Bending properties of tangentially and radially sawn European aspen and silver birch wood after industrial scale thermo-mechanical modification

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Introduction

- Density has a strong positive correlation with mechanical properties
- Average basic density of Finnish hardwood species
  - European aspen (*Populus tremula* L.): 420 kg/m^3
  - Silver birch (*Betula pendula* Roth) : 512 kg/m^3

Compression of wood: basics

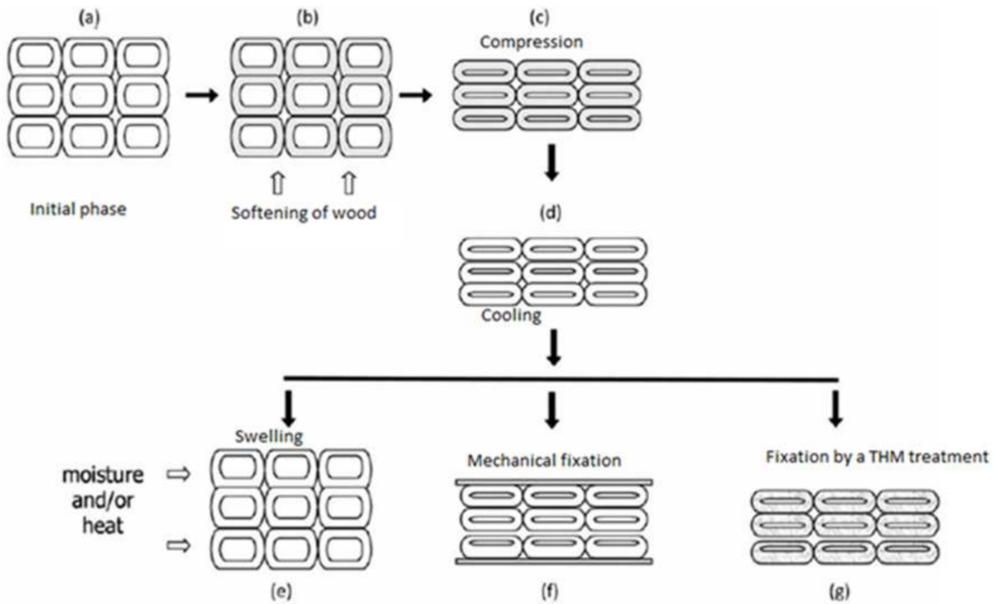
- Density increases as the void volume of lumens decreases
- Viscoelastic behavior
- Softening when heated
- Above glass transition temperature easier compression without rupturing the cell walls

Compression of wood: changes in mechanical properties

- Cellular structure changes either temporarily or permanently
- Effects in general
  - hardness (+)
  - bending strength (+)
  - compression strength (+)
  - shear strength (–)
  - tensile strength (–)

Compression of wood: set recovery

- Tendency to recover to its original shape
- Restricts the use of densified wood in applications with high dimensional accuracy requirements
- One of the emerging methods: *Thermo-Hydro-Mechanical (THM) treatment*



Wood compression and methods of fixation at the cell level. *Figure: Sandberg et al. 2013*

Thermo-mechanical timber modification (TMTM™)

- Developed and commercialized by Nextimber Ltd, Finland
- Processing of sawn timber in a single treatment unit
  - Drying
  - Compression
  - Thermal modification
- The objective of this study: effect of TMTM™ modification on
  - modulus of elasticity (MOE)
  - modulus of rupture (MOR)

  in European aspen and silver birch wood.

Experimental

- Aspen (*Populus tremula* L) boards (in total 112)
  - 79 tangentially sawn
  - 33 radially sawn
- Silver birch (*Betula pendula* Roth.) boards (in total 104)
  - 73 tangentially sawn
  - 31 radially sawn

Process

- Temperature up to 100 °C in 3 hours
- Stabilization (MC: 30%)
- Below the 30% MC, temp up to 130 °C
- The target degree of compression (relative thickness decrease)
  - 30% for European aspen
  - 10% for Silver birch
- Half of the material: thermal modification at 190 °C after drying and compression
- Whole process: 52 h including thermal modification

A set of boards (40 × 100 × 2,700 mm³) before and after the modification.
Figures: Nextimber Ltd.

Batches

Species	N, tangential	N, radial	N, total	Initial moisture in compression	Target degree of compression	Thermal modification
Aspen	19	9	28	Green	30%	–
Aspen	20	8	28	Green	30%	**3 h at 190°C**
Aspen	20	8	28	20 % MC	30%	–
Aspen	20	8	28	20 % MC	30%	**3 h at 190°C**
Aspen[a]	20	8	28	–	–	–
Birch	20	8	28	Green	10%	–
Birch	20	8	28	Green	10%	**3 h at 190°C**
Birch	16	8	24	20 % MC	10%	–
Birch	17	7	24	20 % MC	10%	**3 h at 190°C**
Birch[a]	5	7	12	–	–	–

