57th SWST International Convention
7th Wood Structure and Properties Conference
6th European Hardwood Conference

Sustainable Resources and Technology for Forest Products

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Durability of adhesive bonds in cross-laminated timber (CLT) panels manufactured using Irish Sitka spruce

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Overview

- Opportunities for Irish timber
  - Cross-Laminated Timber (CLT)
- Adhesives for CLT
- Test programme
  - Shear tests
  - Delamination of glue lines test
- Results
- Conclusions

Opportunities for Irish timber
Irish forestry & forest products sector

[IFFPA, 2013]

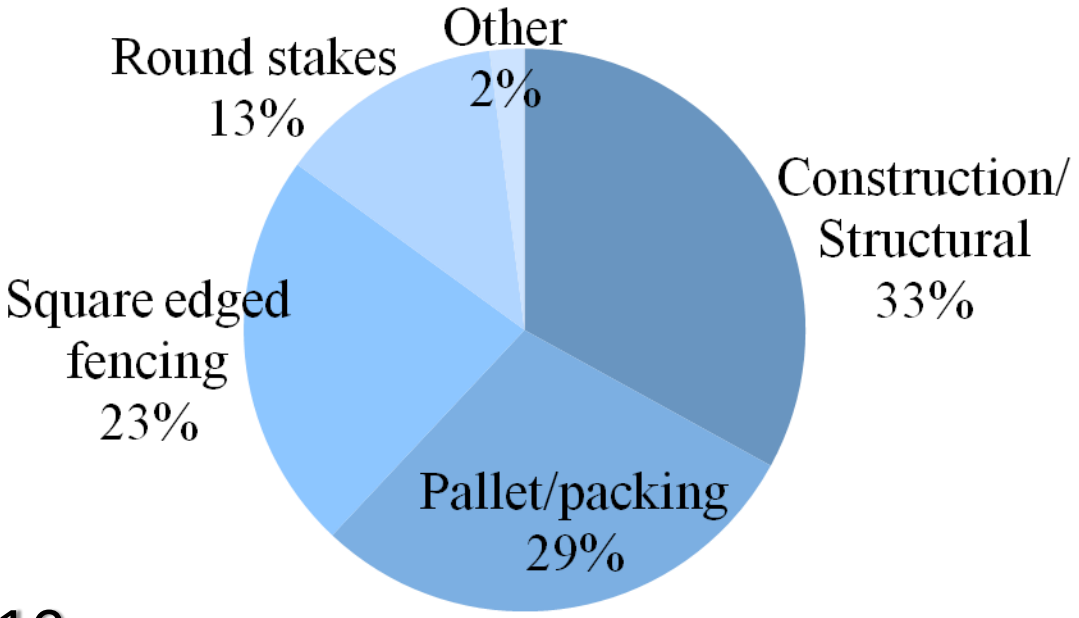
- €2.2 billion in annual output (in 2012 = 1.3% GDP)
- > 12,000 employed
- Increase from 3903 million m^3 in 2011

  to 7110 million m^3 in 2028 of the supply of roundwood

Opportunities for Irish timber
Uses of Irish Sitka Spruce

[IFFPA, 2013]

Uses of Irish timber in 2012 [in relation to m3]



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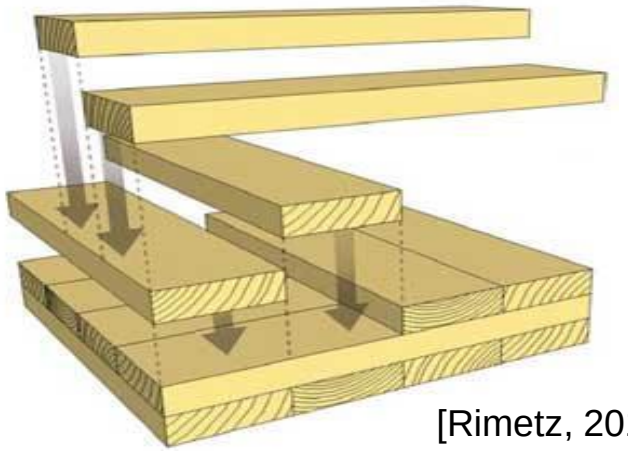
Opportunities for Irish timber
Cross-Laminated Timber (CLT)

[archexamhandbook.com]



