How do Common Finger-joint Defecting Operations Affect Product Stiffness?

The A-Grader a New Grading Tool.

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How do Common Finger-joint Defecting Operations?

Introduction
The intention with this study was to investigate three effects:
1. When knots are removed is there a resultant increase in the overall stiffness of the piece and what is loss in timber volume?
2. When timber is graded by long-span stiffness (LMoE) or other average stiffness measures and then subsequently cut into shooks and rejoined at random is the variation in stiffness similar to original distribution?
3. Traditional advice commonly given to the producers of Glulam beams is to defect timber according to MSG colour mark, defect and re-join matching the MSG colours. The question here is how effective is this in producing lamina with separate and distinct stiffness ranges?

Study Timber
The study timber comprised of 193 - 4.6m lengths of kiln dried machine graded gauged 90x45 lumber.

Effect of Knots on Stiffness
1. Firstly each length of timber (when possible) had all knots exceeding a knot area ratio (KAR) of greater than 50% KAR removed. The KAR were assessed by visual means only as opposed to be measured and calculated. A cut distance from the knot of 30mm was used.
2. The shooks were then finger-jointed in their original orientation together to recreate original timber length albeit shorter.
3. The amount timber lost in this operation was recorded and the long span stiffness as a joist LMoE re-measured.
4. This procedure was then repeated for KAR's of 33%, 25% and 15%.

The following Figures 1, 2, 3 & 4 show the effect on the overall timber batch (all 193 pieces) of using different KAR allowances. Figures 5, 6, 7 & 8 show the effect on only the affected (defected) pieces of timber when removing knots with the different KAR allowances.
>50% KAR Removed  
All 193 pieces plotted

\[ y = 1.0057x \]
\[ R^2 = 0.9898 \]

>33% KAR Removed  
All 193 pieces plotted

\[ y = 1.0197x \]
\[ R^2 = 0.9613 \]

>25% KAR Removed  
All 193 pieces plotted

\[ y = 1.0133x \]
\[ R^2 = 0.9648 \]

>15% KAR Removed  
All 193 pieces plotted

\[ y = 1.0329x \]
\[ R^2 = 0.9538 \]

**Figure 1:** All pieces knots > 50% removed  
**Figure 2:** All pieces knots > 33% removed

**Figure 3:** All pieces knots > 25% removed  
**Figure 4:** All pieces knots > 15% removed

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Tables 1 & 2 show the percentage change in average LMoE₀ for the entire batch (Table 1) and for the affected pieces only (Table 2) along with the lost in timber volume associated with applying the different KAR allowances.
**Table 1:** Summary of $\text{LMoE}_J$ by allowable KAR for the entire batch of timber

<table>
<thead>
<tr>
<th>KAR limit</th>
<th>50%</th>
<th>33%</th>
<th>25%</th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage change in Average $\text{LMoE}_J$</strong></td>
<td>0.7%</td>
<td>2.4%</td>
<td>1.7%</td>
<td>3.4%</td>
</tr>
<tr>
<td><strong>Loss in Timber volume after jointing</strong></td>
<td>Not recorded</td>
<td>-6.1%</td>
<td>-9.0%</td>
<td>-11.5%</td>
</tr>
</tbody>
</table>

**Table 2:** Summary of $\text{LMoE}_J$ by allowable KAR based on affected (defected) pieces only

<table>
<thead>
<tr>
<th>KAR limit</th>
<th>50%</th>
<th>33%</th>
<th>25%</th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage change in Average $\text{LMoE}_J$</strong></td>
<td>4.4%</td>
<td>4.3%</td>
<td>2.8%</td>
<td>5.3%</td>
</tr>
<tr>
<td><strong>Number of affected pieces out of 193 total</strong></td>
<td>35</td>
<td>121</td>
<td>169</td>
<td>189</td>
</tr>
<tr>
<td><strong>Loss in Timber volume</strong></td>
<td>Not recorded</td>
<td>-10.8%</td>
<td>-14.4%</td>
<td>-17.9%</td>
</tr>
</tbody>
</table>

Observations on the change in stiffness based on applying different KAR allowances.

- Defecting based on different allowable knot sizes (KAR) (50%, 33%, 25, & 15%) does produce a small improvement in timber joist stiffness (up to 5% max).
- There is no apparent relationship between the improvement in stiffness versus the reducing allowable KAR (Table 2).
- There is significant loss of timber volume when defecting for KAR, this increases with the reduction in allowable KAR.
- There is a difference in stiffness improvement and timber loss dependent on how the data is interpreted. If the results are based on the batch of timber which probably the most realistic scenario then the resultant stiffness improvement ranges from 0.7% to 3.4% (Table 1) and the loss of timber volume has a maximum of 11.5%.
- The reason behind the differences between Table 1 and Table 2 is that not all the pieces of timber are affected by the different limitations on KAR. For instance only 35 pieces had a KAR greater than 50%. Thus changes related to entire sample will be less and there are pieces that have not been defected.

