Making the Grade & Maximising the Opportunities

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Issues - wood in construction

• Water
• “Figure” and “Defects”
• Anisotropy
• Inhomogeneity
• Variation and uncertainty
  • All materials have some variation and uncertainty
  • Main difference is we don’t manufacture the wood
  • …Trees do
  • Well…actually…trees and foresters do
Construction timber

• Structural design is about buildings
  – Staying safe
  – Staying fit for use

• More specifically
  – Safety of the people and the structure
    • Problem e.g. collapse due to lack of strength
  – The structure remaining functional
    • Problem e.g. too much movement due to lack of stiffness
  – In part, handled by grading – provides the numbers for engineers to use in their design calculations
Small clear testing BS 373

No longer basis for (most) grading

But commonly found in books
Full-size testing EN 408

Current basis for (most) grading

Very different from small clears – mostly due to the ‘defects’
Grade-determining properties

• Strength
  – Usually major axis bending (aka Modulus of Rupture, MoR)

• Stiffness
  – Usually major axis bending (aka Modulus of Elasticity, MoE)

• Density (at 12% moisture content)
  – Also an indirect measure of strength in some elements of timber design

• All the other strength class properties are derived from these 3 main properties
  (By conservative relationships. Equations are in EN 384)
Dealing with uncertainty

Performance demand vs. Probability of infringement

- e.g. Force
- e.g. Strength

Performance ability/capacity
Characteristic values

Mean (used for stiffness)

Lower 5\textsuperscript{th} percentile (used for strength and density)

Probability of being lower = 5%
Characteristic values

Definitions are independent of the probability distribution

Mean

Parameter

Frequency of occurrence

Lower 5\textsuperscript{th} percentile

Probability of being lower = 5%
Grades and classes

- Strength grade
- Strength class
  - Has numerical properties
- Timber grades are assigned to a class
- EN 338 lists strength classes
- C classes for softwoods (or hardwoods)
- D classes for hardwoods
- These are not the only strength classes
### EN338:2016

#### Strength properties in N/mm²

<table>
<thead>
<tr>
<th>Property</th>
<th>C14</th>
<th>C16</th>
<th>C18</th>
<th>C20</th>
<th>C22</th>
<th>C24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Tension parallel</td>
<td>7,2</td>
<td>8,5</td>
<td>10</td>
<td>11,5</td>
<td>13</td>
<td>14,5</td>
</tr>
<tr>
<td>Tension perpendicular</td>
<td>0,4</td>
<td>0,4</td>
<td>0,4</td>
<td>0,4</td>
<td>0,4</td>
<td>0,4</td>
</tr>
<tr>
<td>Compression parallel</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compression perpendicular</td>
<td>2,0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shear</td>
<td>3,0</td>
<td>3,2</td>
<td>3,4</td>
<td>3,6</td>
<td>3,8</td>
<td>4,0</td>
</tr>
</tbody>
</table>

#### Stiffness properties in kN/mm²

<table>
<thead>
<tr>
<th>Property</th>
<th>C14</th>
<th>C16</th>
<th>C18</th>
<th>C20</th>
<th>C22</th>
<th>C24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean modulus of elasticity parallel bending</td>
<td>7,0</td>
<td>8,0</td>
<td>9,0</td>
<td>9,5</td>
<td>10,0</td>
<td>11,0</td>
</tr>
<tr>
<td>5 percentile modulus of elasticity parallel bending</td>
<td>4,7</td>
<td>5,4</td>
<td>6,0</td>
<td>6,4</td>
<td>6,7</td>
<td>7,4</td>
</tr>
<tr>
<td>Mean modulus of elasticity perpendicular</td>
<td>0,23</td>
<td>0,27</td>
<td>0,30</td>
<td>0,32</td>
<td>0,33</td>
<td>0,37</td>
</tr>
<tr>
<td>Mean shear modulus</td>
<td>0,44</td>
<td>0,50</td>
<td>0,56</td>
<td>0,59</td>
<td>0,63</td>
<td>0,69</td>
</tr>
</tbody>
</table>

