.00					
40-60	0.00	0.00		Not determined			
60-80	0.00	0.00					
80-100	0.00	0.00					
Hot 0-20	0.56	1.05	9.15	0.8	no	no	no
20-40	0.25	0.27	3.57	0.5	no	no	no
40-60	0.28	0.34	5.05	0.8	no	no	no
60-80	0.13	0.15	0.99	0.7	no	no	no
80-100	0.08	0.03	0.85	1.7	trace	no	no
100-120	0.09	0.05	1.22	0.7	trace	no	no
120-140	0.05	0.03	0.38	0.3	no	no	no
140-160	0.05	0.02	0.55	2.4	trace	no	no
160-180	0.08	0.02	0.88	1.7	trace	no	no
180-200	0.05	0.00	0.24	1.5	no	no	no
200-220	0.05	0.02	0.31	1.0	no	no	no

It is useful to first compare treatment A (unirrigated) with treatment B (cold/hot water irrigated). We can be confident from the sugar removal rate data generated in previous experiments[1] that the irrigation has removed most of the 'irrigation-removable' sugars and soluble nitrogen-containing compounds from the B billet, yet we still have about 50% of the original sugars and 80% of the original nitrogen in this billet, as indicated by the 'cold water solubles' and total nitrogen analyses (Table 1.5). The cold water solubles test method T207 is clearly more efficient at removing sugars than the cold/hot irrigation, presumably because the former is done on finely-ground wood, while in the latter the water has to pass through a limited, tortuous fluid pathway. We have probably only removed the sugars and nitrogen compounds in the well-swept parts of the cell lumens (voids), but left residual reactants dissolved in the cell walls and poorly swept lumen areas. The kilnstain scores are consistent with a Maillard mechanism, as we observed slightly reduced sugar and nitrogen content and slightly reduced the kilnstain development. But it doesn't prove the mechanism to be Maillard, as the irrigation may have simultaneously reduced (but not completely removed, for the same reasons) the concentration in the wood of chemical species participating in an oxidative reaction. Thus the outcomes of the A and B treatments are consistent with both Maillard and oxidative mechanisms.

A consideration of treatments C and D provides additional information. Because we used only cold irrigation with these dilute aqueous fluids, we could have predicted from the A/B treatments outcome that considerable sugar and nitrogen (and probably also 'oxidisable compounds') would remain in both C and D billets – but these suffered significantly less kilnstaining (away from knots) than the B billet. Thus we have inhibition by both C and D agents. Metabisulphite is a well-known inhibitor of Maillard reactions, and the inhibition mechanism is understood, but as it is not possible to confidently assert that metabisulphite is incapable of inhibiting oxidative browning, we cannot distinguish between Maillard and oxidative mechanisms on the basis of the D results. But, while formaldehyde has been previously demonstrated to inhibit Maillard browning, an extensive search of the literature has not uncovered any evidence that it can inhibit oxidative browning, and it would be difficult to propose a likely mechanism whereby it could prevent oxidative condensation of polyphenols. The inhibition of kilnstain by formaldehyde in the C treatments is therefore considered to provide strong evidence in support of a Maillard mechanism, sufficient to attribute the kilnstain problem to reactions within this class. It is considered likely that formaldehyde preferentially participates in the initial stages of a Maillard reaction instead of sugars, and that the intermediate compounds thus formed are incapable of undergoing the further rearrangement that usually leads (in the case of sugars) to the formation of coloured complexes.

The significant reduction in kilnstain development after irrigations C and D suggested potential preventative treatments. Experiments to explore the application of treatments by dipping of green-off-saw boards are reported in 1.2 and 1.3 below.

1.2 The use of chemical reagents to influence the Maillard mechanism

(see KS aldehyde dips on CD for further detail)

by Jack Norton and Leanne Stephens DPI&F

Summary

Previous work carried out on freshly-felled *Araucaria cunninghamii* (hoop pine) showed that a Maillard mechanism was the most likely cause of kilnstain in this species. Flushing the log with sodium metabisulphite and formaldehyde held promise in preventing or reducing the effects of the Maillard mechanism, and so a more commercially acceptable dipping technique applied to sawn timber was investigated. Freshly sawn hoop pine was dipped for a range of times and concentrations of sodium metabisulphite, formaldehyde and butyraldehyde.

None of the treatments was completely effective in preventing kilnstain, although the high concentration formaldehyde appeared to give the best results. Unfortunately, the use of formaldehyde and butyraldehyde at high concentrations revealed significant work place health and safety issues. The butyraldehyde also caused staining other than the kilnstain being investigated.

Introduction

The work reported in 1.1 above, indicated that logs irrigated with sodium metabisulphite or formaldehyde developed significantly less kiln-stain than hot water irrigated material. The research involved flushing logs with the test reagents using a modified Boucherie procedure (Wilkinson 1979), and concluded that the Maillard mechanism was the most likely cause of kilnstain in hoop pine.

The Maillard mechanism is a major cause of browning of food industry products that contain reducing sugars and proteins. The browning occurs when these products are subjected to high temperature and moisture conditions such as exist when freshly sawn timber is kiln dried.

Two experiments were designed to investigate whether or not the same and related reagents could prevent or minimize the affects of the Maillard mechanism in freshly sawn hoop pine. Test reagents were applied by dipping rather than flushing, as dipping was considered to be a more commercially viable method of treatment.

Materials and methods

Freshly sawn hoop pine boards, 2.7 m x 105 mm x 38 mm were cut at the Hyne and Son mill at Melawondi, Queensland and transported immediately to the DPI&F research facility at Salisbury in Brisbane. Boards that contained blue stain or excessive defects such as knots etc were rejected from the trial. Each board was cut into 900 mm lengths and allocated a treatment code according to the candidate treatment that was to be applied.

Ten boards were treated with each candidate treatment, the combinations of which are presented in Table 1.6.

Table 1.6 Candidate treatment combinations.

Expt	Candidate	Conc^n	Times	Post treatment drying
1	Sodium metabisulphite	5% m/v	1 hr & 1 day & 1 week	• 1 hr boards block stack under plastic 4 hrs - then • Strip stack all boards 24 hrs then • Kiln dry
		20% m/v		
	Formaldehyde	10% v/v		
		38% v/v		
2	Formaldehyde	38% v/v	10 min & 30 min & 60 min	• Block stack 20 hrs and • Immediately strip stacked then • Kiln dried
	Butyraldehyde	7.1% m/m		

All treated boards were kiln dried. The schedule used was 90ºC/60ºC dry bulb/wet bulb until approximately 10% moisture content followed by a 90ºC/85ºC dry bulb/wet bulb equalisation. Air speed was 3m/sec. This schedule was chosen because it is a schedule that would normally induce kiln stain and also the schedule offers a more optimum drying rate then schedules at lower temperatures.

Once dry, boards were held under cover for at least 48 hours to allow them to equilibrate to ambient conditions. After drying, each treated and untreated board was dressed and assessed in 1 mm gradients from the rough surface. A total of 4 x 1 mm gradients were removed.

Assessment was carried out using the same criteria as was used in the previous trials. The scoring system is presented in Table 1.7.

Table 1.7 Assessment scale.

Score	Kiln-stain severity
1	No stain
2	<10% light stain
3	<10% dark stain
4	<25% light stain
5	<25% dark stain
6	>25% light stain
7	> 25% dark stain

Results and discussion

The use of formaldehyde, particularly at the maximum concentration (38%), presented significant work place health and safety issues. Full-face protection with air filtration was required along with protective clothing such as overalls and/or aprons. The sodium bisulphate solutions also produced strong fumes but not to the extent of the formaldehyde. Elbow length impervious gloves were also worn during dipping. The formaldehyde also gave off strong fumes during kiln drying.

The sodium bisulphate caused the brown stain to turn yellow which in turn was assessed using the criteria presented in Table 1.7. Assuming that less than 10% staining is commercially acceptable, numbers of boards from Experiment 1 with less than 10 % of the surface area stained by brown kilnstain are presented in Table 1.8. It is noteworthy that none of the boards in Experiment 2 had less than 10% of the surface area affected by kilnstain.

Table 1.8 Number of boards with less than 10 % staining.

Dip Time	5% sodium bisulphite	10% sodium bisulphite	10% formaldehyde	38% formaldehyde
1 hour	3	5	7	30
1 day	8	26	9	18
1 week	23	19	12	31

The butyraldehyde caused grey staining in the outer two millimeters of the treated wood and pink staining deeper into the timber (Figure 1.1).

Figure 1.3 Pink staining in the board.

Kiln-stain was hard to assess to the criteria presented in Table 1.7 as accurate assessment was often masked by the presence of the described colours.

A dark brown stain that was different in appearance to the brown kilnstain was observed around the 20 mm timber strips used between samples during kiln drying. It is suggested that the stain may have occurred as a result of pooling of the treatment fluid around some of the strippers, resulting in extractives being leached from the stripper and drying slowly on the surface of the wood (Figure 1.4). Areas affected by the brown 'stripper-stain' were excluded from assessment of kilnstain. The brown stripper-stain did not occur on all test material and a possible reason is that timber strips were a mix of softwood and hardwood timber.

There was also an absence of kiln stain under some of the timber strips. This result may warrant further investigation.

Figure 1.4 Staining around sticker.

Conclusion

Applying the criteria of an acceptable level of kiln-stain being a score of '3', (less than 10% dark stain) none of the treatments tested were effective in stopping brown kilnstain.

1.3 The use of thin surface films to influence the Maillard mechanism

(see KS thin film on CD for further detail)

by Jack Norton and Leanne Stephens DPI & F

Summary

Dipping freshly sawn hoop pine in various combinations of sodium metabisulphite, formaldehyde and butyraldehyde was ineffective in preventing more than 10% of the surface of the timber from being affected by brown kilnstain. Work was carried out to investigate a physical rather than chemical approach to preventing or reducing the occurrence of brown kilnstain in kiln dried hoop pine.

Four candidate surface coatings systems were tested for their ability to prevent or reduce brown kilnstain; mono ethylene glycol (MEG), poly ethylene glycol (PEG), poly vinyl acetate (PVA), and water based exterior paint. None of the applied systems were effective in stopping brown kilnstain.

Introduction

Rice *et al* (1988) applied surface coatings to red oak prior to kiln drying. The purpose was to reduce the rate of moisture loss from the surface and consequently the moisture gradient that occurs in timber during the kiln drying process. When applied to the problem of brown kilnstain, it was hypothesized that the Maillard reaction, which is thought to be a major factor in the occurrence of brown kilnstain in hoop pine, will be concentrated towards the surface of the wood, which in turn can be dressed off during the machining process.

Four candidate surface coatings systems were tested for their ability to prevent or reduce brown kilnstain. The coatings were chosen on the basis of availability, coating uniformity, and ease of handling when applied to timber surfaces. The candidate systems tested were: mono ethylene glycol (MEG), poly ethylene glycol (PEG), poly vinyl acetate (PVA), and water based exterior paint.