**Effect of a Stiffness ($\text{LMoE}_J$) sort prior to Defecting**

This aspect of the study addresses the issue of when timber is stiffness graded prior to defecting into stiffness groups and finger jointed at random but inside the original stiffness groups.

The study timber was ranked in order of average joist stiffness ($\text{LMoE}_J$) stiffness then separated into three stiffness groups (A, B & C). The timber within each group was then defected to remove knots with an allowable KAR of 15%. The shooks were then randomised keeping each group separate, finger jointed and re assembled to produce timber of a similar length to original.

Figure 9 show the cumulative frequency distribution for the original $\text{LMoE}_J$ (original) and final $\text{LMoE}_J$ (Mixed). Table 3 shows a statistical summary of this data.
Observations on the change in stiffness grading prior to defecting.

- The stiffness groups after defecting are still well defined and very distinct.
- In the lower stiffness group the spread of stiffness is reduced with a slight improvement (6.5%) in the average stiffness.
- There is virtually no change to the stiffness distribution in the middle stiffness group.
- In the high stiffness group the spread of stiffness is reduced with a slight reduction (6%) in the average stiffness.
- The effect of defecting, randomising and finger jointing has been a smoothing out of the stiffnesses i.e. those few high and low stiffness values have been eliminated.
- This effect would also be apparent when grading by MoE_Paverage or sonic stiffness (SMoE).
- One benefit of grading by LMoE_J or SMoE is that it can be done with the timber in a rough sawn state using the E-grader™ or the A-Grader.
Effect of sorting shooks by $\text{MoE}_{\text{Plank}}$ Stiffness sort prior to Finger-jointing

This aspect of the study addresses the issue of:

If timber were to be supplied machine graded in a dry gauged condition utilising the more traditional $\text{MoE}_{\text{Plank}}$ MSG colours. Then the timber were to be defected according to MSG colour mark and knot size, re-joined matching up the MSG colours, what would be the final stiffness distribution?

In this case the timber was machine stress graded in a commercial operation on which. Forest Research has no data relating to stress grader setup or grader accuracy. Each piece of timber was defected to remove knots with a KAR of 15% and to produce shooks with a common colour. The shooks were then randomised keeping each colour group separate, finger jointed and re assembled to produce timber of a similar length to original. Figure 10 show the cumulative frequency distribution in terms of average joist stiffness ($\text{LMoE}_j$) for the three $\text{MoE}_{\text{Plank}}$ colours (Black, Green, and Purple). Table 4 shows a statistical summary of this data.

![Figure 10: Long Span Stiffness after Timber has been sorted by $\text{MoE}_{\text{Plank}}$ colours, defected and finger-jointed](image-url)
Table 4: Summary of LMoEj stiffnesses based on MoEPlank colour

<table>
<thead>
<tr>
<th>Colour spray</th>
<th>Black LMoEj</th>
<th>Green LMoEj</th>
<th>Purple LMoEj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>7.27</td>
<td>10.05</td>
<td>13.00</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.693</td>
<td>0.927</td>
<td>0.903</td>
</tr>
<tr>
<td>Range</td>
<td>3.08</td>
<td>3.63</td>
<td>4.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>5.79</td>
<td>8.52</td>
<td>10.67</td>
</tr>
<tr>
<td>Maximum</td>
<td>8.88</td>
<td>12.16</td>
<td>14.67</td>
</tr>
<tr>
<td>Count</td>
<td>34</td>
<td>43</td>
<td>27</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>9.5%</td>
<td>9.2%</td>
<td>7.0%</td>
</tr>
<tr>
<td>Ek, GPa.</td>
<td><strong>7.18</strong></td>
<td><strong>9.95</strong></td>
<td><strong>12.87</strong></td>
</tr>
</tbody>
</table>

Observations on the distribution of LMoEj stiffness when sorting for MoEPlank colour

- The stiffness groups after defecting for each colour are well defined and very distinct.
- One disadvantage of this approach is that to grade timber for MoEPlank the timber must be gauged and a further gauging will normally be required in a glulam operation. This double gauging has two effects, firstly it generates more waste and less recovery. Secondly MSG timber normally comes in standard sizes, thus using say 90x45 material hence it is not normally possible to produce a glulam section 90mm wide.
- The curved arris formed by normal gauging operations also impacts on timber recovery and the final glulam section size.
- It is possible to cut and gauge timber with larger dimensions and no arris so that standard width glulam sections can be made however the viability of this would have to be assessed by the MSG timber producer.
- With a finger jointed stud operation with very careful joint set up it is possible to finger joint without requiring a final gauging. Glue selection can be important here for appearance and saleability reasons.