[Rimetz, 2011]

- Made of at least 3 orthogonally bonded layers of timber
- Successive layers of boards placed cross-wise

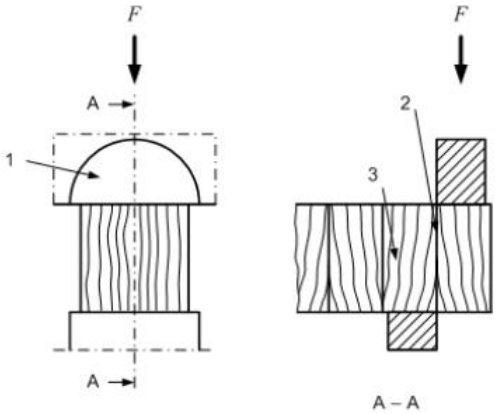
Adhesives for CLT

- **Phenoplast- and aminoplast-adhesives (MUF, PRF)**
- **One-component polyurethane adhesives (1K-PUR)**
- **Emulsion-polymer-isocyanate adhesive (EPI)**

Test programme

prEN 16351 2013

- Shear tests



- Delamination test of glue lines between layers

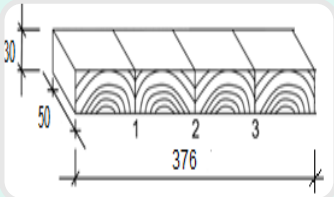
Materials preparation procedure

- Timber conditioning: 3 months: 20 ° C & 65% RH
