**Confidential**

# Thermal Modification of Specialty Species: Results of Scion's Core Funded Experiments

Authors Rosie Sargent, Elizabeth Dunningham

# Report information sheet

| | |
|---|---|
| **Report title** | Thermal Modification of Specialty Species: Results of Scion's Core Funded Experiments |
| **Authors** | Rosie Sargent, Elizabeth Dunningham<br>Scion |
| **Client** | Specialty Wood Products Partnership |
| **Client contract number** | |
| **MBIE contract number** | |
| **SIDNEY output number** | |
| **Signed off by** | Doug Gaunt |
| **Date** | August 2018 |
| **Confidentiality requirement** | Confidential (for client use only) |
| **Intellectual property** | © New Zealand Forest Research Institute Limited. All rights reserved. Unless permitted by contract or law, no part of this work may be reproduced, stored or copied in any form or by any means without the express permission of the New Zealand Forest Research Institute Limited (trading as Scion). |
| **Disclaimer** | The information and opinions provided in the Report have been prepared for the Client and its specified purposes. Accordingly, any person other than the Client uses the information and opinions in this report entirely at its own risk. The Report has been provided in good faith and on the basis that reasonable endeavours have been made to be accurate and not misleading and to exercise reasonable care, skill and judgment in providing such information and opinions.<br><br>Neither Scion, nor any of its employees, officers, contractors, agents or other persons acting on its behalf or under its control accepts any responsibility or liability in respect of any information or opinions provided in this Report. |

Published by: Scion, 49 Sala Street, Private Bag 3020, Rotorua 3046, New Zealand. www.scionresearch.com

# Executive summary

## The problem

The objective of this work is to improve the properties of two specialty wood species (*Eucalyptus nitens* and *Cypressus lusitanica*) through thermal modification.

## Key results

The major findings of this study were:
Improved durability of *C lusitanica* sapwood, maintained durability of heartwood
Improved dimensional stability of *E. nitens* modified in air at 160°C
Very low levels of degrade in pressure steam modified *E. nitens*

## Implications of results for the client

The improved durability of modified lusitanica sapwood would allow sapwood-containing boards to be used in outdoor applications where boards must currently only contain heartwood. This would increase grade recoveries, as boards containing sapwood or intermediate wood could be used for higher value products.
The increased dimensional stability of nitens modified at 160°C in a standard high temperature kiln gives potential for the production of more stable interior products without requiring a specialist thermal modification kiln.
Pressure steam modification presents an opportunity to modify nitens without causing degrade. This will be especially useful if the wood can be modified to a high enough degree to improve durability.

## Further work

Fungus cellar testing is ongoing for both Nitens and Lusitanica samples.
Further property testing (long and short term dimensional stability, mechanical properties) are ongoing for lusitanica.

# Thermal Modification of Specialty Species: Results of Scion's Core Funded Experiments

## Table of contents

# Introduction

Thermal modification is widely used to improve the properties of many wood species, it involves heating the wood to high temperatures in the absence of oxygen. Thermal modification darkens the colour of the wood, improves dimensional stability, and with high levels of modification it also improves durability.

Thermal Modification of *Eucalyptus nitens* (shining gum) has been ongoing at Scion for a number of years. High modification levels give good property improvements to E. nitens, but cause high levels of internal checking. Current work aims to reduce levels of checking in high temperature modifications, and to investigate the property improvements from lower temperature modifications (which give lower levels of internal checking).

Thermal modification can be used to improve the durability of species with some heartwood durability - both the heartwood and the sapwood show durability improvements after modification, potentially leading to sapwood that is durable enough to be used outdoors. This would allow boards with a mix of heart and sapwood to be used, potentially improving recoveries. Here a high level of thermal modification has been applied to *Cupressus lusitanica* to understand the effect of thermal modification on the durability of both the heartwood and the sapwood, with the aim of improving the sapwood durability to allow it to be used outdoors.

# Approach

## *Eucalyptus nitens*

*E. nitens* was modified in two experiments: Modification at 160°C and pressure steam modification. Additionally, new results from ongoing testing is reported here.

### 160°C modification

*E. nitens* was sourced from Specialty Timber Solutions, the trees originated from a farm forest in the North Canterbury area. The wood was cut to 600mm lengths and was from the same material used in the pilot scale thermal modification experiments (reported in the 2016/17 Core funded experiments). Boards were selected to be free of visible drying defects (collapse, within ring checks).

Using Scion's lab-scale high temperature kiln, the wood was heated to 160°C, using a 160/90°C High Temperature drying schedule then the dry bulb temperature maintained at ~165°C for 6 hours to maintain the wood temperature at 160°C. No attempt was made to exclude air from the kiln during the modification.

After modification, the following wood properties were assessed; Wood colour; long- and short-term dimensional stability, as well as subjectively assessing levels of degrade.

