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Thermal Modification of Specialty Species Results of Scion's SSIF-funded experiments

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SWP-T086

Executive summary

The problem

The objective of this work is to improve the properties of two specialty wood species (*Eucalyptus nitens* and *Cupressus lusitanica*) through thermal modification. Thermal modification darkens the colour of wood, increases dimensional stability, and at high levels of modification increases durability. Increased durability has been a primary focus for this work, but due to poor durability results for *E. nitens*, there has been a shift in focus for this species, to see if there is a place for thermally modified timber in interior markets, where durability is not a concern, so severe levels of modification are not required.

Key results

Eucalyptus nitens

Interim (33 month) fungus cellar results for *E. nitens* modified at Scion using an atmospheric steam process are not looking promising. The durability of the modified wood is greater than that of the unmodified controls, but not as great as H3.2 CCA-treated radiata pine. A more severe level of modification is not possible for this modification process, as the existing modification process is already producing excessive levels of degrade in the wood. An alternative pressure steam modification has achieved a similar degree of modification to the atmospheric steam process, while producing no degrade in the wood. This means there is an opportunity to trial a more severe pressure steam modification to increase the degree of durability.

Market research was performed to better understand New Zealand market requirements for interior timbers and how thermally modified wood fits within these. In general the responses were not positive for thermally modified timber, there is considerable market pull for very pale coloured timbers, and high consumer demand for traditional species such as white oak. Dimensional stability is not seen to be an issue with solid wood flooring, and there was a general feeling that existing flooring timbers were able to meet the range. There is anecdotal evidence that some overseas markets have very different drivers for interior wood products, and there could be opportunities for thermally modified wood in interiors in other markets.

Cupressus lusitanica

Interim (12 month) fungus cellar results for *C. lusitanica* are very promising with modified heartwood and sapwood both showing increased durability over unmodified heartwood, and showing similar durability to H3.2 CCA treated radiata pine. Mechanical testing results are in line with what we would expect for a severe level of modification - a slight (5%) decrease in MOE and a substantial (40%) decrease in MOR. A pilot (2.4m) modification has been performed to produce enough material to begin outdoor durability testing. Initial results (colour change and anti-shrink efficiency) show no significant difference in properties between the lab scale and pilot scale modifications. The lab scale modifications showed a high degree of degrade (checking) following modification, but this was eliminated in the pilot scale modification by drying the wood to a very uniform moisture content prior to modification.

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Introduction

Thermal modification is a well-established wood modification technology that can increase the dimensional stability of wood, darken the colour, and at high levels of modification can increase durability. This modification does not require the addition of chemicals, and can be performed on any wood species (unlike chemical modifications which require species with high, and even level of permeability).

Scion has been researching thermal modification of *Eucalyptus nitens* (H. Deane & Maiden) and *Cupressus lustanica* (Mill.) for a number of years. Research to date has concentrated on increasing durability for use in outdoor applications, and ongoing durability test results are presented here. Due to the challenges in achieving a high enough degree of modification in *E. nitens* to confer durability, this year's work has been extended to trying to understand drivers for interior timber markets and seeing how thermally modified wood fits within this.

Materials and methods

Eucalyptus nitens

Previous work on thermal modification of *E. nitens* has been reported in Sargent et al. (2017); Sargent and Dunningham (2016) and Sargent and Dunningham (2018).

Ongoing testing

Interim results from fungus cellar testing of modified *E. nitens* was reported in the 2018 report and further results are given here.

Pressure steam modification

Pressure steam modification involves heating the wood in a high pressure steam chamber, in the absence of oxygen. The use of pressure means that the wood does not dry out during modification, and this should reduce the wood shrinkage during drying, and consequently reduce the level of checking. Pressure steaming was performed in a commercial modification plant in The Netherlands (FirmoLin) in 2017. Three different modifications were performed:

'PS1' - Schedule typically used on timber for outdoor use in Europe

'PS2' - A slightly milder schedule than PS1, but still intended for outdoor use

'PS3' - A subset of boards from the PS2 charge were modified a second time using the same schedule

Further details are given in Sargent and Dunningham (2018). Following modification, changes in wood colour, dimensional stability and durability were assessed using Scion test methods. Specifically, durability was assessed using an in-house (Sutter) lab based durability screening test, and fungus cellar stakelets were installed in June 2018.

Thermal modification for interior use

This work used wood that had previously been modified at lab scale at Scion (Sargent and Dunningham 2016). Additional property data (hardness, dimensional stability) was collected on wood modified at 160°C and 185°C using Scion test methods. Dimensional stability results will be included in a separate report.

Market research was conducted to better understand requirements for interior wood products and understand how the properties of thermally modified wood might fit with these. A range of New Zealand architects, specifiers, retailers and manufacturers were interviewed to better understand what attributes they are looking for in solid wood, and where thermal modification would fit with this.