Materials and methods

Freshly sawn hoop pine boards, 5.4 m x 105 mm x 38 mm were cut at the Hyne and Son mill at Melawondi, Queensland and transported immediately to the DPI&F research facility at Salisbury in Brisbane. Sapwood boards that had very little heartwood, blue stain or excessive levels of defects such as knots etc were accepted for the trial. Each board was cut to length (900 mm) and allocated a candidate treatment.

Solutions of the candidate treatments of mono ethylene glycol, poly ethylene glycol, poly vinyl alcohol, and the exterior water based paint were prepared as follows:

Candidate (MEG, PEG, PVA, paint) –

- $conc^n$ 1 - 1% mass/mass
- $conc^n$ 2 - 5% mass/mass
- $conc^n$ 3 - 25% mass/mass
- $conc^n$ 4 - 50% mass/mass

Ten boards of each treatment were completely submerged in a trough containing the candidate system until the sample was thoroughly coated. All treated boards were then strip stacked for at least 24 hours before kiln drying. The schedule used was 90ºC/60ºC dry bulb/wet bulb until approximately 10% moisture content followed by a 90ºC/85ºC dry bulb/wet bulb equalisation. Air speed was 3m/sec. This schedule was chosen because it is a schedule that would normally induce kiln stain and also the schedule offers a more optimum drying rate then schedules at lower temperatures.

Once dry, boards were held under cover for at least 48 hours to allow them to equilibrate to ambient conditions. After drying, each treated and untreated board was dressed and assessed in 1 mm gradients from the rough surface. A total of 4 x 1 mm gradients were removed. Assessment was carried out using the same criteria as was used in the earlier trials. The scoring system is presented in Table 1.7 above.

Results and discussion

The mean assessment result for each of the ten replicates in each treatment is presented in Table 1.9.

Table 1.9 Average assessment scores for surface coating treatments.

		Candidates					
Concentration	Depth	MEG	Un-Treated	PEG	PVA	Un-Treated	PAINT
1%	1mm	6.5	6.8	6.9	7.0	7.0	6.8
	2mm	6.4	6.8	6.9	7.0	7.0	6.9
	3mm	6.4	6.5	6.7	7.0	6.9	6.8
	4mm	6.0	6.4	6.2	6.0	6.8	6.4
5%	1mm	6.8	7.0	7.0	7.0	7.0	6.7
	2mm	6.9	7.0	7.0	6.7	7.0	6.9
	3mm	6.3	7.0	6.5	6.4	6.6	6.3
	4mm	5.9	6.6	6.4	6.3	6.4	6.3
25%	1mm	6.5	7.0	6.8	7.0	7.0	6.8
	2mm	6.6	7.0	6.8	7.0	7.0	6.9
	3mm	6.3	7.0	6.6	6.8	7.0	6.5
	4mm	5.9	6.9	6.3	6.2	6.9	6.1
50%	1mm	6.9	7.0	6.8	7.0	7.0	7.0
	2mm	6.9	7.0	6.8	7.0	7.0	6.9
	3mm	6.7	7.0	6.6	7.0	7.0	6.6
	4mm	6.5	6.8	6.3	6.5	6.6	6.7

Adopting a score of '3' (less than 10% dark stain) as being commercially acceptable, none of the candidate surface coat treatments examined was effective in preventing kiln-stain. It was observed however, that further dressing would have seen a reduction in the extent of kiln-stain.

1.4 Effect of microwave pre-treatment on Araucaria kiln stain

(see MS5 Apr 04 on CD for further detail)

by David B Hayward, Timber Queensland, Michael J Kennedy DPI&F and

V. Ngyyen Tran Industrial Research Institute, Swinburne University of Technology

Summary

This work was an attempt to use microwave pre-treatment to increase the permeability of green-off-saw Araucaria, without causing structural degradation. It was expected that an increase in permeability might cause the zone of deposition of coloured kilnstain products to change, either closer to the surface (where the discoloration could be easily removed during machining) or to a greater depth (so as not to be exposed during machining). Dielectric properties of green Araucaria were determined. A range of microwave pre-treatments of varying intensities were applied to the central portion of long pieces of green kilnstain-susceptible Araucaria. While the permeability was increased as expected, the pre-treatments did not significantly alleviate the discoloration of the material due to kilnstain when kiln dried using a 90°C schedule.

Introduction

Previously reported observations of improved permeability of wood after microwave pretreatment raised the possibility that such a treatment could be beneficial in ameliorating kilnstain. Increasing the permeability might move the deposition zone of kilnstain deposits closer to the surface of the timber, so that they would easily be removed during machining.

Materials and methods:

Exploratory work was undertaken by Swinburne University to determine the microwave characteristics of green Araucaria. These included -

- The dielectric properties (the dielectric constant e' and the loss factor e") at 922 MHz and 2450 MHz and variation with temperature.
- The thermogravimetric analyses (TGA) of samples.
- The differential scanning colorimetry (DSC) of samples.
- Penetration depth, and rate of temperature rise.

The depth at which microwave enters the timber was obtained from e' and e". The rate of microwave heating is inversely proportional to the loss factor e". The larger the dielectric constant and the loss factor the shallower the penetration depth. Given these results, a 1 kW microwave generator (Figure 1.5) was used to test the feasibility of inducing permeability in the 4 small samples (100 mm x 100 mm) and to dry four samples.

Once the characteristics were known, fresh 4.2 m long 100 mm x 33 mm Araucaria material was obtained from the sawmill, and a 1.2 m length removed from each piece as 'Control' samples for kiln drying without pre-treatment to demonstrate susceptibility to kilnstain. The central one-third zone of the remaining 3.0 m lengths, at 40% moisture content and 1.5 J/g/°C specific heat, were subjected at Swinburne to various microwave pre-treatment regimes involving three pressure conditions (atmospheric, +100 kPa pressure and –75 kPa vacuum) and low, medium and high rates of microwave application. The purpose of the treatment was to increase the permeability of the central section, but not to provide final drying.

Figure 1.5. Microwave generator, Swinburne University of Technology.

The treated lengths were returned to Brisbane where they were cut into three equal sections. The middle ('Microwave Middle') sections and the outer ends ('Microwave Ends') were kiln dried under the standard kilnstain-producing conditions. The development of kilnstain in the initial Control sections had proved that the material was susceptible to kilnstain under the kiln conditions employed, while the development of kilnstain in the 'Microwave Ends' (which should not have received significant exposure to microwaves) demonstrated that kilnstain susceptibility was not affected by the delay or conditions experienced between Brisbane and Melbourne. The degree of stain present in the samples was assessed and rated in line with standard procedures.

Results and discussion

Dielectric properties

The dielectric properties of Araucaria vary considerably (refer to Fig. 4.1 and Fig. 4.2 in MS5 Apr 04). *Araucaria* in the green state was a good absorber of microwaves at 922 MHz and 2450 MHz. 922 MHz is the preferred frequency to use to treat big size material. For the variation of dielectric properties with temperature, see Fig. 4.3 and Fig. 4.4 in Milestone Report 5 (MS5 Apr 04). The variation in dielectric properties means that some form of automatic tuning is required in a microwave process to make sure that all microwaves are tuned into the load. The hot timber tends to heat up slower. This is good because it provides a self-limiting mechanism to prevent thermal run away. This data is needed for the calculation of the penetration depth and the rate of heating.

Specific heat

The specific heat is shown in Table 1.10. The specific heat also shows variation. The lighter material tends to have a higher specific heat. This information is needed to calculate the microwave power absorption by unit volume and the rate of temperature rise. This information is important because it is needed to keep the heating rate at a level not to cause checking and collapse.

Table 1.10. Moisture content (DB) and specific heat of Araucaria wood.

wood	Moisture Content	Specific Heat (J/g/^{o}C)
dark	122% = 55/45	1.5
dark	122% = 55/45	1.7
dark	100% = 50/50	1.8
light	42.9% = 30/70	2
light	53.8% = 35/65	2.5

Penetration depth and rate of temperature rise

Figure 1.6 shows the penetration depth in millimetres and rate of temperature rise (°C/s) for an input power of 1 kW at 922 MHz.

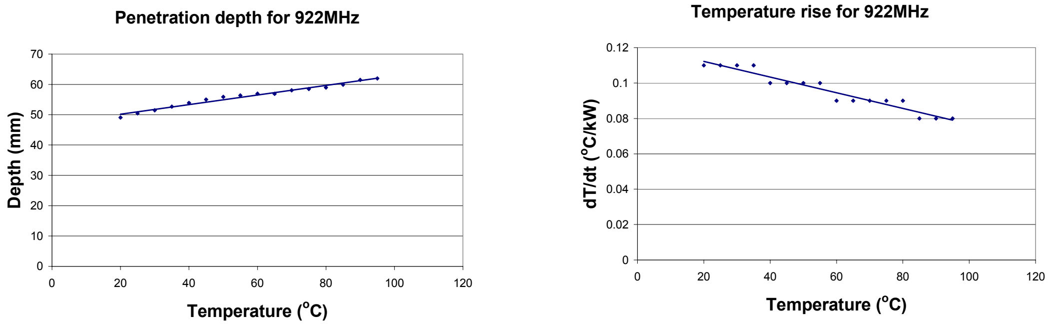

Figure 1.6. Penetration depth and temperature rise at 922 MHz with temperature.

Figure 1.7 shows the same results at 2450 MHz. If the input microwave power is more than 1 kW then the rate will be more. Hence we sometimes express this rate as °C/kW/s to emphasize the significance. To avoid internal checking and collapse the rate of temperature rise must be kept reasonable. Our experiment indicates that it must be below 1°C/s.

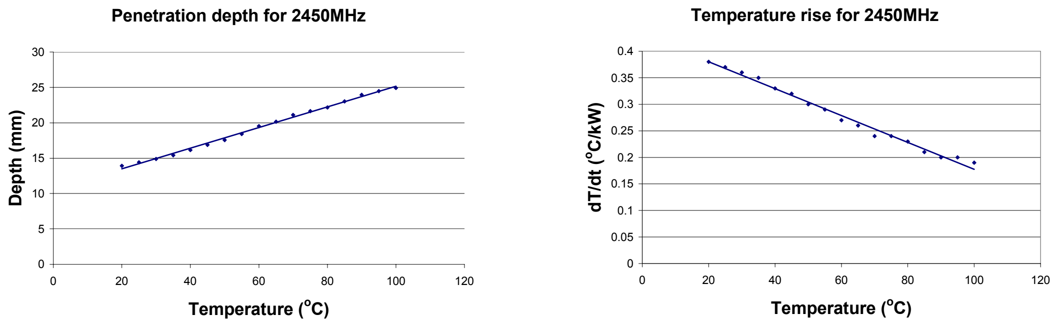

Figure 1.7. Penetration depth and temperature rise at 2450 MHz with temperature.

Permeability improvement

Small samples (100 x 100 mm) were exposed to microwave at 250, 500, 750 and 1000 W, which were then dried. The treated samples lost 25% more moisture than the control sample. This indicates that microwaved samples are more permeable.

Microwave drying

Four received "as is" samples were dried with 34°C dehumidified hot air and 500 W of microwave. The samples lost most of the moisture (6% moisture content remaining) in 10.5 hours. The combination of dehumidified hot air and microwave seems to accelerate the drying of the samples. Four other samples subjected to dehumidified air at 34°C and achieved little drying.