### Pressure steam modification

Wood used in this study was left over from the 2016/17 *E. nitens* screening and drying work (Sargent et al. 2017) and originated from 18 year old unpruned *E. nitens* from Southland. Boards were 500mm long, and were selected to have no visible drying degrade (checking or collapse). Boards were sorted into three charges, with 12 boards in each. End matching was not possible, but where there were several boards from the same tree, these were divided evenly between the three charges.

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). Two modifications levels were used, both at 173°C for either two or four hours. These modification levels are intended to give sufficient durability for outdoor use (i.e. a similar degree of modification to 210°C modification using the Scion atmospheric pressure process).

Following modification, the boards were assessed for levels of degrade, and future durability testing is planned.

### Ongoing testing

Some testing reported in the 2016/17 report were not complete, and further results are included here: Fungus cellar testing, long term dimensional stability testing, long term colour stability testing.

## *Cypressus lusitanica*

*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 210°C for 2 hours, and the other board retained as an unmodified control.

Changes in wood colour, dimensional stability and durability were assessed using standard methods. More specifically durability was assessed using an in-house accelerated decay test. Drying defects (checking and collapse) were subjectively assessed to decide if they would be acceptable for use in an appearance grade product or not.

# Results and discussion

## *Eucalyptus nitens*

### 160°C Modification

*Colour change due to modification*

The colour of the planed surface of the modified boards can be compared to the average colour of the unmodified wood. This colour difference (ΔE) is shown in Figure 1. Previous lab scale modifications are shown for comparison. The 160°C modification changed colour significantly compared to the unmodified controls, but did not change colour as much as the 185°C modification. This is not surprising, as colour change usually increases with increasing modification temperature. Photographs of each wood type are also shown in Figure 2.

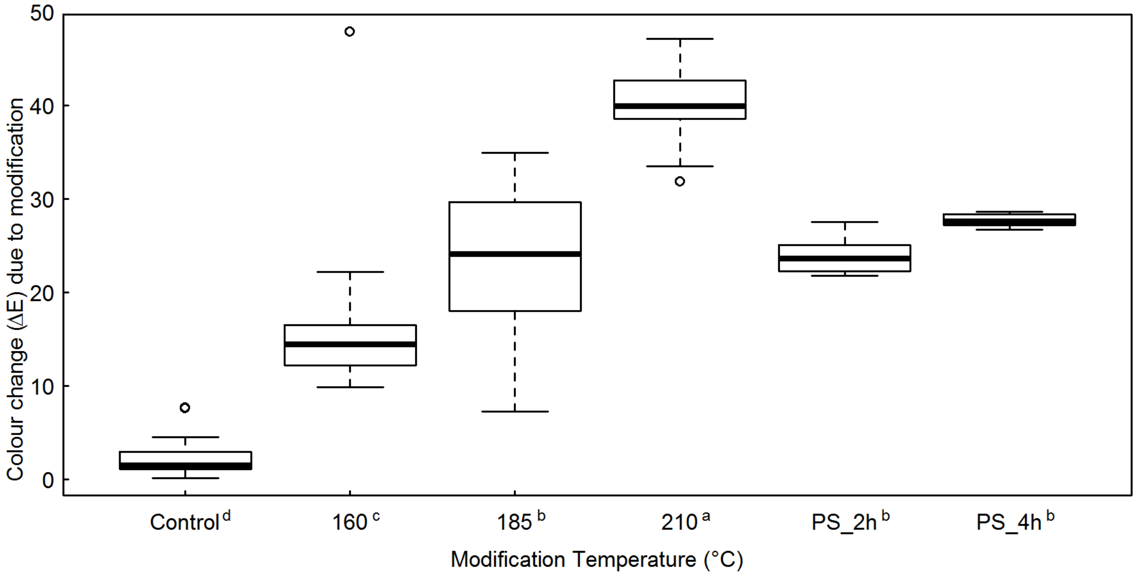


**Figure 1.** Overall change in colour for the 160° modification, compared to previous lab scale modifications, and the pressure steam modifications. Superscript letters indicate treatments that are significantly different to each other (95% confidence level)