Cupressus lusitanica

Previous work on thermal modification of *C. lusitanica* has been reported in Sargent and Dunningham (2018).

Lab Scale Modification

C lusitanica was sourced from MacDirect in Patumahoe. Boards were selected so around half were completely heartwood and half were a mix of heartwood and sapwood. Boards were sold as being dry, but during sample preparation some boards appeared to have a wet core. Replication was 42 pairs of end matched boards, each 600mm long.

Using the Scion Lab scale thermal modification kiln, one board from each pair was modified at 220°C for 2 hours, and the other board retained as an unmodified control.

Previously, changes in wood colour, dimensional stability and durability have been reported for this wood. (Sargent and Dunningham 2018). This report contains data on mechanical properties of the modified wood. Further dimensional stability testing (Swellometer, and long term stability testing) results are included in a separate report.

Pilot Scale Modification.

As with the lab scale modification, *C. lusitanica* boards (100x50mm) were sourced from MacDirect, aiming for a mix of heartwood boards and sapwood-containing boards. Boards were sold as being dry, but during sample preparation some boards appeared to have a wet core, so were low-temperature kiln dried to ~12% MC. It was hoped that this initial drying to give a very uniform moisture content would reduce problems with checking seen in the lab-scale boards. Replication was 40 pairs of end matched boards, each pair containing one 2.4m length to be modified and one 1.2m control board. The boards were random lengths, varying from 3m to almost 5m long. Once the 2.4 and 1.2m lengths had been cut (plus moisture content blocks between), any offcuts longer than ~0.6m were labelled and thermally modified to provide extra material for testing, demonstration samples etc.

The 2.4m lengths, plus the offcuts, were modified in Scion's large thermal modification kiln, aiming for an equivalent schedule to that used at the lab scale.

Dimensional stability and wood colour were assessed, and levels of degrade were assessed before and after modification.

Results and discussion

Eucalyptus nitens

Ongoing testing

Results from the ongoing fungus cellar stakelet testing for *E. nitens* modified at 210°C in atmospheric steam are shown in Figure 1. Not surprisingly all the unmodified control stakelets (both *E. nitens* and radiata pine) have decayed (indicated by a condition of zero). The modified *E. nitens* is performing better than the unmodified *E. nitens*, but is not performing as well as the commercial H3.2 radiata pine. The fungus cellar test will continue for at least another 3 months (to September 2019), but it is typical to continue testing until all the stakelets have failed.