There was some minor 'blackening' on one surface only of three samples (the reason for this was not known). The blackening material appears to be close to the surface and can be removed with sanding.

Kilnstain development on pre-treated timber

From direct observation, no effect of microwave treatment was apparent. A summary of average scores for each treatment is given in Table 1.11.

Table 1.11. Average kilnstain scores and calculated effect of microwave treatment (negative 'Microwave Effect' signifies a reduction in kilnstain associated with microwave treatment).

Microwave Treatment		Control Section						Microwave Section						Microwave Effect						
Air Pressure	Microwave Intensity	Depth (mm)						Depth (mm)						Depth (mm)						
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	Mean
Ambient	Low	6.8	6.3	5.9	5.1	5	4.3	6.2	6.8	5.9	5.8	5.9	4.6	-0.6	0.5	0.0	0.7	0.9	0.3	0.3
Ambient	Medium	7	6.8	6.7	5.1	5.5	3.9	6.8	6.9	5.8	4.9	4	4.2	-0.2	0.1	-0.9	-0.2	-1.5	0.3	-0.4
Ambient	High	6.6	6.6	6.4	5.2	5.6	4.1	6.6	6.6	5.8	4.6	4	4	0.0	0.0	-0.6	-0.6	-1.6	-0.1	-0.5
+ 1.0 atm	High	6.8	6.7	6.1	5.3	5.1	3.1	6.4	6	4.8	3.9	4.3	3.7	-0.4	-0.7	-1.3	-1.4	-0.8	0.6	-0.7
- 3/4 atm	High	6.8	6.8	6.5	5.3	5.5	4.6	6.8	6.6	5	4.4	5.1	4.2	0.0	-0.2	-1.5	-0.9	-0.4	-0.4	-0.5

Conclusion

The physical properties of Araucaria have now been characterised using a DSC and TGA. The results show considerable variation. The data is needed to determine a correct drying regime and rate of heating. The microwave properties of Araucaria have now been determined using a dielectric probe and an ANA for the two industrial frequencies 922 MHz and 2450 MHz. The data is used to calculate the penetration depth and the rate of heating. Microwaves at 922 MHz are more suitable for thicker materials. 25% more permeability is achieved when using microwave. Dehumidified hot air and microwave seemed to dry the samples quickly and to produce a more acceptable appearance.

The microwave treatments applied to the timber had no beneficial effect in kilnstain development during a 90° kiln schedule.

2. Brownheart (brown-stained heartwood)

(see MS1 Apr 02, MS3 Feb 03, MS4 Jul 03 and MS5 Apr 04 on CD for further detail)

by Terry Copley, DPI&F

Objectives

To:

- Collate all previous research conducted into brownheart.
- Conduct a resource and processing survey at each main growing region (Mary River Valley, Brisbane River Valley, Atherton Tablelands).

Introduction to brownheart characteristics

Brownheart, also known as and generally associated with 'wetwood', has been observed in *Araucaria cunninghamii* (hoop pine) since this timber was first harvested from maiden forest. Official reports of its occurrence in plantation Araucaria dates back to at least 1950.

Characteristics of brownheart

Gross features

Brownstain heartwood is characterised by high water content and in some species is discoloured. Wetwood moisture content is generally higher and unpleasant odours are another feature.

Microstructure

Anatomical investigations in 1961 of brownstain in Araucaria from north Queensland concluded that dark "blackish" zones showed evidence of fungal attack. More recent investigations of wetwood or brownstain microstructure in Araucaria found two characteristics, irregular degradation of the wood cell wall, and cavity degradation of the S2 layer of the cell wall.

Strength and other physical properties

Conflicting reports about the strength properties of wetwood (depending on geographical location and position within the log), compared to that of normal sapwood and heartwood, have been attributed to test conditions not being uniform across studies. In Araucaria, there are few physical impediments, the disadvantage being mainly market resistance to BSHW appearance (refer to Milestone 1). Unit shrinkage values were comparable to published values for clear grade Araucaria. Glue strengths for BSHW in Araucaria were slightly below that for clear-grade Araucaria, but were still comparable to shear strengths for solid wood. However, there is some anecdotal evidence that indicates finger-jointed brownstain heartwood affected material is not totally sound (Doug Simms, Ravenshoe Timbers *pers. comm.*). Drying problems have commonly been reported for wetwood-affected timber. Permeability and specific gravity have also been investigated.

Causes

There is no consistent theory on the cause of wetwood formation in trees. It has been attributed to microbial (bacterial), non-microbial (injury) and normal age-growth causes. It is commonly associated with bacteria but the detection of bacteria is not proof of their causative action. Excessive moisture in wetwood has been attributed to direct entry through stem openings or internal sources in the root and stem. However, this is not conclusive evidence of bacteria being the cause of brownstain. It has been proposed that the mechanism causing heartwood wetwood in Araucaria was either an osmotic gradient or more probably concentration differences in organic extractives between wetwood heartwood sap and normal wood. Environmental causes such as site influences, including silviculture, topography, climate, soil and site productivity of wetwood heartwood have been investigated in detail by a few researchers.

Within-stem occurrence

Three general spatial patterns of wetwood occurrence in the stems of affected trees have been recognised. The most common occurrence is in a conical pattern in the central core of the lower stem section. A second pattern is streaks or columns of wetwood, traceable to injuries or dead branch stubs in the upper stem, and the basal section of the stem free of wetwood. A third pattern is for wetwood to occur in both basal and upper stem sections, resulting in wetwood that coalesces into a single massive formation. While generally confined to the heartwood zone in Araucaria, brownstain has been reported to occur within an inch of the bark and therefore well outside the heartwood zone.

Detection

Outward signs of wetwood are not always present, either in logs or in green timber, and may only become apparent after the timber is dried. Longer drying times for wetwood than for normal material makes detection very important economically. In Araucaria, two types of wetwood were identified: 1) wetwood characterised by brown staining, originating in the heartwood of a tree and sometimes extending into the sapwood, and 2) wetwood with no discolouration found only in the sapwood of a tree. Ultrasound-based scanning systems have also been used to identify wetwood in red oak timber with good results. Nuclear magnetic resonance (NMR) imaging is another tool that has been successfully used to detect wetwood within a log.

Previous work undertaken by DPI&F

The following is a summary of this work and is presented in a chronological order (details available in the full report).

1. Bolland (1982): "Stained heart In hoop pine at Wongabel".
2. Bolland (1984): "Phellinus noxius: cause of a significant root-rot in Queensland hoop pine plantations".

3. McNaught (1992): “Mechanical properties of stained and unstained hoop pine ex Atherton”.

4. Palmer and Palisi (1992): “An investigation of drying problems in hoop pine”.

5. Palmer (undated report to ACI Timber Products – Imbil): “Causes of Slow Drying in Hoop Pine Wetwood”.

6. Copley (1995): “Wetwood Determination in PNG and Coen Provenance - Hoop Pine Plus Trees”.

7. Palmer, Taylor and Leggate (1996): “Hoop Pine Wetwood Drying Research”

8. Copley (1996): “Environmental and genetic testing for wetwood in hoop pine plus trees”.

9. Harding and Copley (1998): “Stage 2 - Determining the heritability of heartwood wetwood in hoop pine families”.

10. Copley and Palmer (1999): “Program to determine the level of brown stained heartwood in final crop hoop pine at Atherton”.

11. Francis and Powell (2001): “Pilot Study: Hoop Pine Wetwood”.

12. Leggate, Catchpoole and Kennedy (2001): “Milestone Number 4 Report. Market Repositioning of Hoop Pine Project. FWPRDC Project PN00.1900”.

13. Catchpoole, Kennedy and Leggate (2002): “Market Repositioning of Hoop Pine Project, Three-year program projects. Milestone Number 1 Report. Project 5: Brownstain heartwood survey of physical and working properties”.

14. Leggate, Catchpoole and Pegg (2002): “Relationship between *Phellinus noxius* and the occurrence of brownstain heartwood in *Araucaria cunninghamii* “.

15. Copley (2004): “Preliminary investigation of product quality of rotation Age klinki pine (*Araucaria hunsteinii* K. Schum.) compared to hoop pine (*A. cunninghamii* Ait. ex D. Don) in North Queensland, Australia”.

Survey of Araucaria processors

Information contained in the “Economic impact of brownheart” section of this report has been compiled from a survey of Araucaria processors contained in *“Milestone Number 4 Report- Market Repositioning of Hoop Pine Project. FWPRDC Project PN00.1900”* by W. Leggate, S. Catchpoole and M. Kennedy, June 2001. It is this 2001 information that has been used to estimate the economic potential of this problem later in this report. However, recent contact with some of these processors revealed that their experience with the level of brownstain heartwood remains unchanged and it was considered that re-surveying would not provide any additional useful information. For commercial reasons, processors are reluctant to divulge their complete processing costs and economic returns for their product. Therefore, the full economic costs to processor and additional costs in processing and revenue losses due to product downgrade from brownstain heartwood are difficult to quantify accurately at a processor and industry level. The following processors contributed to this survey:

1. Boral Hancock of Ipswich
2. Austral Plywoods of Brisbane

3. Brims Wood Panels of Brisbane
4. Hyne and Son, Imbil Mill
5. Muller Sawmills in the Brisbane Valley
6. Finlayson's of Brisbane
7. Austicks in Gladstone
8. Ravenshoe Timbers in north Queensland (Cairns and Ravenshoe)

Economic impact of brownheart

Brownstain heartwood in *Araucaria cunninghamii* has a significant impact on DPI Forestry, through its system of royalty discounts, and also to Araucaria processors, due to its difficulty in drying, often requiring double handling and re-drying, and the lack of market acceptance for brownstain affected boards, resulting in its downgrading. The 2001 survey established that the problem was greater in the Mary Valley and north Queensland than in the Brisbane Valley. High levels of brownstain heartwood were also reported from Araucaria plantations in the Wide Bay region (Monto). As solid timber, brownstain was difficult to dry using conventional kiln schedules, as this required re-sorting and re-drying, increasing the processing costs. Once dried it had a greater propensity to take up water than normal wood. Processors of veneers experienced less trouble with brownstain, as much of it remained in the peeler core. End uses for brownstain-affected timber were generally low return products such as chips, case and packaging material, shooks, scantling and ceiling battens.

The processors vary considerably in operational scale, with annual throughput of log ranging from around 13 000 m^3 to 185 000 m^3. Total recovery percentages ranged from between 40 and 50%. Generally, recovery of premium grade material (variously referred to as white, clears or A grade) was less than 10% and typical figures are around 4% or less (Mr Doug Simms, pers. comm. 2004).

The estimated cost of brownstain to DPI Forestry and the Araucaria processors has been estimated, based on information supplied by both groups. The annual sawlog harvest of Araucaria is 380 000m^3/annum, of which approximately 326 000 m^3 is final crop or clearfall. Using the standard royalty paid to DPI Forestry for clearfall hoop pine, the total potential income is approximately $25 million/year for final crop sawlogs (Anon 2001). Due to the extensive occurrence of brownstain in North Queensland and other market and resource (non-pruned) factors, the clearfall material is appropriately discounted resulting in an estimated direct loss in royalty income to DPI Forestry of around $400, 000/annum.