#### Density in kg/m³

<table>
<thead>
<tr>
<th>Property</th>
<th>C14</th>
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<th>C18</th>
<th>C20</th>
<th>C22</th>
<th>C24</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 percentile c density</td>
<td>290</td>
<td>310</td>
<td>320</td>
<td>330</td>
<td>340</td>
<td>350</td>
</tr>
<tr>
<td>Mean density</td>
<td>350</td>
<td>370</td>
<td>380</td>
<td>400</td>
<td>410</td>
<td>420</td>
</tr>
</tbody>
</table>
Critical property

- To comply with the grade, characteristic values must be met (at least*)
- For a species and grade combination usually one property is limiting
  - Strength
  - Stiffness
  - Density
- So strength grading isn’t always about predicting strength

* subject to adjustments
Critical property for spruce

British spruce: Sitka spruce and Norway spruce combined from UK and Ireland (WPCS)

SIRT benchmarking validation, 957 pieces

<table>
<thead>
<tr>
<th>British spruce</th>
<th>C14</th>
<th>C16</th>
<th>C18</th>
<th>C20</th>
<th>C22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>20.9 N/mm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stiffness</td>
<td>8.2 kN/mm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>338 kg/m³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It isn’t density (or strength) that is limiting – it is stiffness
Grading trades yield for class
(with perfect grading – knowing the actual properties of each piece)
British spruce: Sitka spruce and Norway spruce combined from UK and Ireland (WPCS)

<table>
<thead>
<tr>
<th></th>
<th>C14</th>
<th>C16</th>
<th>C18</th>
<th>C20</th>
<th>C22</th>
<th>C24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>100%</td>
<td>100%</td>
<td>90%</td>
<td>73%</td>
<td>55%</td>
<td>26%</td>
</tr>
</tbody>
</table>

The other 74% is C16

(Single grade / reject)

For higher grades, density becomes critical. Yield of C27 ~ 9%
Grading methods for timber

• Visual strength grading
  – (not the same as appearance grading)
  – Knots, grain, species, origin…

• Machine strength grading
  – Machine control (pre-determined settings)
  – Output control (continuous testing)

• Additional overrides
  – Distortion, cracks, rot, insect damage, etc

See “strength grading of timber explained”
Visual strength grading

• Overarching requirements in EN 14081-1
• But done according to national standards
  – BS 4978 (softwoods)
  – BS 5756 (hardwoods)
  – Also German, Canadian, French, Italian, Dutch, Nordic, Spanish...
  – Need not be a formal standard – can make your own
• Assignments to classes in EN 1912
• According to testing to EN 384
• Can also be assignments elsewhere
Machine strength grading

• Machine grading
  – Relates an ‘indicating parameter’ to the critical grade-determining parameter(s)
  – Better accuracy than visual grading…
    …due to the parameters being measured
    …and the automation
    …so assignment to grade is less conservative
  – Fast but expensive equipment
  – but getting cheaper and more portable
Important to realise

• Timber grading does not operate on a piece by piece basis
• Pieces are individually assigned to grades
• …but it is the population of timber in that grade that matters
• And how an individual piece is sorted into the grade depends on the machine operation / visual grading standard
• Collectively, the grade should meet the strength class characteristic values
Bending graders
Minor axis bending stiffness

Cook-Bolinder

- Constant deflection
- Load cell measuring reaction force
- Grade marking equipment
- Computer

Timgrader

- Constant deflection
- Load cell measuring reaction force
- Grade marking equipment
- Computer

Computermatic

- Deflection transducer
- Grade marking equipment
- Outrigger arm
- Bow transducer
- Air cylinder and roller applying constant force
- Computer

Figures from BRE Digest 476 “Guide to machine strength grading of timber”
Acoustic graders

Acoustic velocity, maybe density - effectively stiffness
Work well on British spruce because stiffness is the critical property

ViSCAN (MiCROTEC)  MTG (Brookhuis)

Precigrader (Dynalyse AB)  Triomatic (CBS-CBT)
Acoustic graders
Same principle as tools for forestry (either resonance or time of flight)
Not “grading” … but big potential for segregation or pre-grading
**X-ray graders**

Clear wood and average density, knot size and location

Main machine for UK...because very fast

e.g. GOLDENEYE 702 (MiCROTEC)

Lately also machines based on grain angle
e.g. WoodEye

-origin: MiCROTEC
UK larch with mtgBATCH 962
(in-line version of hand-held MTG with balance)