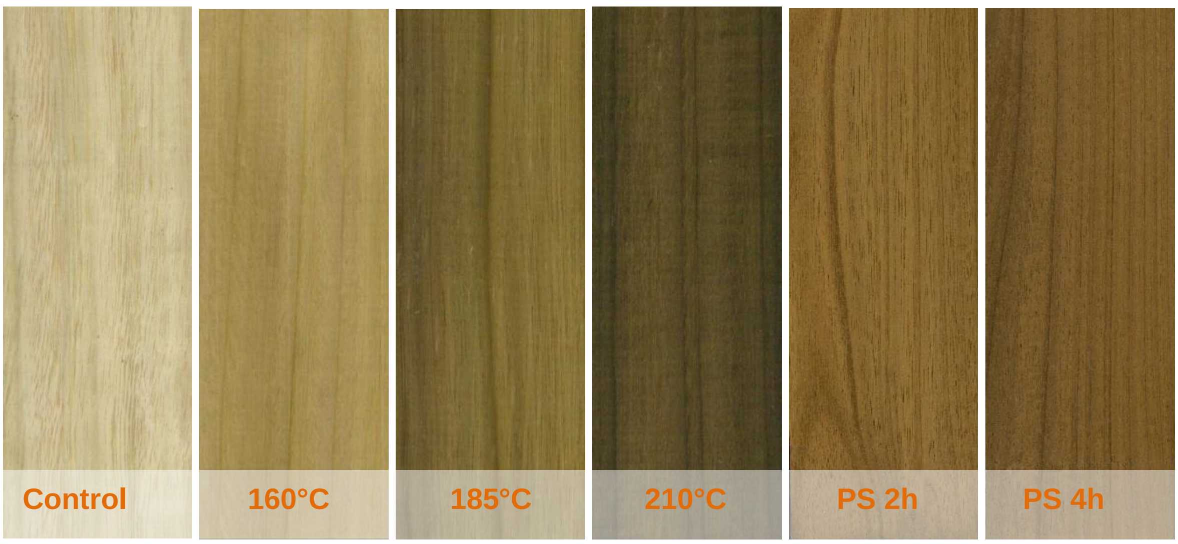


**Figure 2.** Photographs of wood modified at 160°, compared to previous lab scale modifications, as well as pressure steamed modifications

*Anti-shrink efficiency*

Anti-shrink efficiency (ASE) is a measure of how much wood shrinks and swells when in contact with water. A higher ASE value indicates that the wood shrinks and swells less. ASE values are shown in Figure 3. Results from previous lab scale modifications are shown for comparison. The 160°C modification has higher ASE values on average than the controls, but this difference is not significant. Both the 185°C and 210°C modifications do have significantly higher ASE values, indicating that they have improved dimensional stability.

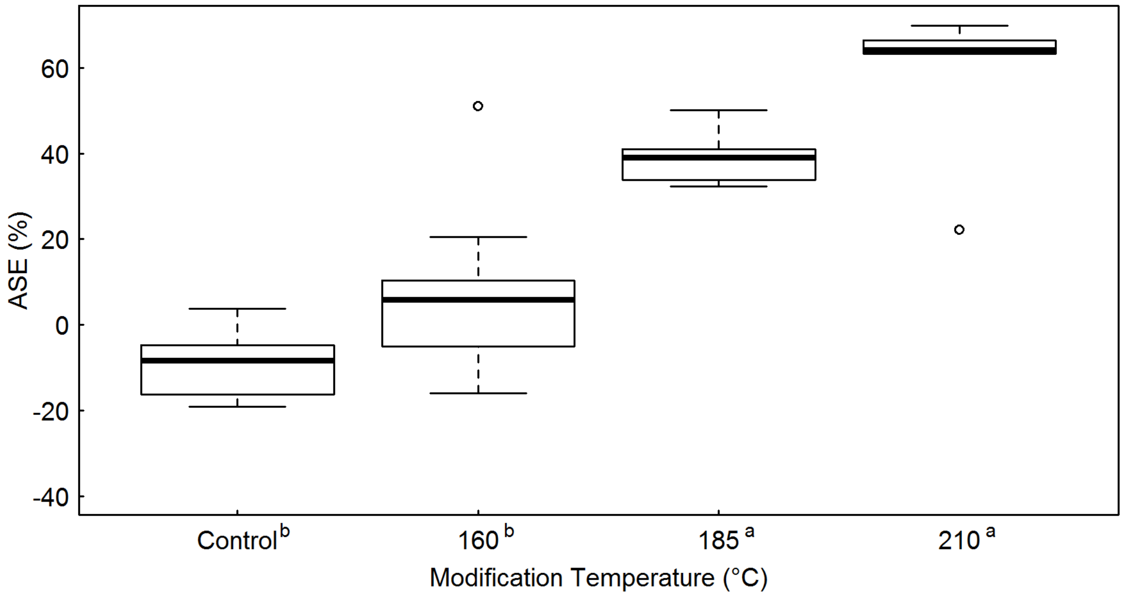


**Figure 3.** Anti-shrink efficiency of boards modified at 160°C compared to other lab scale modifications. Superscript letters indicate treatments that are significantly different to each other (95% confidence level)

*Long term stability*

This test measures how the wood dimensions, and moisture content change as the ambient humidity changes and is based on DIN 52 184 (1979). Samples were equilibrated at three different relative humidities: 90%RH, 65%RH and 35%RH, all at 25°C. At each condition the samples were weighed and the radial and tangential dimensions measured. The equilibrium moisture content (EMC) at each condition is shown in Figure 4.
At each humidity level, the control samples had a significantly higher EMC than both the 160°C and 210°C modifications. The EMC reduced with increasing modification level, with the 210°C modification having significantly lower EMC values than the 160°C modification. Additionally for the 210°C modification, the difference in EMC between the highest and lowest humidities was much lower than for the unmodified controls. Having a reduced EMC at high humidities can make samples better able to resist fungal attack, and having a small change in moisture content between high and low humidity environments will result in the wood shrinking and swelling less, leading to greater dimensional stability.