Lost revenue to the North Queensland processor has also been estimated, based purely on product downgrade. However, this is conservative, as it does not include the extra sawing costs required to maximise recovery of white or clear wood. Log inputs to this processor are approximately 20 000 m^3/annum, and recovery in sawn boards is approximately 42%, or 8 400 m^3. Over the past five years, at least 36%

(Ravenshoe records suggest >40%, Mr Doug Simms, pers. comm.) of the sawn output, or 3024 m^3, was affected by brownstain. As brownstain is often centred on the heartwood, some of this timber would normally be consigned to lower grades irrespective of brownstain, due to the presence of knots and/or pith. Some brownstain-affected material occurs well beyond the heartwood zone, and this material would otherwise fall into higher grades, such as clears or finger-joint grade, if not for the presence of brownstain. Assuming all brownstain material might otherwise at least be of finger-joint grade quality ($660/$m^3$), but due to staining is downgraded to battens ($300/$m^3$), an approximate annual revenue loss of $1.1 million is predicted. (Leggate *et al* 2002).

An attempt to estimate expenses incurred due to extra handling and longer drying times i.e. costs of pre-sorting, drying and post-sorting required for material when it is associated with brownstain heartwood, are difficult to quantify on an industry level as the operational scale, varying costs of production, products recovered and variations in grading systems for the processors varies considerably. The estimated costs of pre-sorting, drying and post-sorting were requested, in January 2004, from the various hoop pine processing industries and has not resulted in any new data being presented at the time of writing this report. The estimates for overall brownstain heartwood loss of combined revenue to processors from North Queensland and the Mary Valley, where brownstain is most pronounced, amount to an estimated $11 million/annum, and to DPI Forestry, loss in royalties of almost $400 000/annum (2002). This estimate of loss in royalties is conservative, since if the problem did not exist in any of the resource, processor returns would be higher and the general royalty would not indirectly include a discount for brownstain. (Leggate *et al* 2002). These estimates will vary continually as a result of fluctuating market forces within the industry.

In the Mary Valley, the incidence of brownstain can also be high, reportedly affecting up to 50% of logs and 30% of boards. With a total annual output of approximately 100 000 m^3 from the major Mary Valley processor, potentially 30 000 m^3 could be affected by brownstain. Assuming a conservative two-third reduction in the value of boards so-affected, the loss in revenue to the processor, for product downgrade alone, is approximately $10 million/annum. (Leggate *et al* 2002).

These estimates indicate the severity of brownstain heartwood to the hoop pine growing and processing industry.

Potential for value-adding and end-uses for brownheart in Araucaria

The following are considered to be major constraints to employment of brownstain heartwood in potential new end-uses:

- high MCs after conventional kiln drying
- dark stain
- altered strength properties
- acrid or sour odour.

Detection of brownstain heartwood material before it is kiln dried with normal material should be the first step in improving returns for Araucaria processors using this material.

The dark appearance of brownstain heartwood is a further constraint to its use, but if it can be economically dried, this problem becomes a marketing issue. Its reported lower strength needs further investigation, as the study by McNaught (1992), was based on a small sample from only one geographic section of the resource. The sour or acrid odour that is sometimes associated with brownstain heartwood is an additional constraint to its use, although it is less pronounced in seasoned timber than in freshly fallen trees.

Potential end-uses for brownstain heartwood were categorised according to the extent of processing required. This approach recognised the potentially greater returns associated with value adding but also the greater costs for the processor, and thus potentially lower net profit. The categories considered were solid timber-base products, veneer-base material and composite products.

Conclusions and recommendations

- Brownstain heartwood presents Araucaria processors with two major issues:
    - material that is difficult to dry under standard kiln schedules, the longer time required drying brownstain heartwood increases costs to the processor (these are difficult to quantify on an industry level), and
    - a product not as yet readily accepted as appearance grade material by the market. Use of brownstain heartwood in board form is constrained by the current market expectation for Araucaria to be light-coloured and is an impediment to achieving higher returns from brownstain heartwood. If it could be marketed as a feature grade material, attracting a premium price, this could offset the additional time and expense required drying brownstain heartwood. The performance of brownstain Araucaria, including its ability to fix (glue, nail and screw) and to accept paint or stains requires further investigation.
- Additionally, in Queensland plantations of Araucaria, *Phellinus noxius* is an important root disease pathogen capable of causing significant losses throughout a rotation. A conservative estimate of possible losses in the remaining 113 ha of first rotation Gadgarra plantation in North Queensland alone is $2.5 million. The total area of Araucaria plantation potentially affected by root rot in Queensland, which includes *Phellinus noxius* and *Rigidoporus vinctus* organisms, is 9000 ha. (Leggate *et al* 2002).

Other areas of research on brownstain heartwood have been recommended in the past in the following areas, some of which are investigated under separate FWPRDC projects:

- Seasoning, new products, workability and performance, strength properties, log breakdown, site factors, tree age/size, genetic influences and pathology.

So how can the industry deal with and minimise the significant predicted revenue losses?

- Detection of brownstain heartwood material before it is kiln dried. New methods for detection of wetwood, in standing trees, logs and sawn green timber. Ideally, detection of brownstain heartwood in standing Araucaria trees would be the most efficient way of handling brownstain heartwood. However, this would focus potential royalty losses onto DPI Forestry and possibly create a market shortfall in the hoop pine industry, particularly in far north Queensland where the problem appears to be the most significant.
- A fungicidal drench could be routinely applied after any silvicultural operations that could have the potential to cause damage to the root structure of hoop pine where *Phellinus noxius* and *Rigidoporus vinctus* organisms could gain entry to the tree.
- A full investigation could be conducted on the relationship between these organisms or bacteria and brownstain heartwood.
- Re-activate a hoop pine breeding program that focuses on breeding resistance to brownstain heartwood and/or *Phellinus noxius* and *Rigidoporus vinctus* organisms.
- Thoroughly investigating the potential of klinki pine (*Araucaria hunsteinii*) as an alternate light-coloured wood product.

There are obviously no "quick fix" solutions available for brownstain heartwood. It is difficult to state exactly what the additional costs are for reprocessing brownstain heartwood affected material, on an industry level, when the hoop pine processing industry is so diverse and affected material has different effects for different products. These economic costs need to be evaluated on an individual processor level. A consolidated combined industry effort is required to minimise this significant problem.

3. Araucaria colour matching

(see ACM Jun 04 on CD for further detail)

by David Hayward Timber Queensland, and Len Hamey, Hamey Vision Systems Pty Ltd.

Summary

Araucaria has a reputation as a blonde timber. However, colour variations, knots and staining are common. The Araucaria colour matching project developed a machine vision system for assessing four of the most significant features of Araucaria: the base timber colour, knots, heartwood stain and kiln stain. These visual features are assessed by computer processing digital images of dressed timber. The technology that has been developed could be used to grade shook and/or to provide information for the control of production processes.

The system provides highly accurate measurement of timber colour. The system uses calibration techniques that ensure long-term consistency in colour measurements. Human inspectors are subject to fatigue and their assessments of colour drift over time. Human assessments of colour are also affected by the environment. A well-known illusion demonstrates that people are sensitive to the environment when estimating colour. In Figure 3.1 the two squares marked with arrows are actually the same colour. They appear to be different colours because their contexts are different. Human perception of colour is influenced by the context. This means that a particular piece of wood may look different depending on the appearance of other objects that surround it.

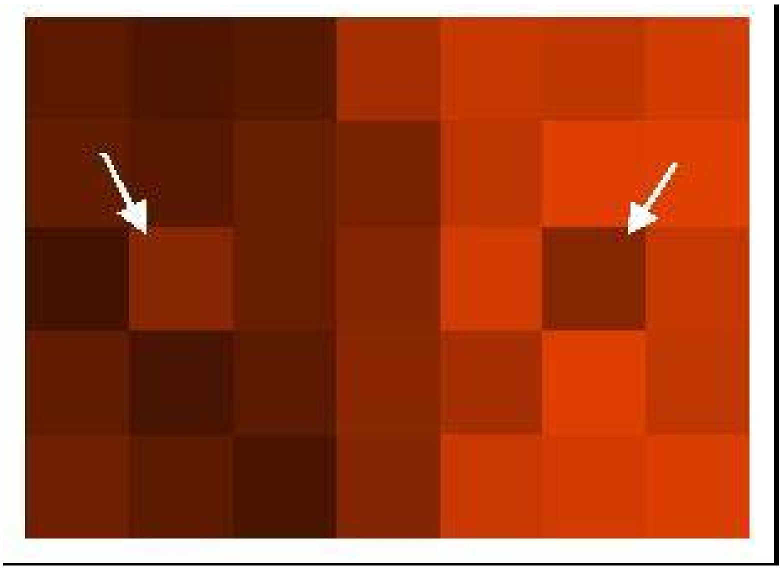

Figure 3.1. The squares marked with arrows are the same colour but appear to be different because of differences in the surrounding colours.

A computer-based colour measurement system is preferred because it is insensitive to the environment and can provide long-term consistency in colour measurements. The system developed uses calibration techniques that ensure long-term consistency in colour measurements that are not affected by the environment. The system is capable of distinguishing between subtle colour differences – it could be used to classify Araucaria shook into up to 10 separate colour grades. This colour measurement capability provides the opportunity to deliver colour matched shook as a premium product.

The system developed measures the colour over each timber sample excluding areas thought to be knots. For each timber sample, the system calculates the average colour over the sample, the standard deviation of colour within the sample and the range of colour within the sample (refer Figure 3.2). These statistics could be used to classify timber samples into different classes or grades. For example, the average colour could be used to separate samples into two or three colour grades. The range and standard deviation could be used to separate out samples that have large colour variation.

Figure 3.2. Sample No. 854: average colour 211; st. dev. 11; colour range 177 to 249.

The system also successfully locates knots, heartwood stain and kiln stain in timber samples. Currently, this information is displayed on a computer screen. Knots are outlined in yellow, heartwood stain is outlined in magenta (bright purple) and kiln stain is outlined in green. The background is displayed as bright blue. With further development, this technology could be used to locate features such as knots and this information could be used to control processing for shook production. Examples of the output to the screen are provided in Figures 3.3 and 3.4 illustrating the detection of knots, heartwood stain and kiln stain.

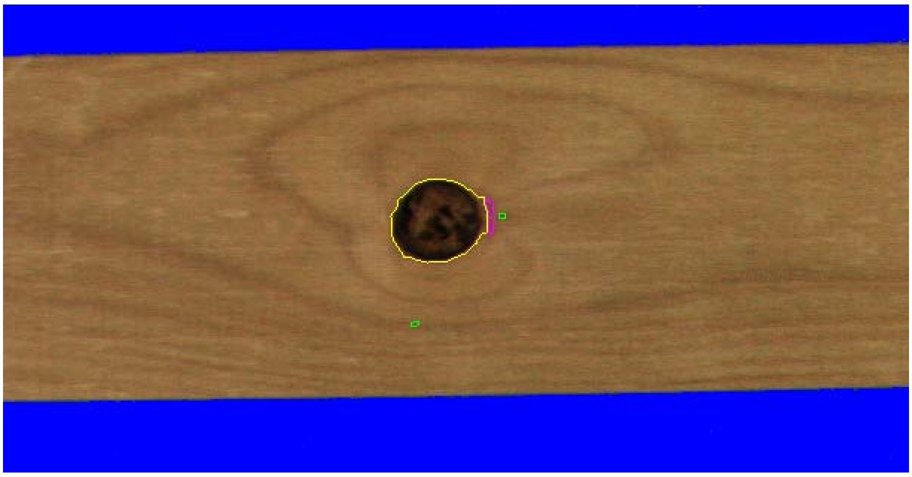

Figure 3.3. Identification of a knot in Araucaria.