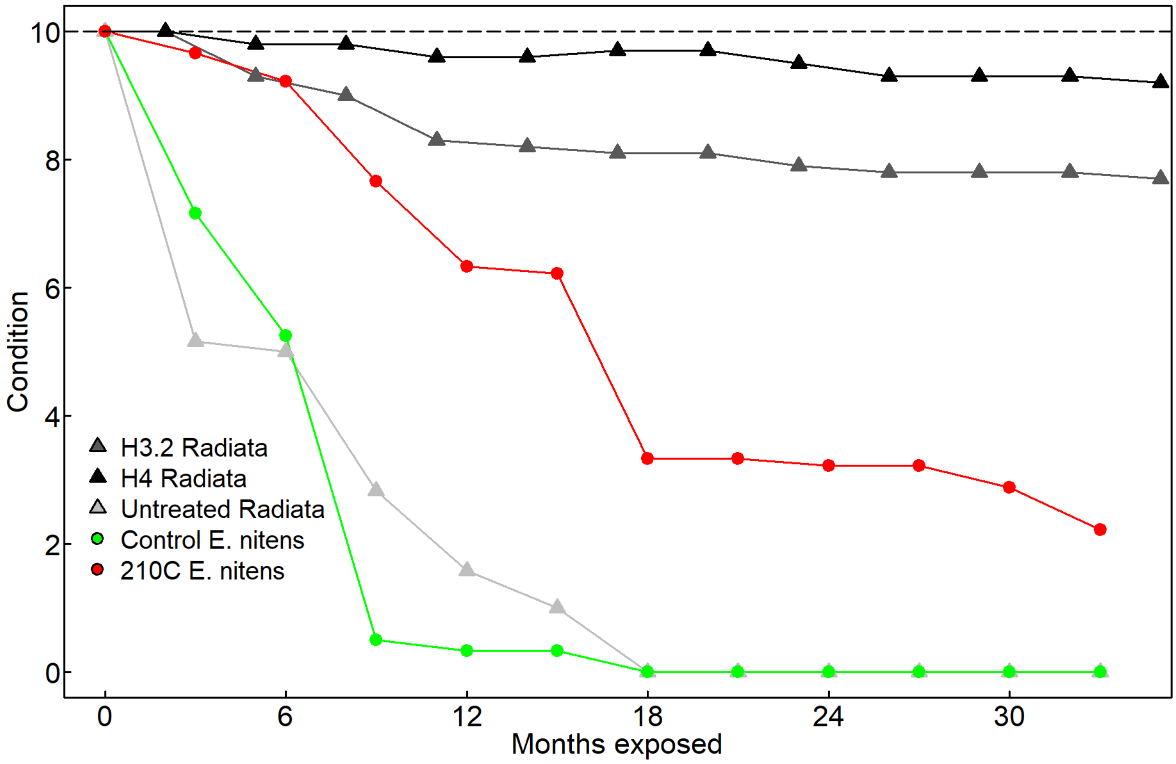

Figure 1: Fungus cellar stakelet results following 33 months of exposure. A condition of 10 indicates no sign of decay, and 0 indicates complete failure from decay.

Pressure steam modification

Figure 2 shows the difference in colour (ΔE) between unmodified *E. nitens* and the three pressure steam modifications. Colour results from previous lab scale modifications in atmospheric steam are included for comparison. The levels of colour change of the pressure steamed boards is not significantly different to that of the boards modified at 185°C in atmospheric steam, and is significantly lower than the boards modified at 210°C. Wood is normally modified at 212°C in atmospheric steam for outdoor use in Europe, so you would expect the PS1 and PS2 boards to be modified to a similar degree to the 210°C boards, and thus have a similar colour change. While this lower colour change would normally be a strong indication that the pressure steamed boards had a lower modification intensity than the boards modified in atmospheric steam, there is anecdotal evidence that the pressure steam modification can have a lower colour change for the same change in other properties (durability, dimensional stability).

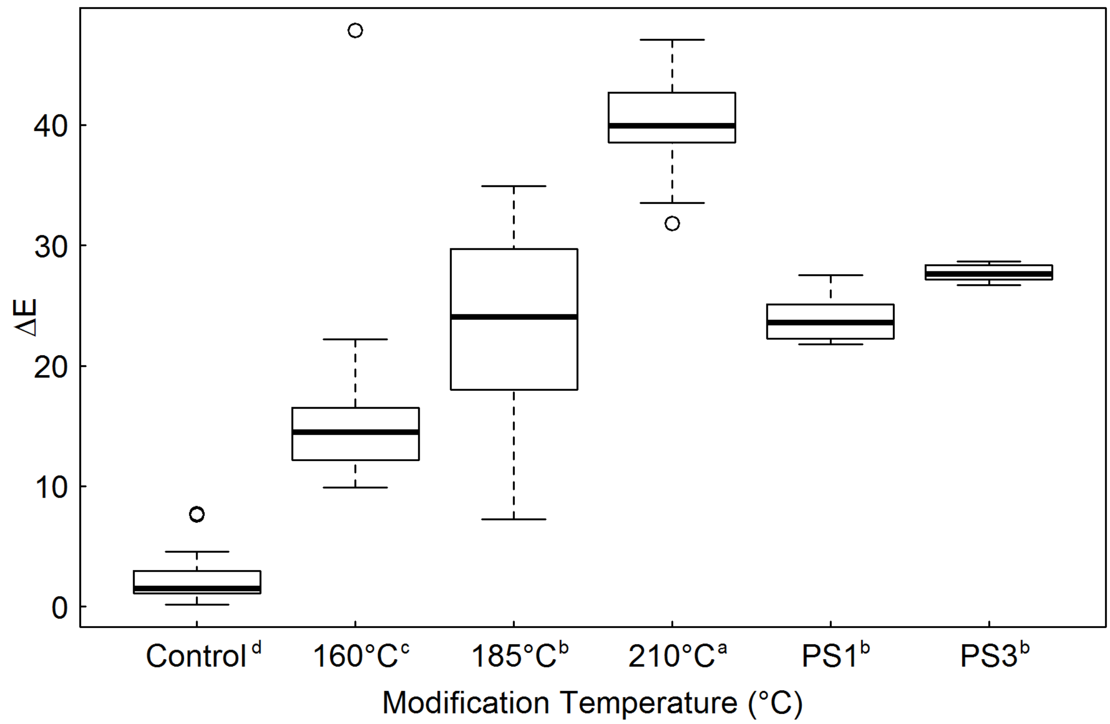

Figure 2: Colour change due to modification of pressure steamed *E. nitens*, compared to previous lab scale (atmospheric steam) modifications. Superscript letters indicate treatments that are not significantly different (95% confidence level).