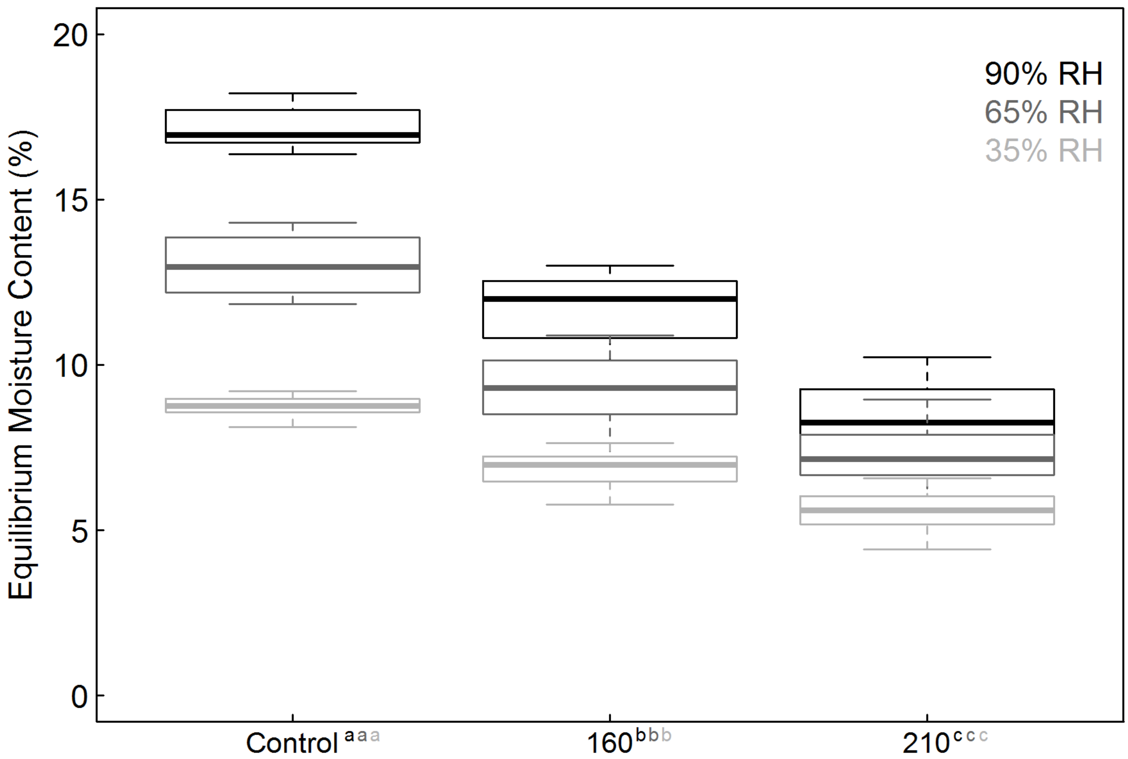


**Figure 4.** Equilibrium moisture content of modified boards at three relative humidity levels (all at 25°C). Superscript letters indicate treatments that are significantly different to each other (95% confidence level)

There are several ways to express dimensional stability, here the Swelling Coefficient defined in DIN 52 184 is used. This is calculated as the percentage swelling in the radial or tangential direction of a sample for every 1% change in the relative humidity of the air. A lower value of the swelling coefficient indicates a smaller change in dimensions, hence greater dimensional stability. The radial and tangential swelling coefficients are shown in Figure 5. For both the radial and tangential directions the modified samples are significantly more stable than the unmodified controls. In the radial direction there is no significant difference in swelling coefficient between the 160°C and 210°C modifications, but in the tangential direction, the 210°C modification is significantly more stable. Not surprisingly, for all samples the level of dimensional change was greater in the tangential direction than the radial direction.

