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OPTIMUM RECOVERY OF COLLAPSE IN EUCALYPTS

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Introduction

The premise of this research is that a considerable amount of research effort (80-100 yrs) has been directed at preventing collapse, unfortunately, in that time no economically feasible method has been obtained, with the possible exception of current microwave treatment technology being developed by the CRC for wood innovations. Current industrial practices (mild pre-drying) are intended to minimise collapse and associated drying degrade.

Collapse recovery by steam reconditioning has been known for approximately 90 years. However, with the focus on preventing collapse, little research has been undertaken on better understanding this process and trying to optimise it both in terms of maximising collapse recovery and minimising associated degrade such as internal checking. An extended summary of some of the research undertaken as part of my PhD candidacy is presented here.

Mean Moisture Content

An experiment (details can be found in Blakemore & Langrish, 2006) was carried out with boards of Mountain Ash (Eucalyptus regnans) to determine the effect of mean moisture content on collapse recovery. Previous work on this topic (e.g. Greenhill, 1938 & 1940) was limited and undertaken on small samples cut from only one or two boards. To provide more industrially realistic results in this study, sixteen (100 × 40 mm) boards were dried under mild pre-drying conditions and were well equilibrated at the nominal moisture content before steam reconditioning was undertaken.

![Figure 1: Collapse and recovery for specimens with a density of ≤500 kg m⁻³.](image)

Figure 1 shows the amount of collapse and collapse recovery that occurred at the different moisture contents. It suggests that below 15% collapse recovery starts to reduce significantly. This conclusion is in keeping with limited work undertaken by Greenhill (1938, 1940), but contradicts those of MacKay (1972) who found an optimal recovery at closer to 12%. The difficulty in interpreting these results is the interaction with drying stresses in the larger samples used in this study. For example, in Figure 1 above the measures of collapse and recovery are dependent on dimensional measurements of total shrinkage in which it is difficult to separate out the effects of drying stresses on the amount of normal or unconfined
shrinkage occurring, and hence the amount of shrinkage attributable to collapse. Related to this, it was thought that the recovery of collapse may have been nearly as high at 25% as at 20%, but that steaming at the higher moisture contents may relieve drying stresses earlier and thus allow more normal shrinkage to occur in the final drying stage. This conclusion also highlights the importance that moisture gradients are likely to have in industrial practice and this was the focus of the follow up experiment described below.

Moisture Content Gradients

Twenty quarter-sawn boards (105 × 50 mm) of regrowth Victorian Ash (*Eucalyptus regnans* and *Eucalyptus delegatensis*) were used in this study. All material was dried under the same initial conditions until the moisture content reached approximately 50%. At which point two different levels of schedule ramping (Table 1) were introduced to produce a range of moisture content gradients.