The Anti-shrink efficiency (ASE) for the different modifications is shown in Figure 3. ASE is a measure of how much wood resists shrinking and swelling between very extreme moisture contents - pressure impregnation with water, and complete oven dryness. All the pressure steam modifications had ASE values that were not significantly different to those of the 210°C modification. This contrasts with the colour change data, suggesting that the pressure steamed boards may in fact have been modified to a similar degree to the 210°C, but with a smaller colour change.

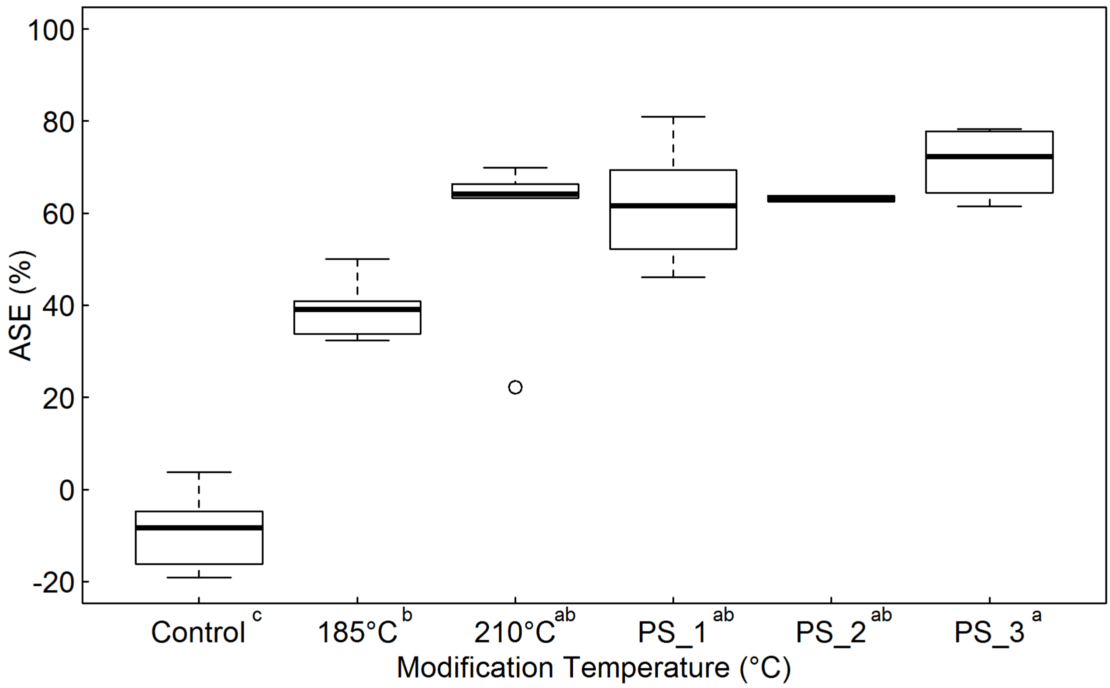

Figure 3: Anti-shrink efficiency (ASE) of pressure steamed *E. nitens*, compared to previous lab scale (atmospheric steam) modifications. Superscript letters indicate treatments that are not significantly different (95% confidence level).

Results of the Sutter durability screening test are shown in Table 1. This test involves exposing small blocks to different strains of fungi, and if the blocks lose less than 2% of their mass during exposure, this counts as a 'pass' value. The PS1 modification passed the same number of tests as the 210°C modification, suggesting a similar level of durability. The PS3 modification passes 7 out of 8 tests, so may be more durable than the 210°C modification. As the 210°C is not performing well in fungus cellar testing, the PS1 modification also may not perform well, but the PS3 modification could perform better.

Table 1: Results of Sutter durability screening.

Treatment	No. passed tests
Control	2/8
185°C	2/8
210°C	6/8
PS1	6/8
PS2	3/8
PS3	7/8

Fungus cellar testing is underway for the pressure steamed boards, and results from the 12 month interim assessment are shown in Figure 4. Results from the atmospheric steamed treatments (Figure 1) are also included for comparison. It can be seen that the pressure steamed stakelets are performing similarly to the 210°C modification, and are not performing as well as the H3.2 CCA treated stakelets. This suggests that the degree of modification is similar between the pressure steam modifications and the 210°C atmospheric steam modification.