Example, grading with stiffness
UK larch (WLAD)
706 pieces of UK grown larch (Resource: 83% Hybrid 17% European)
863 pieces of British spruce (Resource: 92% Sitka 8% Norway)
Variation in the resource
e.g. British spruce (mixture of Sitka spruce & Norway spruce)

Strength class definitions themselves overlap
(because they describe a population with certain variation)

British spruce (SIRT benchmarking validation study)
Variation in the resource

Stand averages of tree measurements with IML hammer

"< 7"

"7 to 9"

"> 9"
### Sources of the variation

<table>
<thead>
<tr>
<th>Source</th>
<th>Density</th>
<th>Strength</th>
<th>Stiffness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between sites</td>
<td>23%</td>
<td>18%</td>
<td>26%</td>
</tr>
<tr>
<td>Between trees on a site</td>
<td>51%</td>
<td>25%</td>
<td>36%</td>
</tr>
<tr>
<td>Between logs in a tree</td>
<td>2%</td>
<td>5%</td>
<td>2%</td>
</tr>
<tr>
<td>Within log</td>
<td>25%</td>
<td>52%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Reducing wastage

Cost
Young trees
Harvest age trees
Logs at the forest
Segregation to other markets
Log / stem data (forest data)

Cost
Logs at the sawmill
Green cants
Fail pre-grading
Timber data \(\rightarrow\) predictive of dry (log / stem data, forest data)

Cost
Green sawn timber
Dry sawn timber
Fail grading
Timber data (log / stem data, forest data)
Co-products

Cost
Secondary processor/end user
Pass grading
Fail quality control
Visual assessment?
Waste

More cost incurred in processing
Higher penalty for incorrect decision
<table>
<thead>
<tr>
<th>Region</th>
<th>km</th>
<th>Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>Log</td>
<td></td>
</tr>
<tr>
<td>cm</td>
<td>Clear wood</td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td>Growth layer</td>
<td></td>
</tr>
<tr>
<td>μm</td>
<td>Cell wall</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cell wall layers</td>
<td></td>
</tr>
<tr>
<td>nm</td>
<td>Molecular</td>
<td></td>
</tr>
</tbody>
</table>

Since 2003

- Forest Research.
- Forestry Commission.
- Aberdeen University.
- Growers.
- Edinburgh Napier University.
- Processors.

The University of Glasgow.
Conifer species researched

- Sitka spruce (*Picea sitchensis*) (PCST)
- Norway spruce (*Picea abies*) (PCAB)
- Hybrid larch (aka Dunkeld larch) (*Larix x eurolepis*) (LAER)
- Japanese larch (*Larix kaempferi*) (LAKM)
- European larch (*Larix decidua*) (LADC)
- Douglas fir (*Pseudotsuga menziesii*) (PSMN)
- Scots pine (*Pinus sylvestris*) (PNSY)
- Noble fir (*Abies procera*) (ABPR)
- Western hemlock (*Tsuga heterophylla*) (TSHT)
- Western red cedar (*Thuja plicata*) (THPL)
- Serbian spruce (*Picea omorika*)
- Pacific silver fir (*Abies amabilis*) (ABAM)
- Japanese red cedar (*Cryptomeria Japonica*) (CYJP)
- Grand fir (*Abies grandis*) (ABGR)
- European silver fir (*Abies alba*) (ABAL)

Hardwoods

- Sycamore (ACPS) (*Acer pseudoplatanus*)
- Birch (BTXX) (*Betula pendula/pubescens*)

Research beginning ‘Resilience’
Range of species

Stocked area
(in Great Britain)

- Other conifers
- Lodgepole pine
- Douglas fir
- WLAD: Larches
- Corsican pine
- Scots pine
- WPNN: Norway spruce
- Sitka spruce
- WPCS

Softwoods

Hardwoods

- Other broadleaves
- Hawthorn
- Hazel
- Willow
- Alder
- Sweet chestnut
- Birch
- Ash
- Sycamore
- Beech
- Oak

National Forest Inventory: 50-year forecast of softwood availability (Forestry Commission, April 2014)
National Forest Inventory: 50-year forecast of hardwood availability (Forestry Commission, April 2014)
Range of species

Standing volume
(in Great Britain)