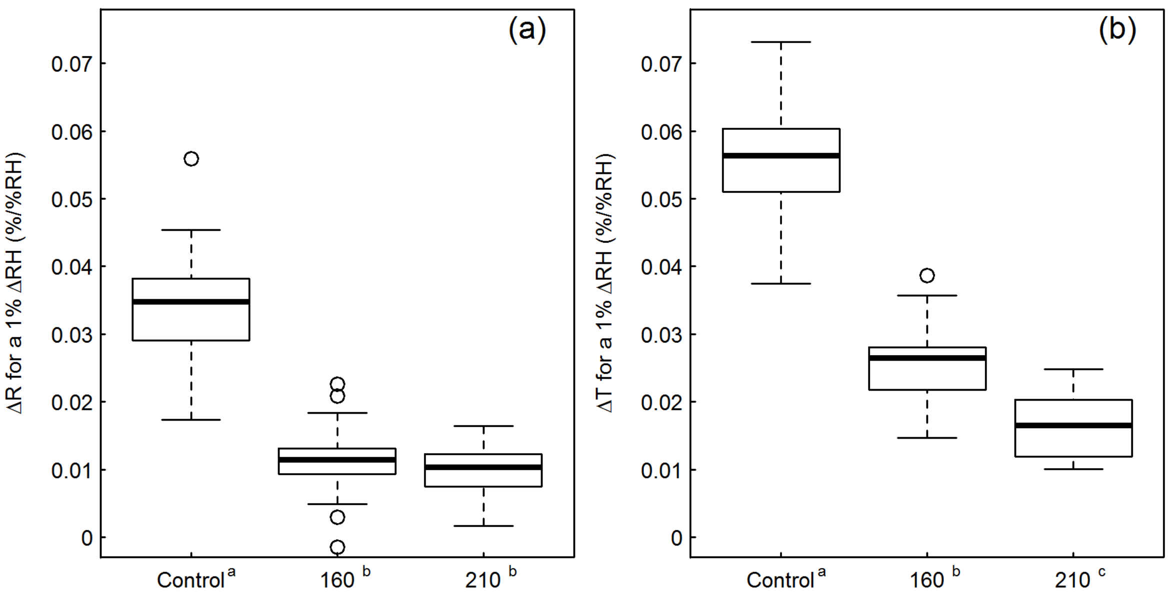


**Figure 5.** Change in the radial (a) and tangential (b) directions for every 1% change in relative humidity. Superscript letters indicate treatments that are significantly different to each other (95% confidence level)

*Degrade*

The levels of between ring checks in boards modified at 160°C are shown in Figure 6. Because the check assessment involves cutting 100mm off one end of the board, there is a chance that there are internal checks already present in the wood prior to modification, but these cannot be seen until the board is docked and assessed after modification. To control for this, the same number of apparently defect free unmodified boards also had 100mm docked from one end and the cut surface assessed for internal checks. This showed that around 10% of boards would be expected to have internal checks that are not visible until the board is docked. The 160°C modification has significantly higher levels of internal checks compared to the unmodified controls, and has a similar number of checked boards to the 185°C modification.

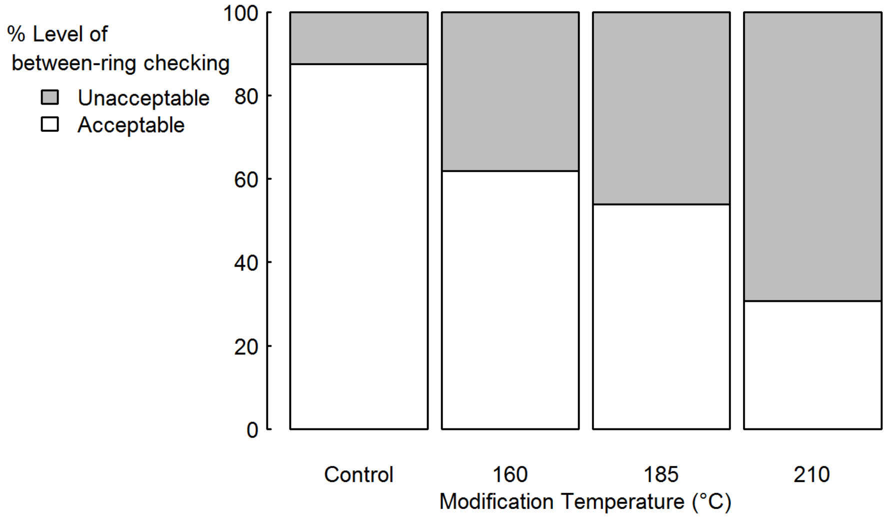


**Figure 6.** Levels of between ring checking before and after modification at 160°C, compared with previous modifications.

## Ongoing testing of Lab- and Pilot-scale modifications

*Long term (Indoor) colour stability*

Samples were left in a sunny window for one year, and matched samples were placed behind these, facing into the room (and hence were not exposed to direct sunlight). Photographs of samples before and after modification are shown in Figure 7. Colour change ($\Delta E$) of the samples after 1 year of exposure is shown in Figure 8. The unmodified control samples did not change colour much at all, which was surprising. Many pale wood species, such as radiata pine, change colour significantly over time when exposed to visible light and UV. In direct sunlight the modified samples changed colour significantly, with both modifications becoming much paler, especially in the earlywood. For the diffuse light, the changes in colour were very small, but the two modifications still had significantly different levels of colour change compared to the controls.