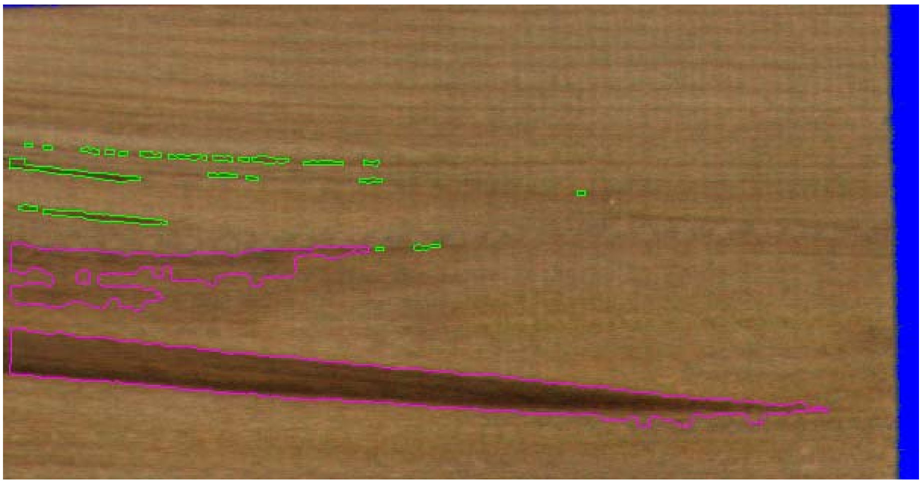

Figure 3. 4: Identification of heartwood stain and kiln stain in Araucaria.

The timber grading system is currently a prototype that can grade individual timber samples. Further work is required to develop the technology into a system or systems that can be deployed in a production environment. Application opportunities include production control and timber grading to produce premium product.

4. Effect of reduced rotation length on wood quality

(see MS1 Apr 02 and MS2 Sep 02 on CD for further detail)

by Kevin Harding DPI&F

Introduction

Current rotation length of Araucaria plantations is around 45 to 55 -60 years. A strategic review undertaken by DPI Forestry established that demand from current Araucaria processors was likely to exceed the capacity of the existing resource to supply premium log products, based on non-declining future resource supply scenarios (Anon 2001). Further, the significant improvements in genetic resources and silvicultural management techniques could only be realised during the re-establishment phase of the next rotation. The increased demand in the short to medium term can be met by harvesting plantations at a reduced rotation age. This would also enable the grower (DPI Forestry) to bring on stream the genetically improved second rotation (2R) plantations at an earlier stage.

A reduction of rotation length for the existing thinning age stands will change the nature of the Araucaria resource, by reducing log ASV and increasing the proportion of juvenile wood and knotty core in the harvest at clearfall. This could impact on both total and grade recovery. However, as the industry gradually moves into higher yielding, genetically improved stands under direct regime stockings, the current recovery of clearwood may be equalled or exceeded and the proportion of loose knots and dead branches may be reduced.

The crux of the issue for DPI Forestry and the processing industry is the likely impact on returns of selling 45-year-old rather than 55- to 60-year-old trees, particularly as some of the most valuable wood is laid down in the last ten years of growth in the current resource.

Tree parameters affecting wood quality

The Araucaria Australia Group was formed to reposition hoop pine (*Araucaria cunninghamii*) as Araucaria, a premium grade, quality, tropical softwood through industry collaboration and co-operation. As part of this repositioning, high value markets were to be identified and targeted. The types of products achieving high returns are generally those in appearance products, such as mouldings, joinery, panels and furniture. Desirable raw material properties for such applications include stability, uniform and satisfactory density, defect free or clear wood and an absence of distortion problems.

Tree and wood characters influencing wood quality in Araucaria include basic density, tracheid length, micellar angle, spiral grain, stability and distortion, compression wood incidence, knot size, frequency and type, brownstain heartwood, kilnstain, and the volume of juvenile wood (Palmer and Palisi 1992). Available information on these properties of Araucaria was reviewed to determine if and how a reduction in rotation length and/or a reduced average stem volume might affect these properties.

Average wood property values for Araucaria for most parameters of interest have been described (Smith and Eccles 1979). However, in the current project investigation of the effects of a reduction in rotation length, the within-tree variation in properties is probably of greater importance. Within-tree wood properties of plantation Araucaria were intensively studied for a small sample of stems in the late 1950s and early 1960s, when most of the resource was around 25 to 30-years-old. Whole tree and wood properties were also investigated for 51-year-old plantation Araucaria in the 1980s. The key findings from a review of the available information are summarised below.

Basic density

Decreases from breast height to relatively constant values up the stem with a slight increase in the upper part of the merchantable stem.

Tracheid length and micellar angle

There is a definite trend for tracheid length to increase and micellar angle to decrease with distance from the pith.

Spiral grain

Spiral grain mean values show an initial increase in the first 6 growth rings years from the pith and then decrease. The core of wood in Araucaria with grain spirality likely to affect distortion of sawn timber is about 135 mm in diameter. There is a general increase in spiral grain with height in the stem and decreasing distance from pith. Increases in mean spiral grain lead to increases in the proportion of material affected by twist whereas increases in stem size have the opposite effect.

Shrinkage (stability) and distortion

Transverse shrinkage, from green to air dry, is very low in Araucaria (Smith and Eccles 1979), and unit shrinkage in Araucaria ranges from 0.23 in the tangential direction to 0.18 in the radial direction (Kingston and Risdon 1961). Investigations of shrinkage found that it varied within the stem and between stems independently of stem size (Balodis 1966). Longitudinal shrinkage increased with height and decreased with distance from the pith (Balodis 1966). Tangential and radial shrinkage both increased with distance from the pith and with height in stem (Balodis 1966).

Twist is the main cause of seasoning degrade in Araucaria, followed by spring (Smith and Eccles 1979). A significant linear relationship was established between twist and spiral grain in Araucaria (Balodis 1972), as discussed above. Twist was the most serious seasoning defect observed in sawn material of plantation-grown Araucaria, while spring and bow were confined to occasional boards and cupping was practically non-existent (Balodis 1966). Spring plus bow was independent of position in the stem while twist increased with height in stem and decreased with increasing distance from the pith (Balodis 1966).

Compression wood

In Araucaria compression wood is fairly common in the butt logs of older trees and it impacts on the amount of usable product obtained from such trees (Blake and Greve 1986). Compression wood in Araucaria is characterised by higher basic density, shorter fibres, thicker cell walls, higher micellar angle and lower cellulose and higher lignin contents (Smith and Smart 1972). Its strength as sawn timber in tension and shear is generally lower than that of normal wood through the effects of its shorter, thicker-walled tracheids with poorer cell wall organisation and higher lignin content (Smith and Eccles 1979). The tendency to spring and or bow in drying is higher, as is longitudinal shrinkage. It also gives lower cellulose yields and poorer quality pulp (Smith and Smart 1972).

Knots

Knots often have a much greater effect on processed product yields and value than the inherent clearwood properties (Smith and Eccles 1979). Live knots result in less degrade in board stock, appearance grade veneers and the outer veneers of structural plywood than the loose, unsound and/or defective knots due to dead branch enclosure. Branches of Araucaria are generally thin and flat-angled which results in a less depreciative effect on strength and appearance of sawn and peeled timber products (Smith and Eccles 1979). However, live knots can be troublesome in Araucaria, due to their impregnation with “hard resin”, resulting in chipping when machined (Smith 1977).

Brownstain heartwood

An obvious brownstain occurs in the central zone of many *Araucaria cunninghamii* trees, which persists through milling and drying and affected boards are often consigned to lower value grades. A review of brownstain in Araucaria (Catchpoole, S. 2001) revealed:

- brownstain is generally associated with a condition known as wetwood, which is characterised by higher than normal moisture contents;
- it is commonly associated with bacterial infestation, but it is not a form of decay (fungal origin);
- no study has conclusively established the cause of brownstain or wetwood in Araucaria or any other affected species;
- it generally occurs in the heartwood zone in the lower stem section but occasionally extends beyond this zone;
- the amount of brownstain has been observed to increase with increasing tree size or age.

Juvenile wood

From the preceding review of key wood properties of Araucaria, spiral grain appears to be the most important factor defining the extent of the juvenile wood zone. Basic density showed minimal pith to bark variation, unlike most exotic conifers that display a distinct increase and subsequent levelling off in basic density with distance from the pith. Available information on tracheid length and micellar angle indicated a trend of increasing tracheid length and decreasing micellar angle maximum with distance from the pith. Detailed within-stem data on spiral grain variation for trees aged 51 years revealed that in the lower two-thirds of the trees, spiral grain angles were predominantly less than 3° beyond 20 rings from the pith. In the upper third of the trees, spiral grain was predominantly greater than 5° to at least 25 rings from the pith. Inside 14 rings from the pith up the entire length of the stem, spiral grain values were predominantly greater than 5°. Based on this information, the juvenile core could be considered as being contained within the first 20 rings. The real problem material, with spiral grain values of greater than 5%, would be contained within the first 15 rings from the pith.

Analysis of impacts

There were two issues under consideration in this part of the AAG project. One is a reduction in rotation length from around 55 years to around 45 years. The second is a reduction in average stem volume (ASV) that will occur regardless of what rotation length is adopted. Both may potentially affect the value of Araucaria through their influence on the tree and wood properties reviewed above. The effect on juvenile wood is considered first, since the extent of juvenile wood in the stem also affects a number of related wood properties in Araucaria, including the proportion of wood with high spiral grain, shorter tracheids and tracheids with high micellar angle.

A reduction in rotation length may result in an increase in the proportion of juvenile wood. Due to the high grain angles that occur in the juvenile core this could increase problems with stability and distortion in sawn boards. To determine to what extent a reduced rotation length and/or reduced ASV might affect juvenile wood proportions, the WEEDS/PLYSIM system (DPI Forestry) and STEPS software (Catchpoole and Nester 2001) were used to model 45- and 55-year-old plantation Araucaria trees for Imbil State Forest. It was assumed that the initial effective stocking was 750 stems/ha, pruning was to 5.4 m and one commercial thin was conducted at 30 years. Four site indexes, 21, 24, 27 and 30, were investigated. To estimate the volume of mature wood in 45-year-old, versus 55-year-old trees, it was assumed that the juvenile core was contained in the first 15 rings from the pith. The WEEDS/PLYSIM system and STEPS software was used to determine diameter at breast height of a 15-year-old tree for the four site indexes chosen. It was not possible, however, to determine the volume contained in the first 15 rings from the pith within a 45 or 55-year-old tree using the WEEDS/PLYSIM system and STEPS software. Instead, volume contained within the first fifteen rings from the pith was calculated using actual data for six trees from the CON64 research database. The results of the simulation allowed analysis of the effect of a reduction in rotation length for a given site index and analysis of the effect of a reduction in ASV, for a given rotation length, on the proportion of juvenile wood in a tree. Given the assumptions made the output results should be regarded as indicative only.