Softwoods

Hardwoods

Other conifers
Lodgepole pine
Douglas fir

Larches

Corsican pine
Scots pine

Norway spruce
Sitka spruce

Other broadleaves
Hawthorn
Hazel
Willow
Alder
Sweet chestnut
Birch
Ash
Sycamore
Beech
Oak

Edinburgh Napier UNIVERSITY
blogs.napier.ac.uk/cwst #ICFTimberCon 28 April 2016
Range of species

Available volume  
(in Great Britain)

- Other conifers
- Lodgepole pine
- Douglas fir
- WLAD "larches"
- Corsican pine
- Scots pine
- WPNN "British pine"
- Norway spruce
- Sitka spruce
- WPCS "British spruce"

Softwoods

Hardwoods
GB volume forecast

WPNN “British pine”

WPCS “British spruce”

WLAD “larches”

Douglas fir

Lodgepole pine

Alder

Birch

Ash

Sycamore

Beech

Oak
Species mix change...

30 years from now

- Less spruce
- More Scots pine
- Very large (proportional) increase in hardwoods
- But Sitka remains important!
UK-grown timber - potential

<table>
<thead>
<tr>
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</tbody>
</table>

- Actual resource
  - Spruce (Sitka & Norway)
  - Larch (European, hybrid & Japanese)
  - Scots pine (estimate based on existing settings)

- Indications of ~45 year rotation crop
  - Douglas-fir
  - Western hemlock
  - Noble fir
  - Western red cedar

- Indications from limited datasets
  - GS Larch
  - GS Douglas-fir
  - GS Sitka & Norway spruce
  - GS Scots pine

- Actual resource
  - SS Larch
  - SS Douglas-fir
  - SS Sitka & Norway spruce
  - SS Scots pine

- EN 1912
- SS Douglas-fir large dimension PD 6693
British timber myths

- “No good for construction”
- “Because it grows too quickly”
- “Means low density and low strength”

See “rate of growth” & “grade in Britain”
Density and bending strength

Raw data from SIRT benchmarking validation study

R² = 0.1875
Mechanical properties

• Amount of cell wall material
  – Wood density

• How that cell wall material is arranged
  – Grain, earlywood, latewood

• How that cell wall material is made up
  – Cellulose : lignin
  – Microfibril angle
Juvenile core (softwoods)

Microfibril angle

Density

Stiffness, $E$

Also more drying distortion
Factors → softwood quality

- Position within the tree
  - Radially & vertically
- Silviculture
  - Spacing, thinning, rotation length etc
- Site
  - Exposure, temperature, rainfall, soil type etc
- Genetics
  - Species, variety and individual
So what’s next? (1/2)

• Growth areas – and variability
  – Machine grading and visual grading

• Quality shifts
  – During production
  – Since settings were approved
  – Output control is too slow to adjust
  – Also better grading of “good” stands of timber?

• A better way to establish grading?
  – Better for species diversity
So what’s next? (2/2)

• Resource segregation
  – Standing trees, felled logs
  – Opportunities for making it work better
  – Figuring out the consequences for grading

• Tree breeding for better properties?

• Cheaper and more portable grading machines…could mean grading is done by the fabricator…no longer need to use ‘commodity’ strength classes…
Does not necessarily make sense to grade British spruce to C16 and then use it as studs, where bending stiffness is not as important as the strength that is reduced by the C16 strength class definition.
C16+

C16+ is a user defined UK grade for studs. Its primary characteristic values are:

\[ f_{m,k} = 18,5 \text{ N/mm}^2, \quad E_{0,\text{mean}} = 8000 \text{ N/mm}^2, \quad \rho_k = 330 \text{ kg/m}^3 \]

Other characteristic values can be calculated from the equations given in EN 384.

(Strength > C18, and density of C20)
Secondary properties

• The secondary properties in EN338/EN384 are rather conservative
• You are permitted to specify your own values, established by testing
Visual grading

• For large cross-sections, visual grading will result in good yields since the knots are comparatively small
• There is good scope for improving visual grading assignments for home grown timber
• (Although that would require testing work)
Some current projects

• “Alternative” species
  – Including sawmill survey to gather information
• Drought crack in spruce
• Extractives content of UK trees
• British and European grading standards
• Improving resource segregation
• …And early information
• Education and knowledge transfer