**Figure 7.** Comparison of wood colour before modification, and after 1 year of direct or diffuse sunlight indoors.

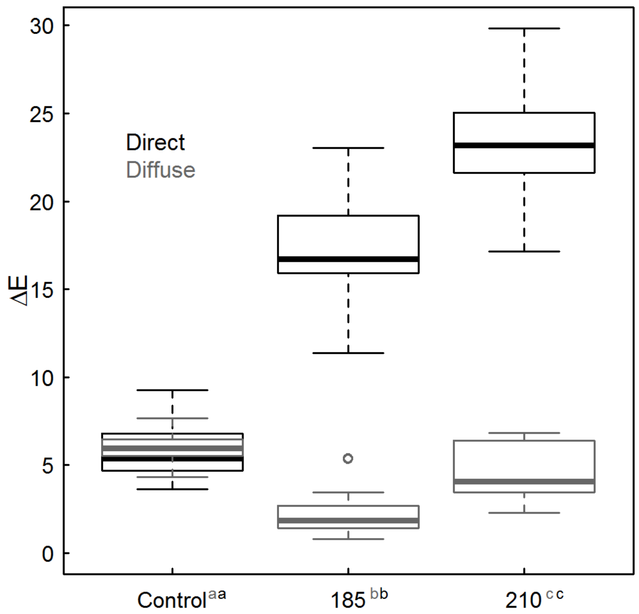


**Figure 8.** Overall colour change (ΔE) after 1 year of direct or diffuse indoor sunlight. Superscript letters indicate treatments that are significantly different to each other (95% confidence level)

*Fungus cellar*

Interim results from the first 21 months of fungus cellar testing are shown in Figure 9. In the latest assessment all the unmodified nitens stakelets have failed, as have all the untreated radiata pine stakelets. This is not surprising, as these stakelets are not expected to have any durability. The H4 treated stakelets are still in good condition, with an average condition rating between 9 and 10. The H3.2 stakelets have an average condition of 8. The thermally modified nitens has an average condition of around 4, and its condition has reduced sharply since the 15 month assessment, whereas the treated stakelets are changing condition very slowly. This suggests that the thermally modified stakelets have some durability improvement, but nowhere near H3.2 level.

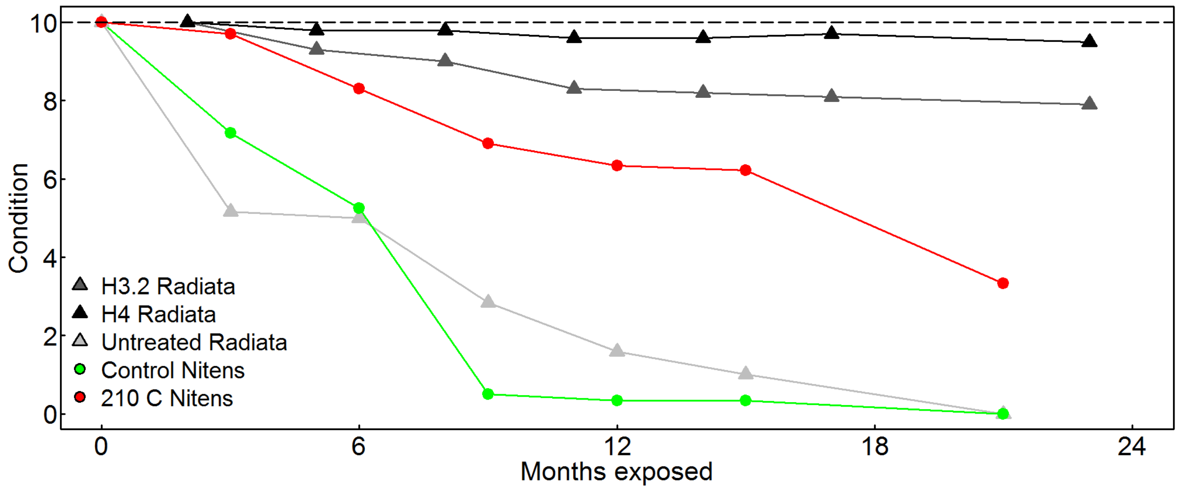


**Figure 9.** Average condition of fungus cellar stakelets over 21 months of exposure. Treated and untreated radiata pine has been included for comparison.

## Pressure steam modification

*Colour change due to modification*

Photographs of the pressure steamed boards are shown in Figure 2. These do not appear as dark as the 210°C modification. Colour change is broadly correlated to modification intensity, irrespective of thermal modification method, so it is possible that the pressure steam modification has not been modified to the same degree as the boards modified at 210°C under atmospheric pressure (as was the intention). The colour change of the pressure steamed boards (Figure 3) is also lower than the 210°C modification. Lab scale (Sutter) durability testing is planned to confirm the level of durability of the pressure steamed boards.

*Degrade*

No boards had any evidence of between-ring checking. One board modified for 2 hours had within-ring checking, but this was likely to have developed during initial drying, and was only uncovered when the end of the board was docked for the degrade assessment following modification.

## *Cypressus lusitanica*

*Colour change*

The change in colour ($\Delta E$) between the modified boards, and the average colour of the unmodified wood is shown in Figure 10. Photographs of the boards are shown in Figure 11. The modified boards changed colour significantly compared to the unmodified controls, and have a very wide range of $\Delta E$ values, showing that the colour of the modified wood is much more variable than the unmodified wood.