- Timber planing: 30 mm x 94 (or 96) mm
- Thickness tolerance measurements: required : 0.1 mm
- Bonding: 0.1 mm adhesive layer; clamping: 120 min
- Reconditioning: 20 ° C & 65% RH
- Cutting

Specimens preparation for shear testing

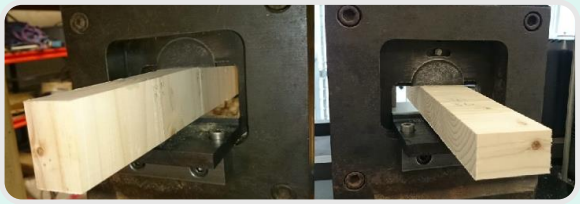
Bonding

- blocks of 4 edge bonded 300 mm long boards
- 0.6 N/mm^2, 0.8 N/mm^2, 1.0 N/mm^2



Specimen

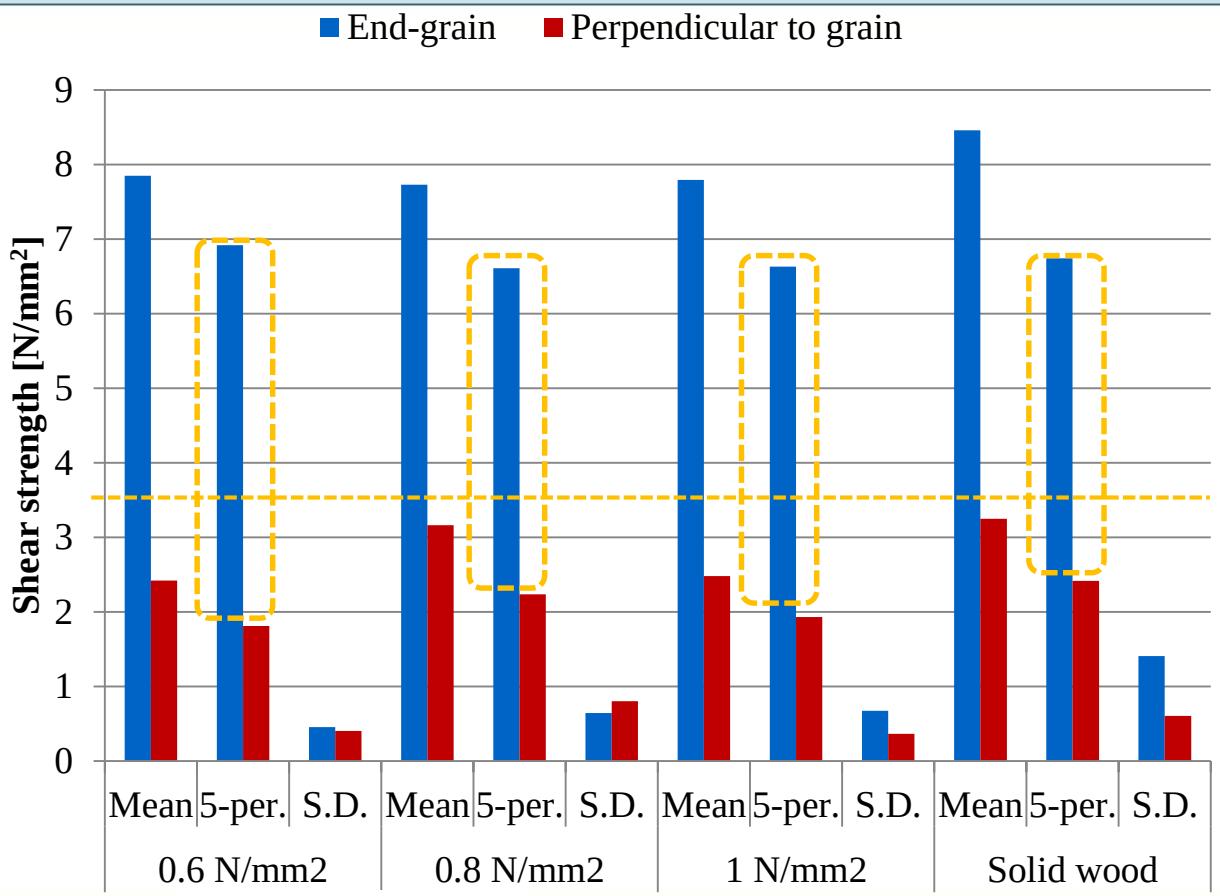
- glue line (or solid wood): 30 mm x 50 mm
- 2 loading directions: · End-grain, · Perpendicular to grain