**Table 1:** Pre-drying and laboratory kiln drying schedules.

<table>
<thead>
<tr>
<th>MC</th>
<th>DBT</th>
<th>WBD</th>
<th>RH%</th>
<th>Air Vel.</th>
<th>Com</th>
<th>MC</th>
<th>DBT</th>
<th>WBD</th>
<th>RH%</th>
<th>Air Vel.</th>
<th>Com</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green</strong></td>
<td>20</td>
<td>Minimal</td>
<td>99</td>
<td>Covered in Plastic</td>
<td>9 days</td>
<td>Same as Control</td>
<td>20</td>
<td>&lt;0.1</td>
<td>&gt;99</td>
<td>Plastic Removed</td>
<td>7 days</td>
</tr>
<tr>
<td>22</td>
<td>&lt;0.5</td>
<td>95</td>
<td>&lt;0.5</td>
<td>Covered in Plastic</td>
<td>7 days</td>
<td>Same as Control</td>
<td>40</td>
<td>25</td>
<td>26</td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td>35</td>
<td>25</td>
<td>28</td>
<td>3</td>
<td>79</td>
<td>0.5-1</td>
<td></td>
<td>30</td>
<td>3</td>
<td>3</td>
<td>79</td>
<td>0.5-1</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>29</td>
<td>4</td>
<td>73</td>
<td>0.5-1</td>
<td></td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>72</td>
<td>0.5-1</td>
</tr>
<tr>
<td>45</td>
<td>25</td>
<td>30</td>
<td>5</td>
<td>67</td>
<td>0.5-1</td>
<td></td>
<td>20</td>
<td>3</td>
<td>32</td>
<td>6</td>
<td>62</td>
</tr>
<tr>
<td>30</td>
<td>25</td>
<td>32</td>
<td>6</td>
<td>62</td>
<td>0.5-1</td>
<td></td>
<td>18</td>
<td>2</td>
<td>4.6</td>
<td>67</td>
<td>2 days equalising in kiln</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>35</td>
<td>7</td>
<td>59</td>
<td>2 days equalising in kiln</td>
<td>12</td>
<td>30</td>
<td>4.8</td>
<td>67</td>
<td>2 days equalising in kiln</td>
<td>55</td>
</tr>
<tr>
<td>12</td>
<td>30</td>
<td>35</td>
<td>5</td>
<td>59</td>
<td>2 days equalising in kiln</td>
<td>0</td>
<td>100</td>
<td>NA</td>
<td>NA</td>
<td>Same as Control</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 2 shows that in general larger drying gradients did result in lowered recovery of collapse. The exception being that the collapse recovery in the control material reconditioned at 20% moisture content was slightly higher than in the matching material reconditioned at 15%, despite it having slightly greater moisture gradients. The practical implication of this is that if material is well equilibrated before reconditioning, it may be better to target a moisture content closer to 20%. If the material, is to be less well equalised it may be better to target 15% in order to minimise the number of boards with unacceptably high moisture gradients.
Figure 2: Collapse recovery of individual sub-samples plotted against the core to surface MC difference in the sub-samples prior to steam reconditioning.

In keeping with earlier research by people such as Ilic (1999), Figure 3 shows that the low density material is generally also the most collapse prone. The most collapse prone material was also generally the material in which the largest moisture content gradients were still present prior to reconditioning (Figure 4). This is an important observation as most models for hardwood drying (e.g. Innes (1996) or Langrish et al (1997)) are based on simple diffusion models. In such models, it is normally expected that lower density material should dry more quickly than higher density material (Keey et al, 2000). The most likely explanation for this contradiction is that tension set or case hardening is greater in the collapse prone boards, and this is causing the retardation of the drying rate, at least for the moisture being dried from the core of these boards.

Figure 3: Relationship of collapse with basic density.
Internal Checking

The two different levels of ramping of the pre-drying schedules were also specifically chosen to investigate the effect of ramping on internal checks. The emphasis on minimising collapse is usually placed upon reducing initial drying temperatures and drying conditions. Ramping those conditions up prior to reconditioning is common, although little was previously known about the effect of this ramping on collapse or internal checking.

Figure 5 shows that despite the material in the three different pre-drying schedules being end-matched, the boards dried with the standard schedule showed the greatest amount of collapse as measured from external dimensions. In contrast, Table 2 shows that the internal checking levels were greatest in the accelerated boards followed then by the control boards. It is possible then, that the collapse potential was more or less the same in all the boards. For some reason though, some of the collapse potential was expressed more as shrinkage in the standard boards and as internal checking in the accelerated and control boards. This may have been due to either slight variation in material properties between the sets of boards, or alternatively, it may have been due to the different schedules. For example, in the standard boards, the gradual increase of temperature may have allowed for more creep than in the control boards. In the case of the accelerated boards, the increased drying stresses may have countered any creep effect and resulted in increased internal checking.
Figure 5: Collapse plotted against the average MC% the sub-samples were at prior to steam reconditioning. Letters indicate statistical differences ($\alpha = 0.05$) based on the Scheffé post-hoc test on square root transformed data.

Table 2: Mean area of internal checks ($\text{mm}^2$) present before steam reconditioning.