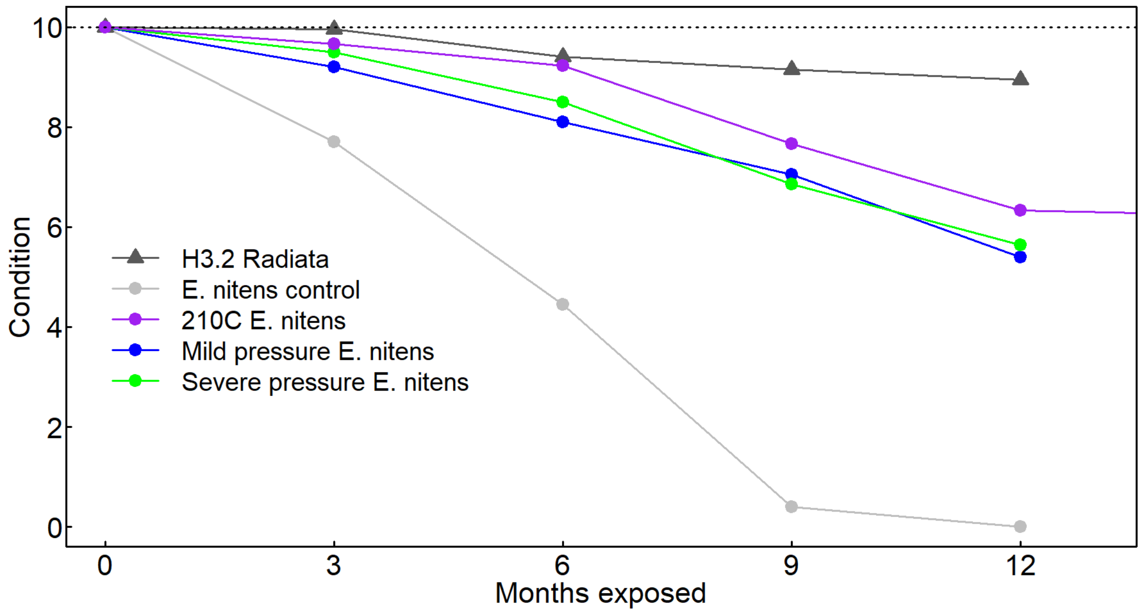

Figure 4. Results for pressure-steamed stakelets following 12 months of fungus cellar testing

To increase the level of durability of the pressure steamed stakelets, a more severe pressure steam modification would be required (higher temperature or longer duration). For the atmospheric steam modification the 210°C modification was already causing considerable damage to the wood (Sargent and Dunningham 2016), so a more severe modification is not practical. The pressure steam modified boards had practically no degrade (Sargent and Dunningham 2018) so trialling a more severe modification is a promising option.

TM for interior applications

Due to the difficulty in achieving sufficient durability for exterior uses, research was done on the New Zealand market for interior timbers to understand whether thermally modified wood fits these requirements, and if it offers any advantages over existing interior timber products.

One strong trend that came from the research was a desire to stick with known products, both from consumer pull (requesting a timber that is popular) and from wholesalers and specifiers needing a consistent supply of timber over time. Some said they had previously stocked New Zealand grown specialty species (e.g. *E. nitens* and Silver beech) but sometimes had problems getting enough timber to fill orders, so are wary of trialling new species with a small and variable resource.

The story of thermally modified wood being sustainable, chemical free and New Zealand grown were not seen to be important factors for a lot of consumers. Some architects said that they would choose sustainable and New Zealand made materials where possible, but this was not an important factor for most of their clients.

The dark colour of thermally modified timber was not seen as an advantage, because pale ‘Scandinavian’ timbers are currently fashionable, and producing darker colours using a stain was seen to be easier than stocking thermally modified timber.

There were very few perceived shortcomings for existing interior wood products - other than fire performance (which is not improved by thermal modification). Some interviewees felt that the hardness of *E. nitens* might be marginal for flooring (average Janka hardness of 5kN), but others did not see hardness as being a prime concern. We were surprised with the lack of knowledge, or interest, in wood properties like hardness and dimensional stability which will affect how wood behaves in service.

There is some anecdotal evidence that overseas markets have different market drivers for interior timber and there may be suitable markets for interior use of thermally modified wood in other countries.

Cupressus lusitanica

Lab Scale Modification

The majority of the property testing for the pilot scale modification were given in Sargent and Dunningham (2018), however some testing was not complete at that stage.

Results from Mechanical (small clears) testing of the lab scale modification shown in Table 2. Equivalent values for radiata pine are included for comparison. Following modification, the MOE is slightly reduced, and the MOR and moisture content (MC) are significantly reduced. This is in line with what we would expect for a softwood that has undergone severe modification like this.

Table 2: Mechanical properties of modified *C. lusitanica*

	MOE (MPa)	MOR (MPa)	MC (%)
Radiata Control	9929	92.6	12.9
C. lusitanica Control	7102	80.2	11.8
220°C	6757	48.4	5.6

Fungus cellar testing is underway for the modified *C. lusitanica*, and interim results after 12 months of exposure are shown in Figure 5. The modified *C. lusitanica* heartwood stakelets are in slightly better condition than the commercial H3.2 treated radiata pine and are in much better condition than the unmodified heartwood stakelets, which ware in similar condition to the red beech heartwood controls. The modified *C. lusitanica* sapwood stakelets are in worse condition than the modified heartwood but are in better condition than both the unmodified sapwood and unmodified heartwood. This is a very promising result and suggests that the modification may increase the level of durability of both the heartwood and the sapwood above that of the unmodified heartwood.