Bonding pressure	***0.6 N/mm²***	***0.8 N/mm²***	***1.0 N/mm²***	***Solid wood***
End-grain	36	36	36	36
Perp. to g.	36	24	36	36

Shear tests results

- Characteristics strength (end-grain) > 3.5 N/mm^2
- For solid wood 64% reduction in characteristic strength perpendicular to grain compared to end-grain
- 74% ↓ for 0.6 N/mm^2
- 66% ↓ for 0.8 N/mm^2
- 71% ↓ for 1.0 N/mm^2



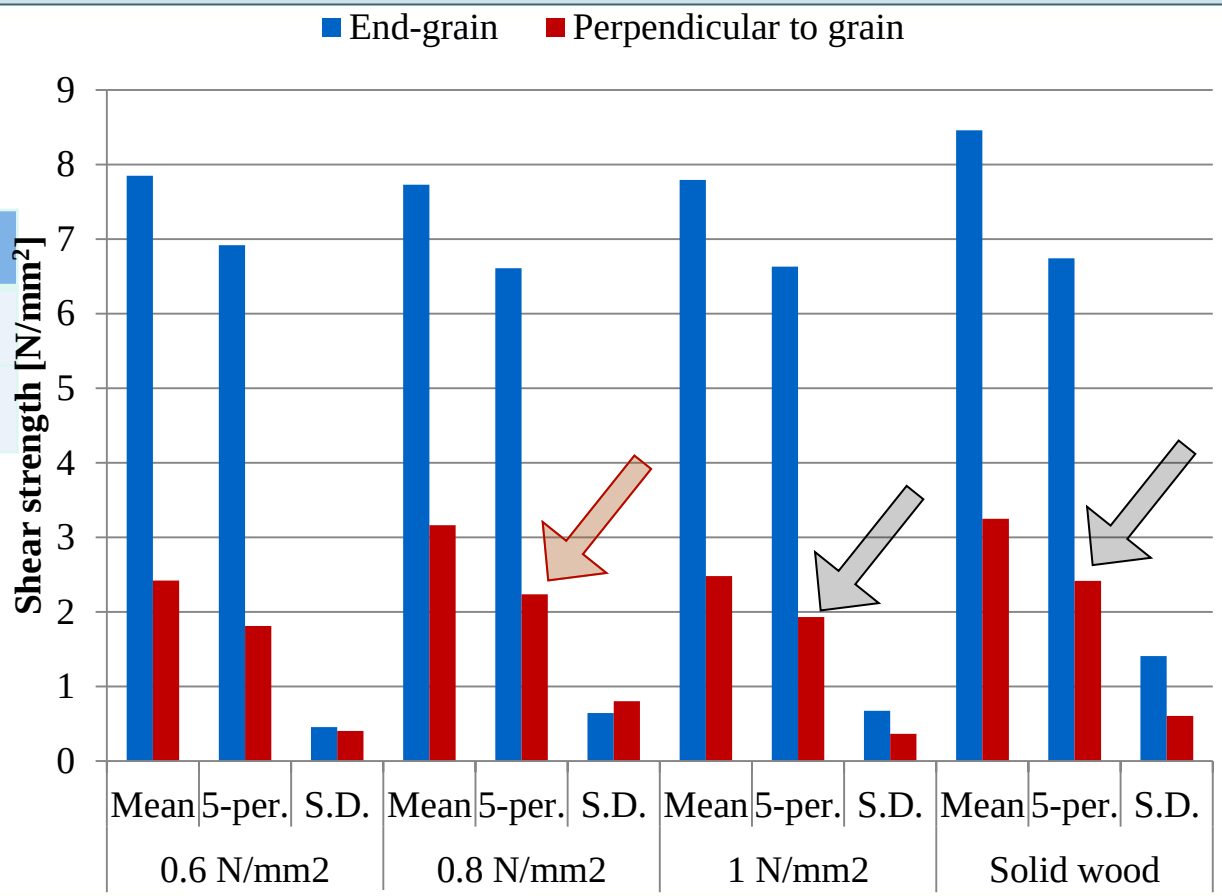
Shear tests results

- Student's *t* test:
  - Comparison with solid wood:

P.[N/mm²]	0.6	0.8	1.0
E.-g.	Sig. Dif.	Sig. Dif.	Sig. Dif.
Perp. to g.	Sig. Dif.	No Sig. Dif.	Sig. Dif.

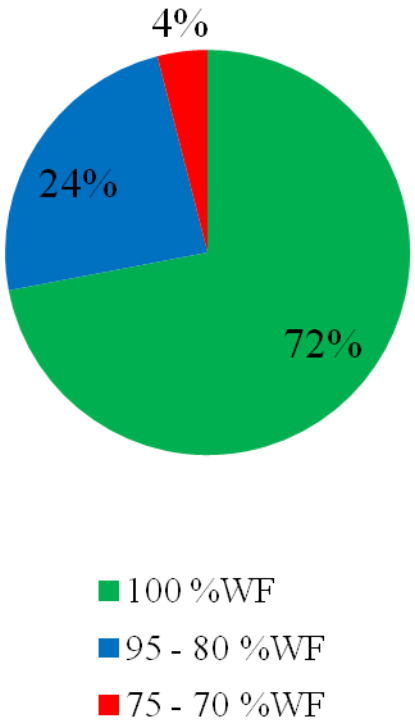
  - Comparison with 1.0 N/mm²

P.[N/mm²]	0.6	0.8
E.-g.	No Sig. Dif.	No Sig. Dif.
Perp. to g.	No Sig. Dif.	Sig. Dif.