Summary of impacts of reduced rotation length

The review of existing information has identified the following:

- the juvenile core in Araucaria is probably contained within the first 15 growth rings from the pith, with spiral grain being a chief determinant of its extent within the stem;
- a reduction in rotation length for a given site index will reduce ASV and mature wood volume, with an increase in the proportion of juvenile wood;
- for a given rotation length, lower ASV stems were estimated to contain a lower proportion of juvenile wood (based on the assumptions made and crude simulations using WEEDS, PLYSIM and STEPS software); regardless of juvenile wood proportions, smaller stems will yield a higher proportion of pith-in material;
- an increase in the proportion of juvenile wood, due to a reduction in rotation length, could affect wood quality due to an increase in the proportion of the recovery containing high spiral grain, shorter tracheids and higher micellar angle;
- high spiral grain and high micellar angles adversely impact on wood quality through their influence on twist and longitudinal shrinkage, respectively;
- positive outcomes from a reduction in rotation length might include an increase in the proportion of live knots in upper stem sections and a reduction in the extent of brownstain heartwood;
- the uniformity in basic density within Araucaria stems means reduced rotation lengths and lower stem ASVs are unlikely to have a major impact on this wood property, and
- the effect of a reduction in rotation length on the incidence of compression wood and timber susceptible to kiln-staining could not be established from the available information.

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5. Araucaria Wood Characteristics

(see MS2 Sep 02, MS3 Feb 03 and MS4 Jul 03 on CD for further details)

by Kevin Harding, Innovative Forest Products, DPI&F

Introduction

The wood properties of Araucaria (*Araucaria cunninghamii*) priority parent trees used in breeding programs and seed production orchards need to be considered to maximise the wood quality of future plantations. First and second generation plus tree selections for the Araucaria breeding program in south-east Queensland focussed on improving growth rate and tree form (Nikles *et al* 1988) with little emphasis on wood properties (Harding and Woolaston 1991). Parent trees need to be ranked for wood quality so their relative merit can be strategically considered in specifying crosses to be made in seed orchards for both operational deployment and for breeding.

The aim of this project was to develop a ranking of priority Araucaria parent trees used in breeding programs and seed production orchards for wood properties. However, for this to be done in a cost effective manner, preliminary work was needed to determine the critical zone of wood property variation in the juvenile wood so that screening of genetic material could be restricted to and focused on the critical growth rings.

Wood property variation

Background

Information on within-tree variation was required to determine the critical number of growth rings from the pith to sample to screen parents for wood quality traits. The traits of interest were spiral grain and microfibril angle (MfA), as a large degree of wood distortion and stability issues in Araucaria, particularly in the juvenile core, can be related to these two traits. Although not considered problematic in Araucaria, density was also sampled in the course of Silviscan assessment of MfA, and is also reported.

Materials and methods

Suitable stands of average site quality at Amamoor and Yarraman State Forests, approximately 30-years-old, were selected for sampling to map within-tree wood property variation. Sampling was carried out in:

- Compartment 6A, Zacharia Logging Area, Amamoor State Forest (planted December 1968)
- Compartment 6A Gilla Logging Area, Yarraman State Forest (planted November 1970).

Ten randomly selected trees were felled at each site and disc samples were removed from them at breast height, 20, 40, 60, 80 and 100% of merchantable height. The disc samples were processed into two matching diametral (bark to bark) strips. One sample was retained for spiral grain analysis while the other was split into two radial (pith to bark) samples with the best of these sent to CSIRO Forestry and Forest Products for analysis of detailed within- and between-ring air-dry density variation and MfA pith to bark trends, using Silviscan. Air-dry density variation was assessed with a sampling rate of 50 microns and MfA at 5mm intervals.

The Silviscan data was analysed at two levels of detail. For pith to bark trends in density and MfA, a detailed ring-by-ring analysis of the data was carried out on Discs 1, 3 and 5 of the twenty trees sampled. For trends in density and MfA up the stem, area-weighted disc averages were investigated on all six discs of all twenty trees.

Spiral grain was analysed on 10 of the twenty trees sampled, five from Amamoor and five from Yarraman State Forest. Discs 1, 3 and 5 (corresponding to the breast height, 40% and 80% of total tree height samples) were used for detailed spiral grain analysis.

Results

Mean source tree data are presented in Table 5.1 below.

Table 5.1. Average dimensions of sample trees.

Site	Planting date	Average total height (m)	Average diameter at breast height (dbh cm)
Amamoor	December 1968	27.8	27.89
Yarraman	November 1970	21.9	26.77

Table 5.2. Average disc sampling heights up the stem in sample trees.

Site	Disc number.	% merchantable height*	Average height (m) in tree (n=10)
Amamoor	1	breast height	1.1
	2	20	3.3
	3	40	6.4
	4	60	9.7
	5	80	12.9
	6	100	16.0
Yarraman	1	breast height	1.2
	2	20	2.8
	3	40	5.7
	4	60	8.5
	5	80	11.4
	6	100	14.1

*Note: merchantability limit was 20 cm diameter under bark for trees >26 cm DBHOB. For smaller trees (20 to 26 cm DBHOB), this merchantability limit was relaxed to approximately 15 cm DOB so that samples were evenly distributed at 2 to 3 m intervals up the stem.

Spiral grain analysis

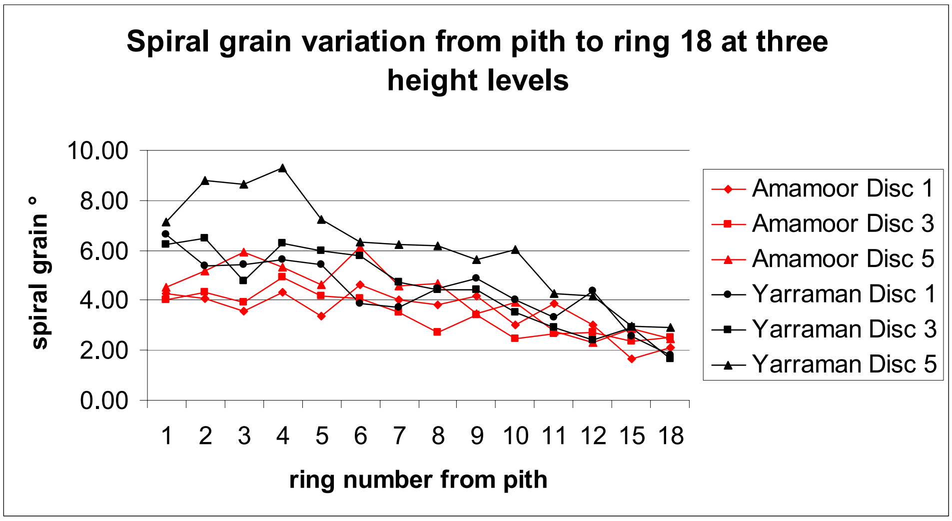

Figure 5.1. Variation in spiral grain from pith to ring 18 and up the stem in approximately 30-year-old Araucaria from Amamoor and Yarraman State Forests. Average disc heights 1.1 m (disc 1), 6.0 m (disc 3) and 12.2 m (disc 5). Each point represents the average of five trees. (Disc 1 = breast height, disc 5 = 80% of merchantable height).

Generally, spiral grain values were higher in the trees sampled at Yarraman than those sampled at Amamoor at all three within-tree heights (Figure 5.1) and there was greater variation up the stem at Yarraman than at Amamoor. There was a trend of increasing spiral grain up the stem in at least the first six rings and the trend was more pronounced in the Yarraman samples than in the Amamoor samples. The difference in spiral grain values up the stem was more pronounced between disc 3 and disc 5, than disc 1 and disc 3.

Silviscan density analysis

Density results as determined from the Silviscan analyses are presented in Figures 5.2 and 5.3.

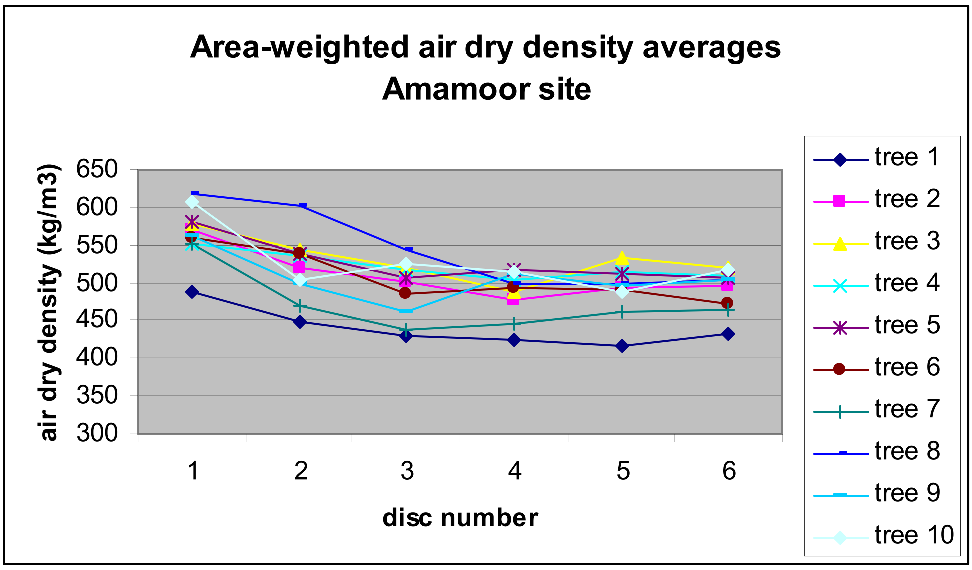

Figure 5.2. Trends in area-weighted air dry density up the stem (disc 1 = breast height to disc 6 = merchantable height) for all trees sampled at Amamoor State Forests. Refer to Table 5.2 for disc heights.