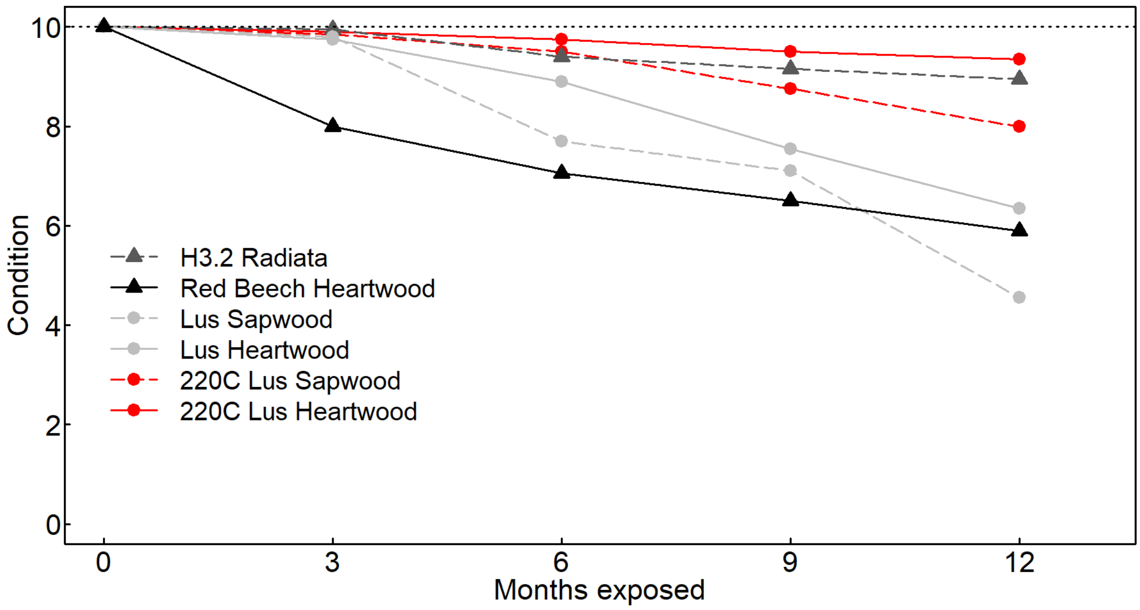

Figure 5. Fungus cellar stakelet results for modified *C. lusitanica* following 12 months exposure.

Pilot Scale Modification

Result for the boards modified at pilot scale (2.4m lengths) are compared to the boards modified at the lab scale (0.6m). Figure 6 shows the overall change in colour (ΔE) due to the thermal modification. Both modifications have a similar average colour change, but the pilot scale modification had a slightly higher and less variable change in colour. These differences are statistically significant.