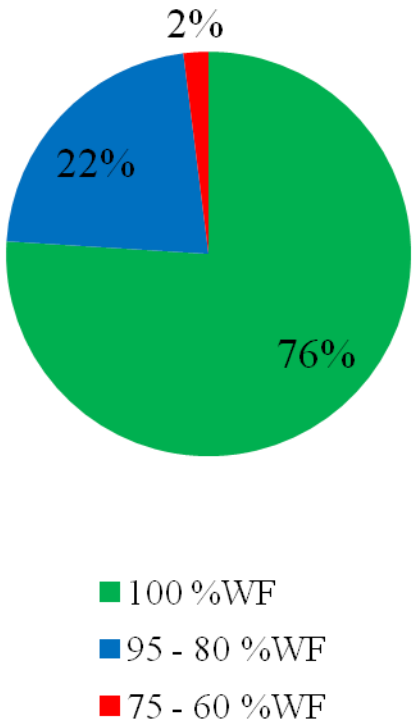


Wood failure percentage:
95% specimens ≥ 80 %WF
67% specimens = 100 %WF

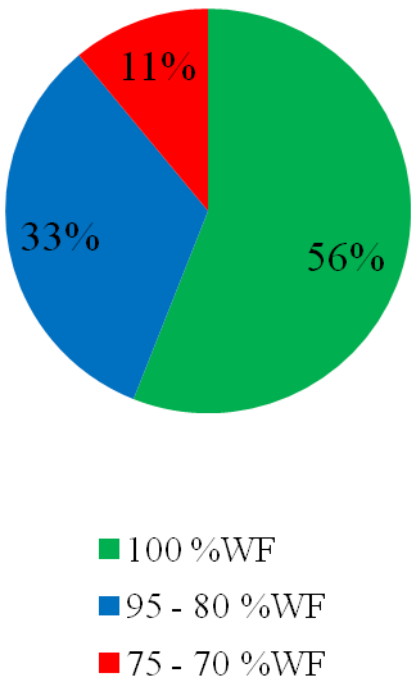
p = 0.6 N/mm²



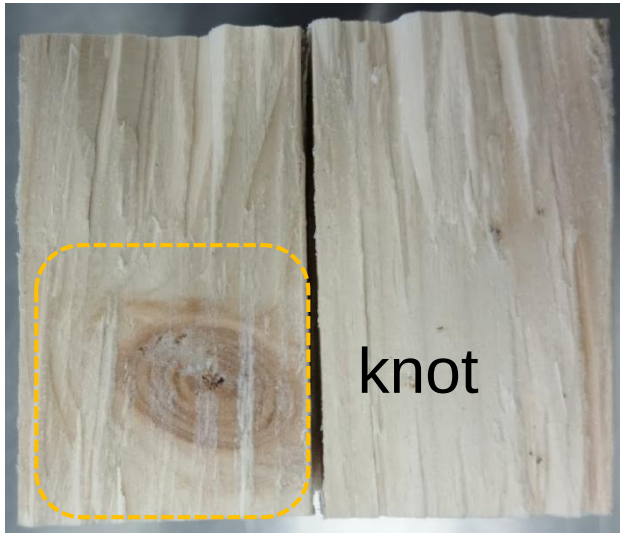
p = 0.8 N/mm²



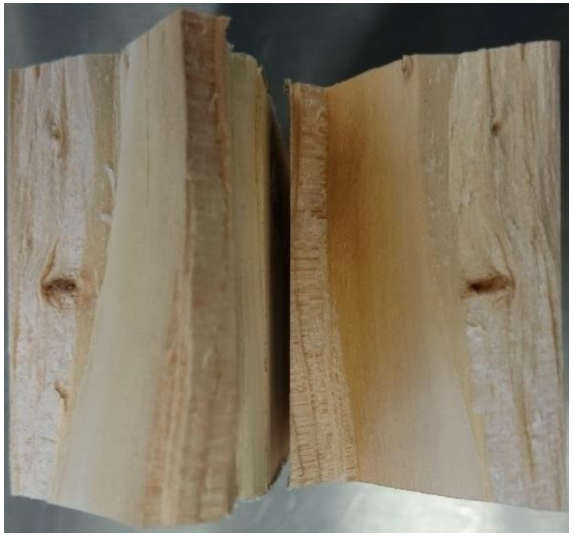
p = 1.0 N/mm²



Wood failure percentage
Min.: 60 %WF for 0.8 N/mm^2 pressure and tested perpendicular to grain



60% wood failure
loaded perpendicular to grain



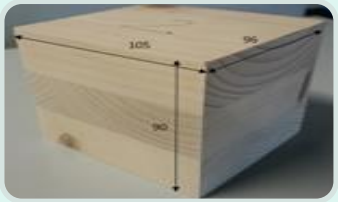
100% wood failure
loaded perpendicular to grain

100% wood failure
loaded at end-grain

Delamination of glue lines test

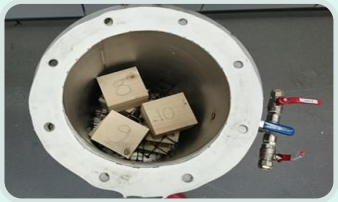
Clamping

- 3-layer panel of 90 mm (3x 30 mm) x 600 mm x 192 mm
- 0.8 N/mm^2



Sample

- 10 specimens
- 105 mm x 96 mm x 90 mm



Vacuum-pressure soak cycle

- submerged in water (~15 ° C) » vacuum of ~80 kPa for 30 min » pressure of ~550 kPa for 2 h » drying for ~15 h in 70±5 ° C