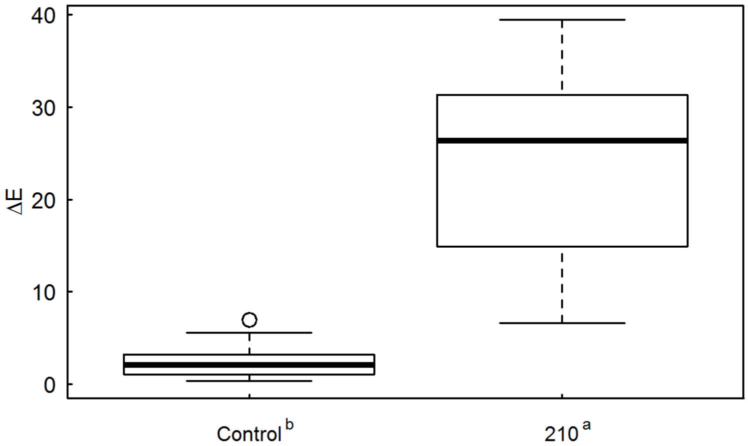


**Figure 10.** Overall change in colour following modification. Superscript letters indicate treatments that are significantly different to each other (95% confidence level)

*Durability*

Results from the Sutter screening test are shown in Table 1. For each fungi s mass loss below 2% is considered a ‘pass’, and if the wood passes most of the test conditions, the wood is likely to have improved durability. The lusitanica heartwood passed against all the fungi, indicating a good degree of durability. The lusitanica sapwood only passed against two fungi out of eight, indicating a low degree of durability. The untreated radiata pine also showed no durability. Following thermal modification, the heartwood still passed against all eight fungi (and with lower weight losses than before modification, indicating less fungal activity), and the sapwood also passed against all fungi. This shows that the sapwood is likely to have increased durability, and the heartwood is likely to be at least as durable as before modification, but longer term testing (such as fungal cellar) is required to confirm this.

**Table 1.** Sutter block results for lusitanica heartwood and sapwood. Blue shaded boxes indicate a 'pass' rate where the samples indicate resistance to the fungi

| **Treatment** | **Fungi** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ***C.puteana*** | | ***A.xantha*** | | ***O.placenta*** | | ***T.versicolor*** | |
| | **Unleached** | **Leached** | **Unleached** | **Leached** | **Unleached** | **Leached** | **Unleached** | **Leached** |
| Untreated Lusitanica heartwood | 0.95 (0-1.25) | 0 | 0.51 (0.34-0.66) | 0 | 0.86 (0.72-1.03) | 0.01 (0-0.05) | 0.82 (0.55-1.11) | 1.71 (0-8.63) |
| Untreated Lusitanica sapwood | 16.53 (11.35-20.33) | 14.49 (10.72-17.63) | 0.70 (0.22-1.47) | 0.88 (0-3.04) | 22.49 (19.32-24.83) | 24.24 (20.08-28.78) | 10.86 (3.76-14.00) | 12.35 (6.55-15.49) |
| TM Lusitanica heartwood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.46 (0-3.68) |
| TM Lusitanica sapwood | 0 | 0 | 0 | 0 | 0.20 (0-1.60) | 0.19 (0-1.18) | 0.63 (0-5.04)) | 0.13 (0-1.00) |
| Untreated radiata pine | 17.47 (10.02-34.21) | 13.67 (10.43-16.82) | 15.93 (12.61-20.33) | 12.07 (7.91-18.45) | 25.57 (21.46-27.60) | 25.93 (22.99-28.33) | 12.82 (9.09-15.97) | 9.83 (6.58-14.75) |

**Figure 11.** Photographs of board surfaces before (left) and after (right) modification. For each image, the top board is predominantly heartwood and the bottom board predominantly sapwood.

*Anti Shrink Efficiency*

The anti-shrink efficiency for the modified lusitanica, and unmodified controls is shown in Figure 12. The modified boards have significantly higher ASE values than the unmodified controls, indicating improved dimensional stability. The average ASE for the modified samples is around 60%, indicating that on average the modified samples swell and shrink 60% less than the unmodified controls. This gives a similar average ASE value to the modified nitens, but for the lusitanica, there is a much greater spread of ASE values, with some samples showing ASE values of 80-90% (indicating an 80-90% reduction in the amount they shrink and swell).