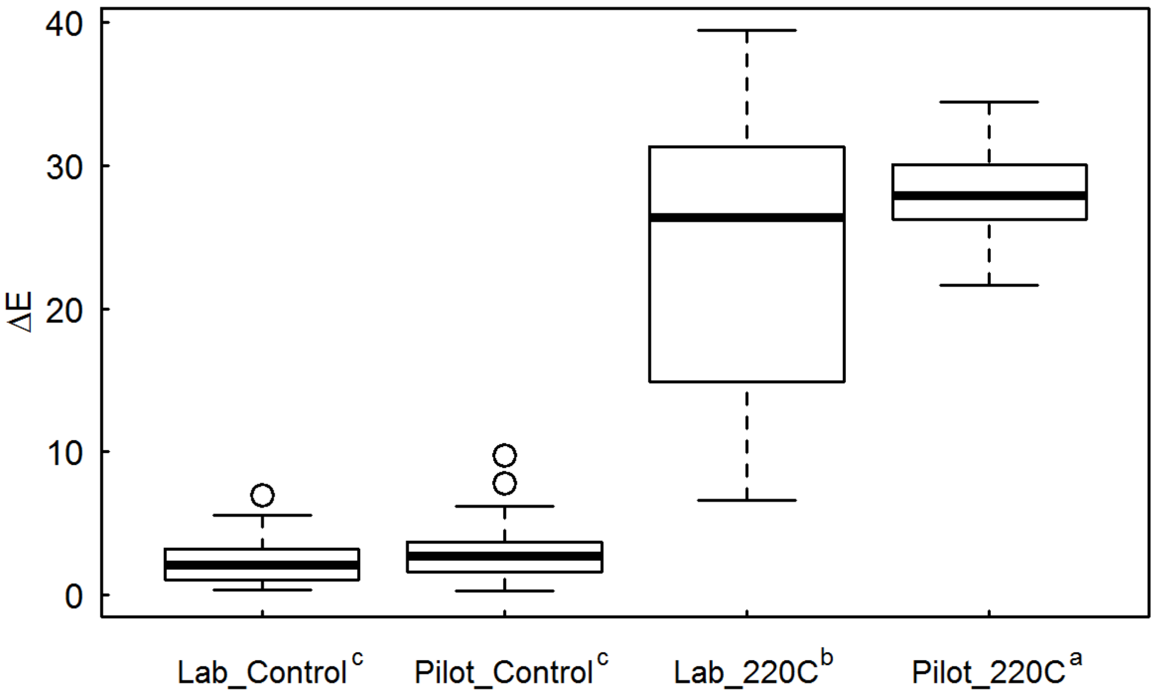

Figure 6: Colour change (ΔE) due to modification for the pilot- and lab-scale modification of *C. lusitanica.* Superscript letters indicate treatments that are not significantly different (95% confidence level).

Figure 7 shows the Anti-shrink efficiency (ASE) for both the pilot- and lab-scale modifications. For both modifications the ASE is significantly increased compared to the unmodified controls. The pilot scale boards have a slightly lower ASE than the lab scale, but this difference is not significant.

When looked at alongside the colour change results, these suggest that the level of modification is similar between the two scales.

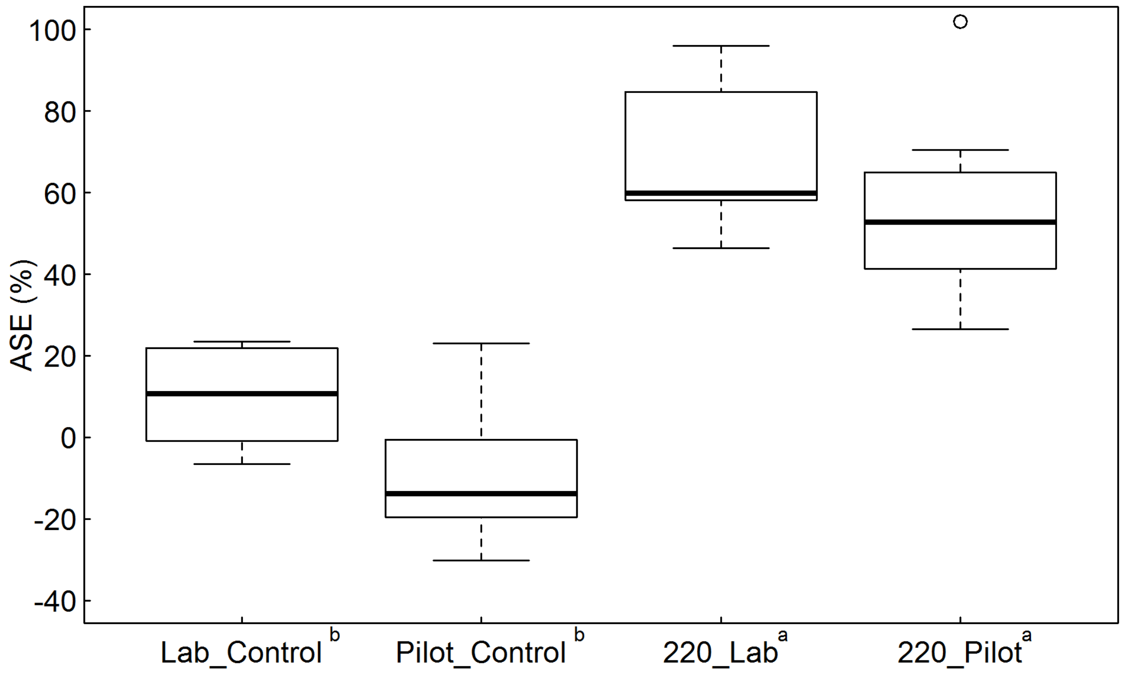

Figure 7: Anti-shrink efficiency (ASE) for lab- and pilot-scale modifications of *C. lusitanica.*

Figure 8 shows the proportion of boards with between-ring checks, both before and after thermal modification. None of the unmodified boards had between- ring checks, which is not surprising as the wood was air dried, then dried slowly in a kiln. Between-ring checks tend to be associated with severe conditions towards the end of the drying process. Following thermal modification, a high proportion (over half) of the lab scale boards had between-ring checks. It is believed that these boards may not have been completely dry when they were modified. They were supplied as being at around 12% moisture content, but this was not confirmed by measuring the moisture content prior to modification. The pilot scale boards show much lower levels of checking following modification (around 10% of all boards). These boards were well above 12% MC as supplied, so were kiln dried to a uniform moisture content prior to modification.