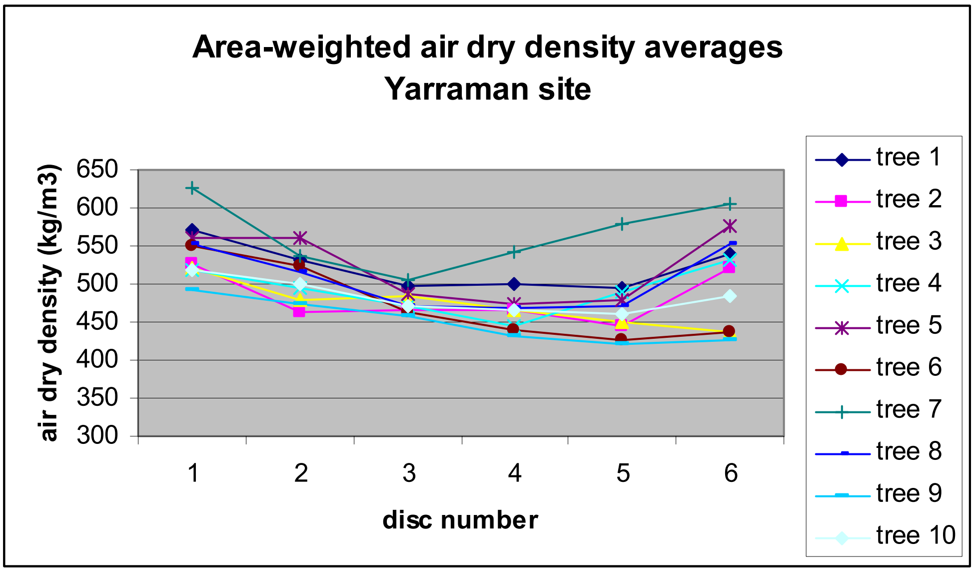

Figure 5.3. Trends in area-weighted air dry density up the stem (disc 1 = breast height to disc 6 = merchantable height) for all trees sampled at Yarraman State Forests. Refer to Table 5.2 for disc heights.

Silviscan MfA analysis

Microfibril angle results as determined from the Silviscan analyses are presented in figures 5.4 and 5.5.

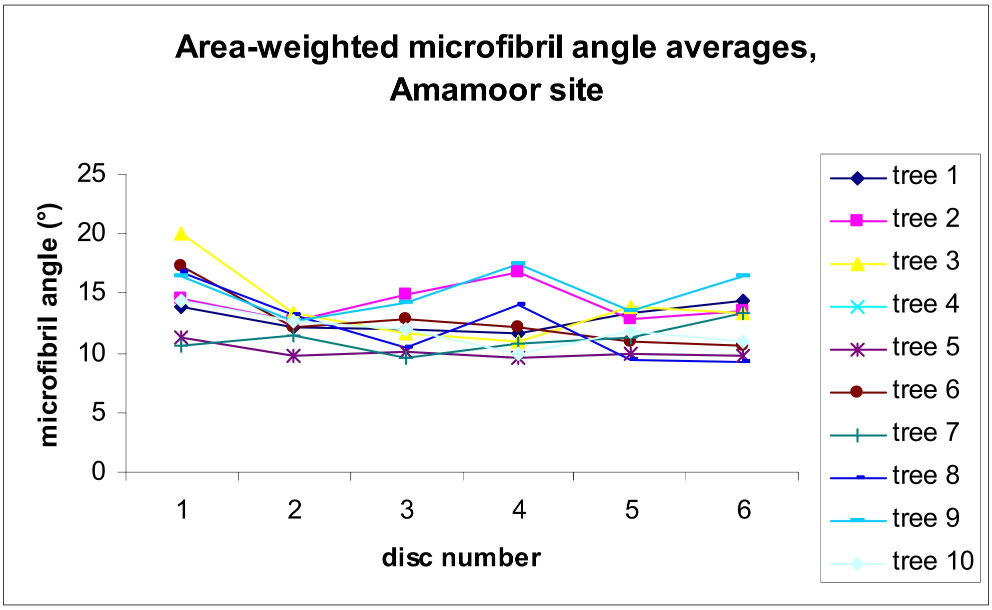

Figure 5.4 Trends up the stem in area-weighted MfA for all trees sampled at Amamoor State Forests (disc 1 = breast height, disc 6 = merchantable height).

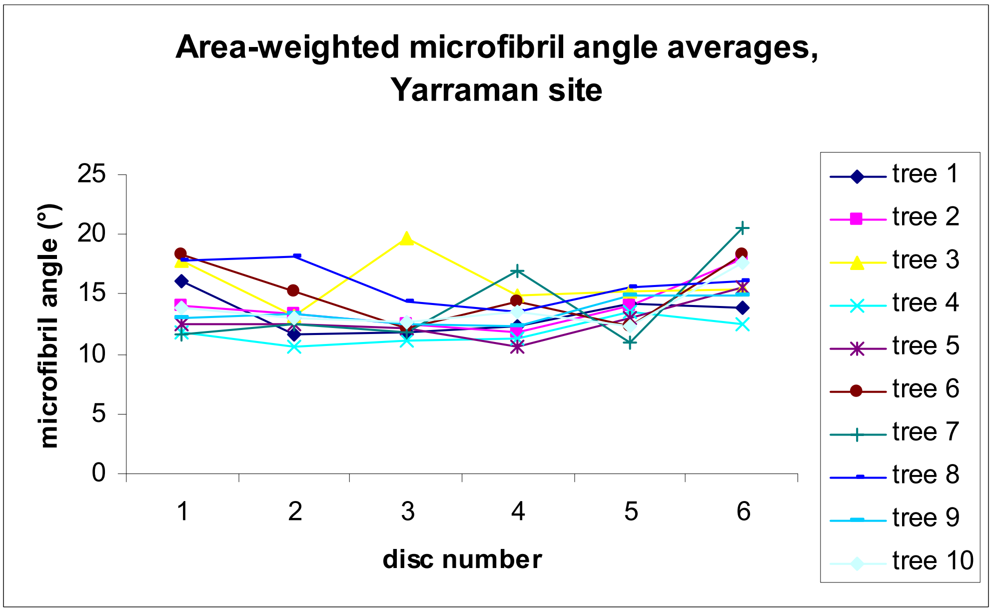

Figure 5.5 Trends up the stem in area-weighted MfA for all trees sampled at Yarraman State Forests (disc 1 = breast height, disc 6 = merchantable height).

Improving wood properties in the future resource

Introduction

The Department of Primary Industries Forestry identified 11 parents as important to current crossing and seed collection programs. Wood properties of interest were:

- spiral grain;
- microfibril angle (MfA);
- basic density.

The results from sampling of the Amamoor and Yarraman stands summarized above, suggested that Silviscan analysis of the first 7 growth rings from the pith should be adequate to detect any 'rogue' parents with extreme density, undesirable MfA readings (> 30°) or high maximum spiral grain angles.

Materials and methods

Three ramets of each parent (clone) were sampled from seed orchard grafts. Two core samples per ramet were collected. A 12 mm hand corer was used to extract diametral samples, from bark to bark through the pith. Core sampling was conducted above the graft height, beyond any abnormal wood formed at the union itself and midway between branch whorls to avoid abnormal wood associated with branches. Due to the height of some graft unions, up to 4 m above the ground, core samples had to be collected using a truck-mounted cherry picker. In the laboratory, sample processing for density, MfA and spiral grain analysis was similar to that set out in the methodology described above.

Results

Density

Average air dry density of the selected parents generally ranged between 400 and 500 kg/m^3 between rings zero and seven from the pith.

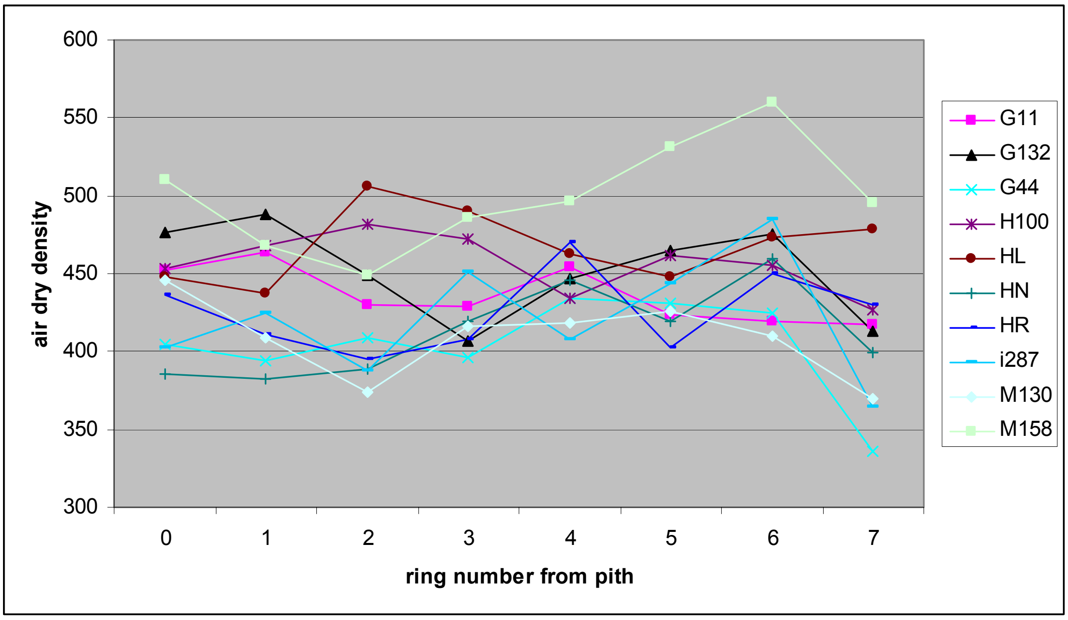

Figure 5.6. Average air dry density for rings zero to seven from the pith. Each point represents the average of three ramets.

Microfibril angle

The trend in average MfA values was consistent for all parents sampled (Figure 5.7) and between-ramet variation for each clone was also minimal. Peak values, observed closest to the pith, were generally between 20 and 25° and at ring seven from the pith average values for all clones were less than 20°.

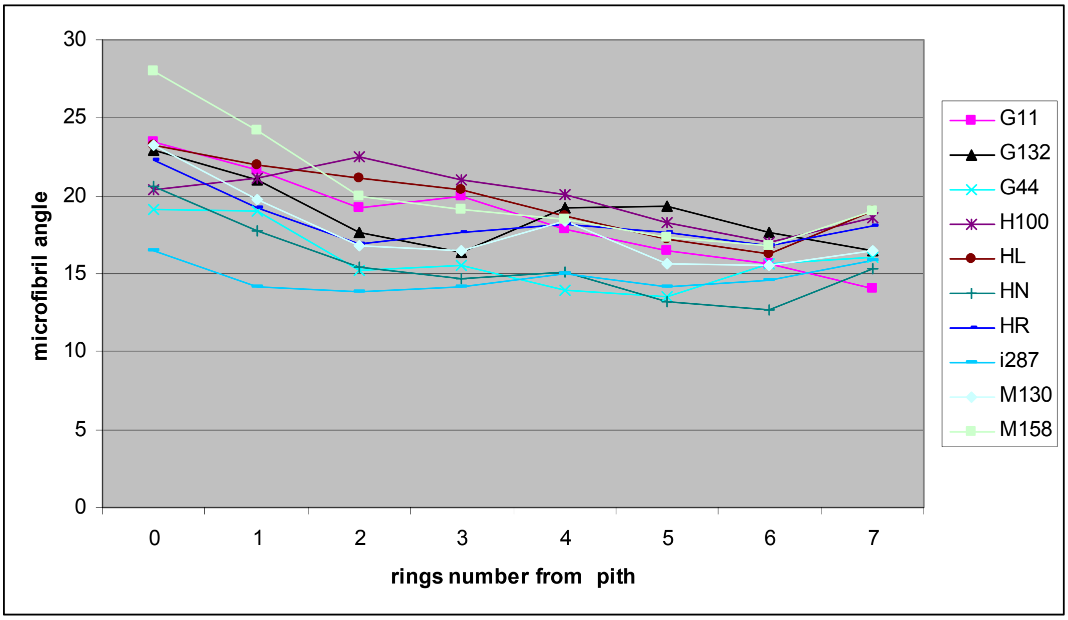

Figure 5.7 Average MfAs for selected priority parents. Each point represents the average of three ramets.