Conclusions

- Defecting for knots does not provide any significant improvement in stiffness
- There is a significant loss of volume in defecting for knots as could be expected.
- Presorting prior the defecting into stiffness groups using either MoE_{Paverage} the E-grader™’s longspan LMoEJ stiffness or the A-Grader’s sonic stiffness will produce finger-jointing material with distinct and well defined stiffness ranges.
- Defecting to matching up MSG MoE_{Plank} colours does produce material with distinct and well defined stiffness ranges. The need for standard machine stress grading of timber to be gauged can clash with standard glulam section sizes.

References

The A-Grader a new grading tool.

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New Zealand Forest Research Institute Ltd

A-Grader and Acoustic Measurement of Stiffness

The A-grader is based on the principal of sonic resonance. Just as a bell rings when it is struck, so does almost any other physical thing with sufficient stiffness. This principal has been used for a long time to check the quality of products; like the crystal glass maker of old checking the quality of the crystal glass by listening to the ring that is made when a rod of the crystal glass is struck.

Not all materials produce such a loud, clear ring as crystal might when struck, but as technology has evolved so the applications that use this principal grow. Fifty years ago the advent of cheap, good-quality electronic amplifiers saw sonic resonance being regularly used to check the stiffness of concrete samples. What can be applied to concrete can be applied to timber, and in the last 20 years or so people have used sonic resonance to check the stiffness of wood in various forms, from tree stems right down to laboratory samples the size of matchsticks. The only obstacle to this has been marrying sufficiently developed technology to the fundamental principal.

The fundamental principal used in the A-grader is based on a sonic wave moving repeatedly from one end of the timber to the other. The sonic waves used in the A-grader are called compression waves because as they move along the timber they compress and expand the timber. This compression is very small; you can’t see it, but you may be able to feel it. It should be no surprise then that these sonic compression waves are affected by the stiffness of the timber. In fact, the speed of the wave is affected by the stiffness – as the stiffness increases the speed increases.

Unfortunately, it’s not just the stiffness that affects the speed of these sonic waves, but also the density of the timber; as the density increases the speed decreases. This makes sense, because the heavier something is the harder it is to move around – heavier things move more slowly, you might say.

Back to resonance; as these sonic waves bounce backwards and forwards along the timber some of the waves almost exactly overlap. These overlapping waves build up and become bigger, while the sonic waves that don’t overlap tend to cancel each other out. The sonic waves that build up on each other are resonating. It’s very much like being on a playground swing – if you push at the right time when the swing is swinging you make the swing move out more, if you push at the wrong time you make it stop.

By looking at which sonic waves become large compared to the other waves, we can tell how often the sonic waves are bouncing backwards and forwards along the timber. Then by knowing the length of the timber, we can determine the speed of the waves. Now that

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we know the speed of the sonic waves, we then use the density of the timber to calculate the stiffness. The A-Grader measures both the density of the timber and speed of the sonic waves in the timber to produce a stiffness value for the timber.

There are two technologically demanding aspects to measuring the speed of the sonic waves in timber on a chain: generating and measuring the vibrations of the timber when it is moving on a chain, and quickly working out which sonic waves are resonating. The former requires non-contact devices or devices that track with the timber, and the latter requires clever signal processing algorithms and significant computer processing power.

**A-Grader Applications**

The A-Grader has been developed by Forest Research, in conjunction with Falcon Engineering, the “A-Grader” can measure stiffness for the first time on green/dry, rough-sawn/gauged, random length random size lumber.

This grading technology can be applied in the following applications:
- Sorting by stiffness on green rough-sawn, random size, and random length lumber on the green chain.
- Stiffness grading dried gauged, random size, and random length structural lumber.
- Finger joint blocks.
- The larger structural sections that cannot be grading by the traditional grading machines.

**Finger-joint Blocks**

Many re-manufacturing companies buy in finger-joint blanks to produce structural products such as studs. The final studs then need to be graded for sale and those that do not come up to scratch must be sold as a lower grade or used elsewhere. A significant amount of time, energy and money is regularly spent on these rejected products. The logical approach is to grade the raw material first, culling out substandard blocks. This dramatically decreases the reject studs at the end of the process.

The A-Grader technology can stiffness grade these blocks at finger-joint production speeds so the block can be sorted into stiffness groups corresponding to the final product stiffness requirements. The traditional grading machines cannot stiffness grade these short lengths.

The first A-Grader for grading shooks is currently being developed.
The following Figures 11 & 12 show the kiln-dried gauged ‘A grader’ type technology MoE vs the kiln dried gauged MoE in both joist and plank directions.

![Figure 11: Dry G4S ‘A grader’ vs KD G4S MoEj](image1)

![Figure 12: Dry G4S ‘A grader’ vs KD G4S MoEp](image2)

These two figures show a good relationship between the dry gauged A-Grader stiffness (based on nominal dry gauged dimensions) and the gauged kiln dried bending stiffness.

**A-Grader Manufacture and Support**

The A-Grader is marketed, manufactured and supported by

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Forest Research provides technical support and consultancy service on the associated structural grading and quality assurance area.

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