Delamination of glue lines

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Total delamination *Delam*$_{tot}$

$$Delam_{tot} = \frac{l_{tot,delam}}{l_{tot,glueline}} \times 100\%$$

$l_{tot,delam}$ total delamination length (in mm)

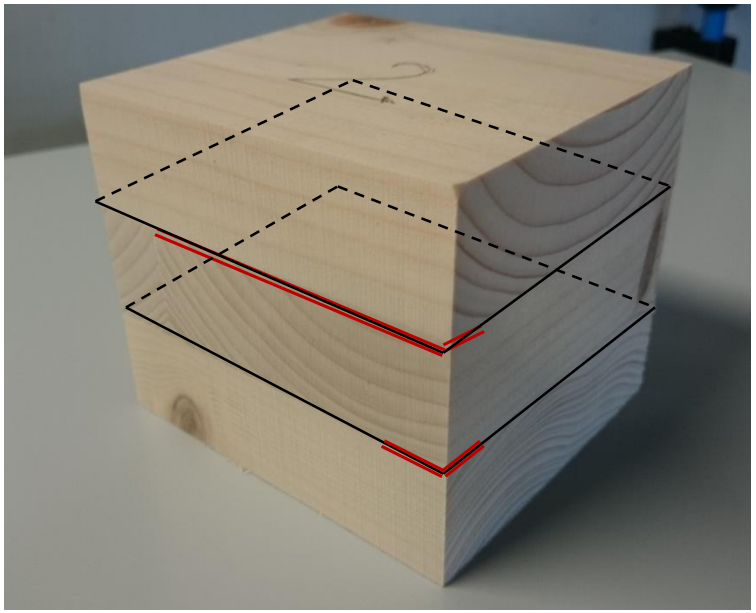
$l_{tot,glueline}$ sum of the perimeters of all glue lines in a delamination specimen (in mm)

Maximum delamination *Delam*$_{max}$

$$Delam_{\max} = \frac{l_{\max,delam}}{l_{glueline}} \times 100\%$$

$l_{max,delam}$ maximum delamination length (in mm)

$l_{glueline}$ perimeter of one glue line in a delamination specimen (in mm)



Delamination of glue lines - results

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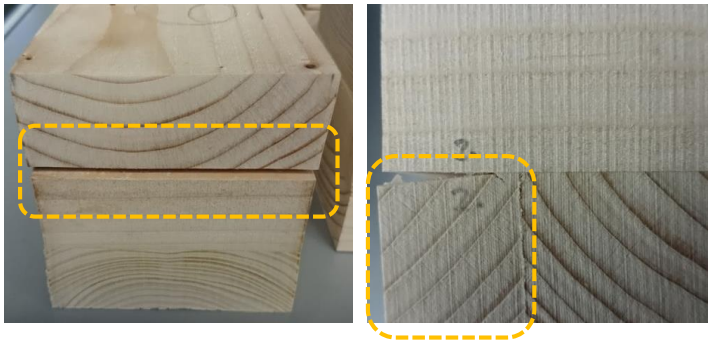
- $Delam_{tot} \leq 10\%$ and $Delam_{max} \leq 40\%$ when exceeded

- Lower of the wood failure percentages from two glue lines, $FF_{min} \geq 50\%$

  &

  Minimum wood failure percentage of sum of all split glued areas $\geq 70\%$

Specimen ID	$Delam_{tot}$ [%]	$Delam_{max}$ [%]	FF_{min} [%]
1	16.8	33.7	80%
2	17.6	35.2	75%
3	27.3	54.2	60%
4	16.0	32.0	85%
5	19.5	38.9	70%
6	21.7	43.7	65%
7	17.0	34.0	80%
8	23.1	46.2	65%
9	19.8	39.6	70%
10	28.2	56.3	60%



- Delamination occurred in one glue line on one side
- Widths of the narrowest timber elements in each test piece determined depth of delamination

Conclusions

- lowest pressure of 0.6 N/mm^2 is sufficient for Irish Sitka spruce in terms of shear strength requirements
- wood percentage failure results for PUR type adhesives are very high with small variations
- shear strength within the required limits
- durability requirements are satisfied
- widths of the narrowest timber elements in CLT test piece determine the size of delamination

Thank you!

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