<table>
<thead>
<tr>
<th>Nominal MC% for Reconditioning</th>
<th>Accelerated</th>
<th>Standard</th>
<th>Control</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>15%</td>
<td>7.8</td>
<td>6.6</td>
<td>7.8</td>
<td>7.4</td>
</tr>
<tr>
<td>20%</td>
<td>13.3</td>
<td>6.7</td>
<td>9.0</td>
<td>9.7</td>
</tr>
<tr>
<td>Total</td>
<td>10.6</td>
<td>6.7</td>
<td>8.4</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Appendix 1 provides examples of cross-sections cut from one of the boards that were prone to severe internal checking. The important thing to note is that while ramping may have slightly increased the area or number of checks, the internal checking was still severe in the control dried material. In all boards, not just the one shown in appendix 1, all of the internal checks that occurred were within ring checks and all occurred in earlywood. Provided that the core moisture content was not excessively high ($<25-30\%\text{MC}$) the internal checks were closed and final drying had minimal effect on re-opening or closing internal checks after reconditioning was undertaken.

**Length of steaming and recovery mechanism**

Figure 6 provides an example of measurements taken of the mass, temperature and width changes during steam reconditioning. This figure shows that for this material it took about 90-120 minutes for the core of the board to reach 100°C. Most of the increase in the width dimension also occurred in this period of time.
Figure 6: Measurements of mass, temperature and width changes during steam reconditioning for sub-samples from board B18–3 (Basic density $\approx 490$ kg m$^{-3}$). Dried using the accelerated schedule and reconditioned nominally at 15% moisture content.

Figure 7 shows the mean moisture content profile of all boards before and after steam reconditioning. This figure suggests that most moisture uptake during reconditioning was limited to the outer 10 mm of board thickness. This figure in conjunction with Figure 6 suggests that the steam reconditioning is mostly heat related and apart from the effects of mean moisture contents and gradients discussed earlier, moisture uptake or movement during reconditioning may in itself not be essential for collapse recovery.
Figure 7: Mean MC profiles through the thickness of end sections before and after steam reconditioning. Error bars show the 95% confidence intervals for individual board measurements.
Preliminary Recommendations

- Slow drying boards with wet cores prior to reconditioning are likely to be highly collapsed boards. Equilibration before reconditioning is therefore critical to ensure maximum recovery of collapse in these boards.
  - Core to surface moisture gradients should target 5% and at a minimum be less than 8-10% moisture content before reconditioning.

- If boards are to be well equilibrated, with moisture gradients targeting 5% before reconditioning, a target moisture content of close to 20% will achieve a slightly higher recovery of collapse than at 15%.

- If time or kiln restraints limit equilibration it is better to target a MC% closer to 15% in order to make it easier to reduce the core to surface moisture gradients to acceptable limits.
  - Need to be careful not to over-dry some material as moisture contents below 15% will progressively reduce collapse recovery.

- Provided moisture contents are within the above guidelines, reconditioning only needs to be undertaken for as long as it takes to heat the core of the boards to the maximum temperature (as close to 100°C as possible).
  - This will depend on board thickness, boiler capability and reconditioning chamber design.

- Ramping of pre-drying schedules may increase collapse levels and the number or size of internal checks within certain growth rings, but does not appear to cause or create significant new internal checks in material that was previously free of checks.
  - In all of the ramping schedules trialled, internal checking was all within ring and all in the earlywood part of the growth ring.
  - Provided the core moisture content was within recommended levels, all internal checks could be closed during reconditioned.
    ■ The impact of these closed checks on end-product performance is unclear.

Acknowledgments

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Timber for the experiments looking at the effect of gradients on collapse recovery was kindly supplied by Neville Smith Timber Industries in Heyfield.

References


APPENDIX 1: Example cross-sections showing examples of internal checking (Approximate core MC% are indicated above cross-sections)

B18-3 (Accelerated)
Before

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32.8%</td>
</tr>
<tr>
<td></td>
<td>16.9%</td>
</tr>
</tbody>
</table>

After

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35.2%</td>
</tr>
<tr>
<td></td>
<td>14.2%</td>
</tr>
</tbody>
</table>

12%
B18-1 (Standard)

Before 33.8% 15.5%

After 30.5% 16.4%

12%
### B18-2 (Control)

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.6%</td>
<td>20.6%</td>
</tr>
<tr>
<td></td>
<td>16.4%</td>
<td>16.3%</td>
</tr>
</tbody>
</table>

12%