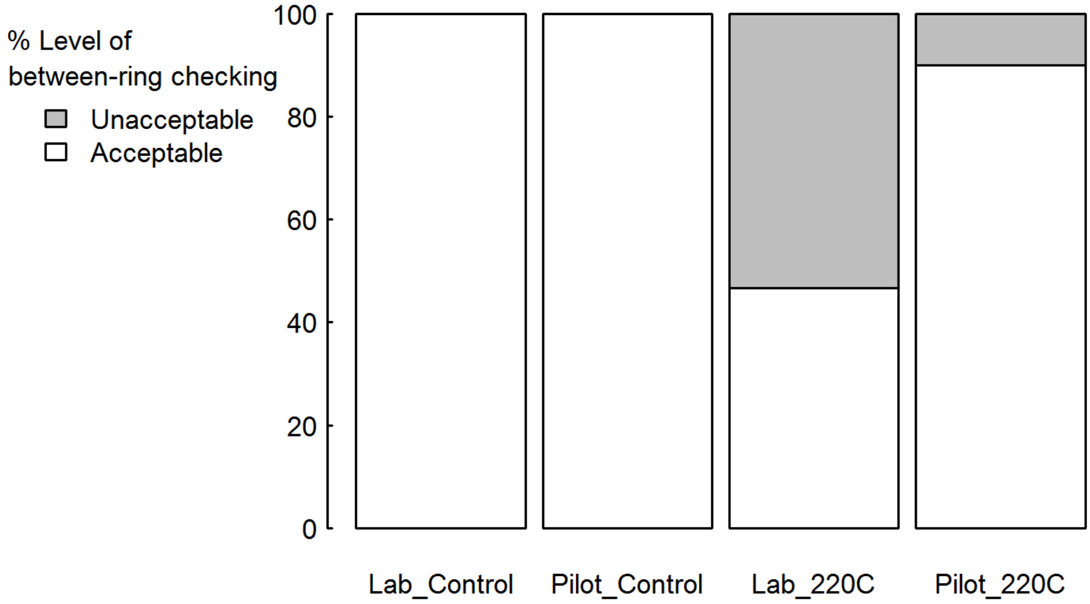

Figure 8: Proportion of boards with unacceptable levels of between ring checking.

The lab scale boards had a high proportion of boards (40%) with within-ring checking, and around 7% of unmodified boards also had within ring checking. This normally forms early in the drying process and may have been caused by boards being insufficiently dry prior to thermal modification. The pilot scale boards were dried to an even moisture content prior to modification, and no within ring checks were seen in either the modified boards or unmodified controls.

Recommendations and conclusions

Ongoing fungus cellar results for *E. nitens* are not looking promising. A more severe modification would be required to ensure sufficient durability for outdoor use, but the atmospheric steam modification already causes so much degrade in the boards that this is not feasible. An alternative high-pressure steam modification has been trialled at lab scale, and this showed similar (or higher) levels of durability to the 210°C modification, but with no additional degrade. Fungus cellar stakelet tests are underway for the pressure steamed material to confirm the level of durability, from initial results it appears to be similar to the 210°C modification. Because levels of degrade are so low in the pressure steamed material, it should be possible to achieve a greater degree of durability using a more severe modification without causing excessive levels of degrade.

Market research into indoor use of thermally modified wood for New Zealand markets is not especially promising, with few perceived shortcomings with existing products, and a reluctance to move to new species. There is some anecdotal evidence that overseas markets (e.g. Asia) are interested in thermally modified wood for interior use.

Thermally modified *C. lusitanica* has previously shown good results in lab-based durability tests, and fungus cellar stakelet tests are now underway. Interim results from 12 months of testing are very positive with both the modified heartwood and sapwood showing greater durability than the unmodified heartwood, and similar durability to CCA treated H3 radiata pine. The mechanical properties of the modified *C. lusitanica* are in line with what would be expected from a severe modification like this - a small reduction in MOE and a large reduction in MOR and equilibrium moisture content (EMC). A pilot (2.4m) scale modification was successfully completed. This will provide additional modified material for further testing (including outdoor durability testing).

Acknowledgements

E. nitens timber was sourced from John Fairweather at Specialty Timber Solutions, and from logs supplied by SouthWood Exports Ltd.
C. lusitanica timber was supplied by Murray Grant and MacDirect.
Steve Riley and Ian Simpson assisted with the sourcing and preparation of the wood.
Pressure steam modification was performed by Wim Willems of FirmoLin in the Netherlands.
Jamie Agnew and Bruce Davy prepared samples for property testing.
Maxine Smith and Jackie van der Waals performed property testing.

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