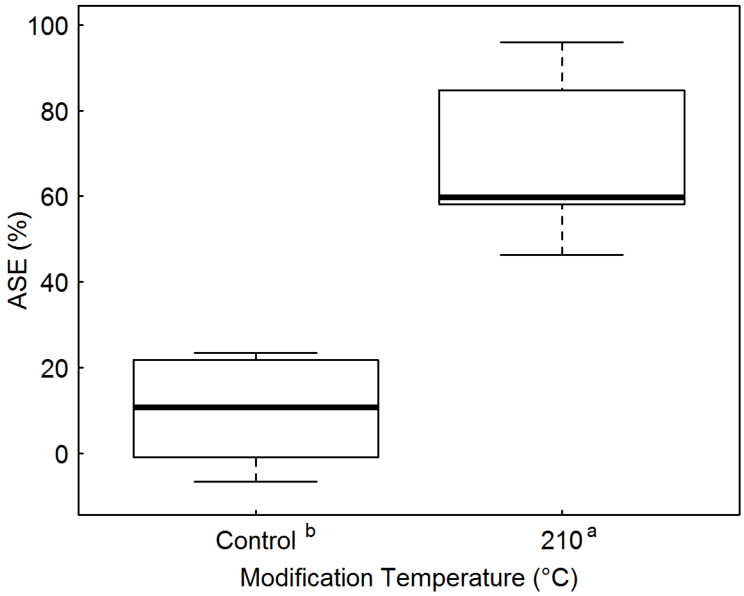


**Figure 12.** Anti Shrink Efficiency of modified and unmodified lusitanica. Superscript letters indicate treatments that are not significantly different (95% confidence level)

*Degrade*

Levels of between ring checking in the control, and modified boards are shown in Figure 13. The modified boards showed large numbers of between ring checks (<50% of boards affected). This high level of checking is of concern and future trials will aim to reduce this.

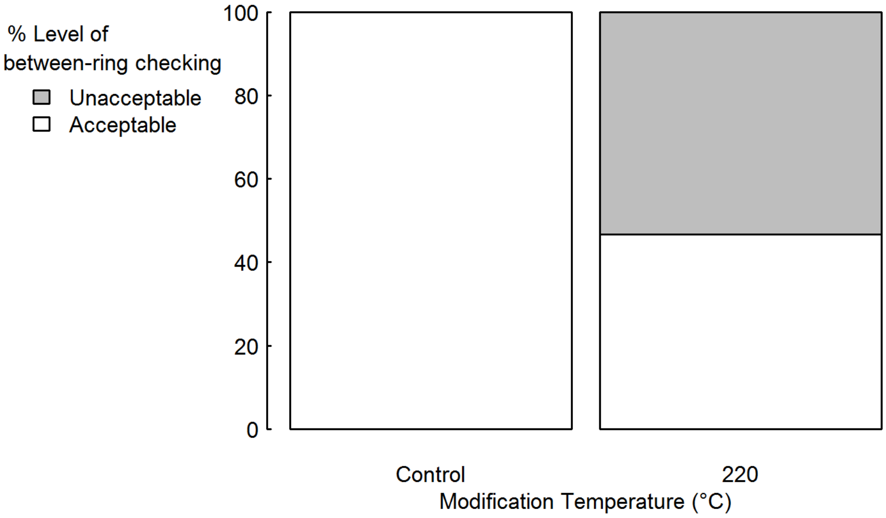


**Figure 13:** Levels of between ring checking before and after modification.

# Recommendations and conclusions

Thermally modifying E. nitens at 160°C using a standard high temperature drying schedule improved the dimensional stability and slightly darkened the wood colour. Unfortunately the incidence of between ring checking was still high following this lower temperature modification.

Nitens boards thermally modified using pressure steam did not have any internal checks following modification. This process was intended to give a similar degree of modification to the 210°C modification used at Scion, but the wood colour of the pressure steamed boards was much paler than the 210°C modification, suggesting the level of modification is lower. Durability testing is planned to confirm the level of modification in the pressure steamed boards.

Dimensional stability improved in nitens modified at both 160°C and 210°C, with the 210° modification having the greatest dimensional stability. The darker colour of the thermally modified boards faded after 1 year in direct sunlight, but did not change appreciably after 1 year of diffuse light. The unmodified nitens did not change colour appreciably in either the direct sunlight or diffuse light.

Following 21 months of exposure, the fungus cellar results are not looking promising, with the modified nitens stakelets having an average condition of 4 (out of 10), compared to H3.2 radiata with an average condition of 8, and H4 radiata with an average condition of 9.5.

The *Cypressus lusitanica* boards showed good indications of durability in the Sutter block test. The heartwood retained (or possibly improved) its durability, and the sapwood durability increased to a similar level to the heartwood. Further longer-term durability testing is planned to confirm these results. Anti-shrink efficiency (dimensional stability) was significantly higher after thermal modification.  Levels of degrade (between ring checking) were unacceptably high (>50% boards affected), so this needs to be addressed in future studies.

# Acknowledgements

Jamie Agnew and Bruce Davy assisted with sample preparation. Maxine Smith performed the long term stability testing. Colleen Chittenden and Jackie van der Waals performed the durability testing, Colleen also measured the colour stability experiments.
Wim Willems at FirmoLin in the Netherlands did the pressure steam modifications.

# References

DIN 52 184 (1979) Testing of wood; determination of swelling and shrinkage.

Sargent R, Gaunt D, Riley SG, Stovold T, Suontama M, Emms G (2017) SWP-T022 Drying *Eucalyptus nitens:* Screening for checking and collapse. Scion, Rotorua