Spiral grain

Spiral grain patterns from ring 3 to ring 7 varied widely between the sampled parents (Figure 5.8). At ring 7, average spiral grain ranged from a very acceptable 2.7° (clone G11) to a rather disturbing12.1° (clone HL). Variability between the ramets of some clones was also high. Clones HL and M130, which had the highest average spiral grain values at ring 7, also displayed high variability among ramets. Clones H54, H100 and

G11 were among the better clones sampled with respect to spiral grain, with low values that were also trending downwards with distance from the pith and low among-ramet variability. Spiral grain values in excess of 4° to 4.5° can be expected to result in significant twist in sawn products as well as decreased stiffness and strength as angles increase.

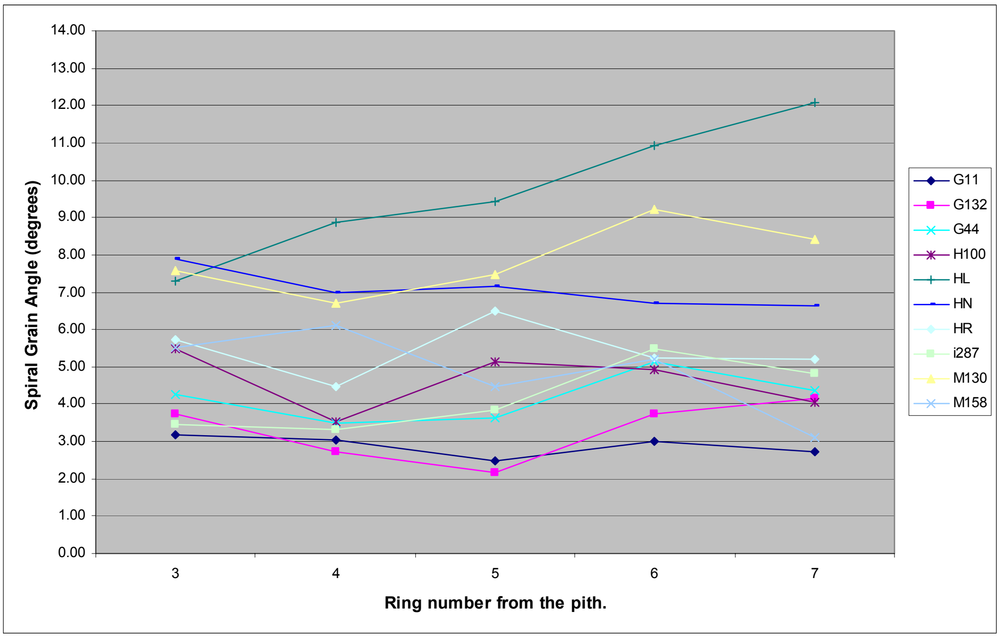

Figure 5.8 Average spiral grain angles for selected priority parents. Each point represents the average of three ramets.

Conclusions and recommendations

The trends from pith to bark and up the stem in basic density, MfA and spiral grain observed in the trees sampled at Amamoor and Yarraman State Forest were in agreement with results from earlier studies on Araucaria. They provided more useful results based on age or on a growth ring number from the pith basis rather than distance from the pith that had been used in the past. The relatively uniform pith to bark density values observed were further confirmation of Araucaria's reputation for within-stem uniformity in density (Smith and Eccles 1979).

Generally, MfA in Araucaria has been regarded as excellent throughout, apart from odd rogue trees (Smith and Eccles 1979). Within-tree trends in MfA in Araucaria follow the normal pattern for conifers of a decrease with age and distance from the pith (Smith and Eccles 1979). MfA exceeding 30° tends to be associated with unacceptable distortion in dried boards. None of the trees sampled in the current resource recorded high MfA values (> 30°) and from the eighth ring from the pith, average values were at or below 20° at all heights sampled in the selected stems.

Previous reports of spiral grain in Araucaria increasing with height in the stem and decreasing distance from pith (Balodis 1960) were confirmed in sampling of the current resource. Highest spiral grain values in the current resource were observed in the first seven rings from the pith and from ring 15 average values at both the Amamoor and Yarraman sites were below 4°.

On the basis of the results of density, spiral grain and MfA analysis of the current resource, analysis of samples from priority-breeding parents was restricted to rings zero to seven (inclusive) from the pith. The analysis found that trends in density and MfA conformed to trends observed in both the current resource, sampled and analysed for the present investigation, and to trends reported in earlier studies (Smith 1959; Balodis 1960). None of the priority parents sampled displayed density or MfA values that would downgrade their utility for use in priority-breeding programs.

Spiral grain analysis of the sampled parents revealed considerable variation between parents and among ramets of individual parents. Furthermore, unacceptably high spiral grain values (> 4°) were observed at ring seven from the pith in the ramets of many parents. Spiral grain therefore appears to be the critical character that will dictate which parents should be selected for priority-breeding programs for wood property improvement in Araucaria.

With data from only three ramets of each parent, it would not be prudent to confidently select any of the ten sampled parents for priority-breeding programs. This is primarily due to the unacceptably high average spiral grain values in many parents and to the large among-ramet variation in spiral grain values. G11 and G132 are the only two parents that appear to have acceptable, or close to acceptable, grain spirality. It was hoped that the consistency of values among ramets might have been high enough to give a reasonable level of confidence in results from a small sample size as dictated by available funds. However, it is clear that spiral grain is highly variable and a larger sample size will be needed to have confidence in the quality of particular parents.

It is recommended that more extensive sampling be undertaken of both a greater number of parents and a larger number of ramets per parent to identify Araucaria parents with consistently low grain spirality. This expanded wood sampling program should focus on assessment of spiral grain in the first 7 to 10 rings from the pith. Follow up assessment of the more expensive MfA and density analyses should then be undertaken as a second phase screening confined to only those parents showing acceptable spiral grain values.

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6. Araucaria logging practices

(see MS3 Feb 03 and MS4 Jul 03 on CD for further details)

Summary from reports by Kenn Bubb DPI Forestry

Harvesting in 'wet' and 'dry' conditions

A ground-based excavator extraction system recently developed in DPI Forestry's steepland *Araucaria* plantations was assessed as part of the Araucaria sector R&D 3 –year-projects in regard to impacts on plantation productivity and potential off-site effects. The study investigated the trafficking system used by a 20 t excavator to lift and transport whole trees to roadside log dumps. This system is based around a semi-controlled traffic pattern where the excavator operates down roughly parallel snig tracks approximately 30 m apart. The key soil indicators of bulk density, saturated hydraulic conductivity and organic carbon were used to investigate compaction and erosion hazards associated with harvest operations in 'wet' and 'dry' conditions.

During 'dry' conditions (i.e. soil moisture <15%), compactive stresses from the laden excavator were limited to a depth of 20 cm. After multiple excavator passes over a snig track, soil bulk density in the upper 0 to 10 cm increased to levels regarded as severely compacted. Further to this, surface permeability was reduced sufficiently for snig tracks to be considered as a high erosion risk. It should be noted that even under 'dry' conditions these soils can become severely compacted despite the continuous rutting depth being below the 10 cm maximum limit outlined in DPI Forestry's harvesting guidelines.

Under 'wet' conditions, compactive stresses from the laden excavator were transmitted to a depth of 20 to 30 cm below the disturbed surface. Irrespective of soil moisture regime, after ten or more excavator passes, soil bulk density was increased to levels regarded as severely compacted. Further to this, surface permeability was reduced sufficiently for snig tracks to be considered as having a high erosion risk by channelling water down long and steep slopes. Both the erosion and compaction risk suggest that a controlled trafficking system is warranted, and that all snig tracks require an erosion mitigation system, as well as some form of amelioration to alleviate compaction to a depth of between 20 and 30 cm.

Using a GPS-based system a survey of trafficking patterns found the harvesting system produces around 300 m of snig trail per ha, this accounts for 4 % of the general plantation area (GPA) with log-dumps extending over a further 12 %. The lateral transmission of compactive stresses during trafficking in 'wet' conditions can almost double the area of GPA affected.

Following relatively crude cultivation to the snig track with the excavator's grapple, impacts to both bulk density and surface permeability were generally reversed to at least pre-trafficking levels in 'dry'conditions. Similarly, in 'wet' conditions crude cultivation with the grapple fully reversed increases in bulk density from 40 passes to a depth of 20 cm, but only partially for the 20 to 30 cm profile (i.e. 50 to 60 cm below original surface). It is likely that where excessive rutting has occurred during periods of high soil moisture additional cultivation will be required to take into account impacts to the soil profile immediately adjacent to the track.

7. Technology transfer

Araucaria industry representatives were invited to an R&D Forum in Brisbane on Thursday 16 September, 2004. A research summary report, including CD of milestone reports, was distributed to stakeholders during the forum. Researchers presented results from project conducted under Project Number FWPRDC PN01.1901 (known as the 'three-year project') and participants discussed the implications of these final results, including recommendations for further work for the Araucaria industry.

The CD contained complete copies of each milestone report for the 3-year project, as well as reports on two subsequent kiln stain trials and a colour-matching project. Projects discussed in each milestone report appearing on the CD are listed below. (Abbreviations: MS milestone; KS kiln stain).

MS1 Apr 02		
	Project 2	Glue strength testing after cyclic humidity treatment
	Project 5	Brownheart (brown-stained heartwood) survey of physical and working properties
	Project 7	Increasing hardness
	Project 11	Reduced rotation length- working plan
MS2 Sep 02		
	Project 7	Increasing hardness
	Project 8a	Surface aberration in formply
	Project 9	Characterisation of wood properties- progress report
	Project 11	Effect of reduced rotation length on wood quality
	Project 12	Technical market support
MS3 Feb 03		
	Project 9	Characterisation of wood properties
	Project 10	Managing risks to site productivity from mechanical harvesting systems in non-conventional terrain
	Project 12b	Market development- brochure
	Project 5	Brown-stained heartwood and sapwood wetwood
	Project 6	Colour matching
MS4 Jul 03		
	Project 1	Mechanism of Araucaria kiln stain
	Project 5	Brownheart (brown-stained heartwood in Araucaria
	Project 9	Characterisation of Araucaria wood properties- past, present and future
	Project 10	Managing risks to site productivity from mechanical harvesting in non-conventional terrain
MS5 Apr 04		
	Project 1	Kiln stain

Project 5	Brownheart (brown-stained heartwood)
Project 4	Microwave pre-treatment to eliminate kiln stain

KS aldehyde dips

The effect of formaldehyde and butyraldehyde on kiln-stain in *Araucaria cunninghamii*

KS thin film

Use of a permeable film to reduce kiln stain in *Araucaria cunninghamii*

ACM Jun 04

Araucaria colour matching