Tangential G

Radial, G

Tangential, MC20

Radial, MC20

Tangential G

Tangential, G+TM

Radial, MC20

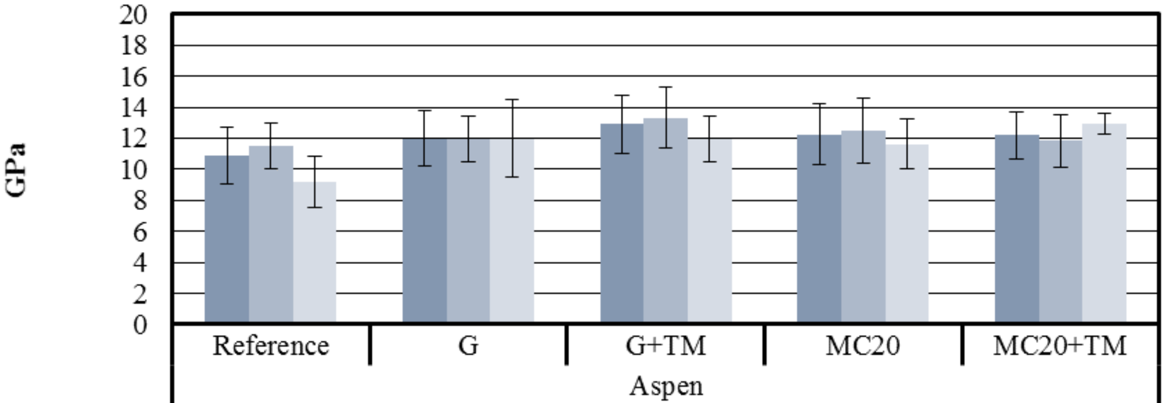
Radial, MC20+TM

Examples of the cross-section of aspen (left) and birch (right) board, with 30% and 10% target degree of compression, respectively.
Figure: Veikko Möttönen

Determining MOE and MOR

- MOE: Static four-point bending test method ISO 3349 (1975)
  - With an exception with aspen
- MOR: Static three-point bending test method ISO 3133 (1975)
- Clearwood specimens: 20×20×340 mm^3
- Specimens in tangential and radial direction in order to determine differences between sawing patterns
- Combining the groups in analysis (G, G+TM; MC20, MC20 + TM; G, MC20; G+TM, MC20+TM)

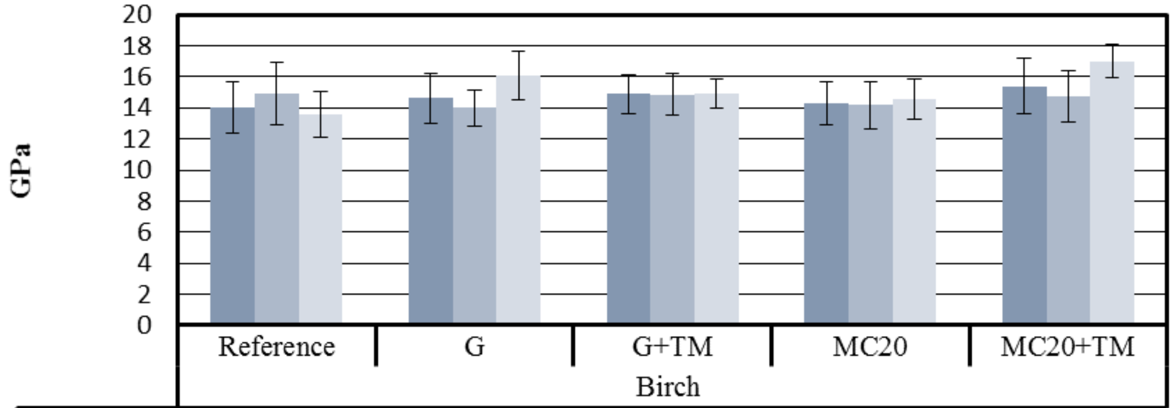
Results: MOE of European aspen wood



	Reference	G	G+TM	MC20	MC20+TM
Average	10,9	12,0	12,9	12,3	12,2
Tangential	11,5	12,0	13,3	12,5	11,8
Radial	9,2	12,0	12,0	11,6	12,9

- Significant difference between tangential and radial grain directions was observed only in reference group (***)
- Compression increases MOE and equalizes the differences in MOE related to grain direction in all treatments

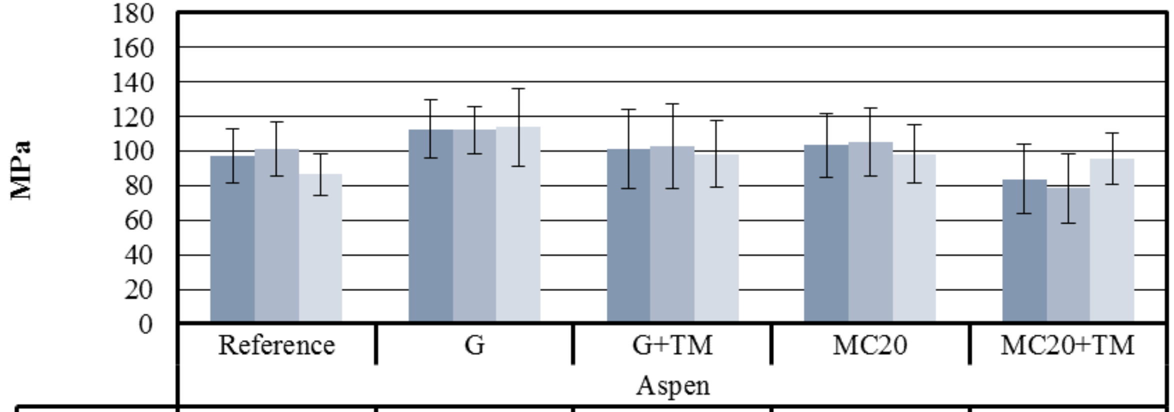
Results: MOE of Silver birch wood



	Reference	G	G+TM	MC20	MC20+TM
Average	14,0	14,6	14,9	14,3	15,4
Tangential	14,9	14,0	14,9	14,2	14,7
Radial	13,6	16,1	14,9	14,6	17,0

- Sig. differences in MOE between thermal and non-thermal treatments (*)
- Sig. differences in MOE in all combined treatment groups between grain directions
- MOE increased especially in radial direction as a result of modification

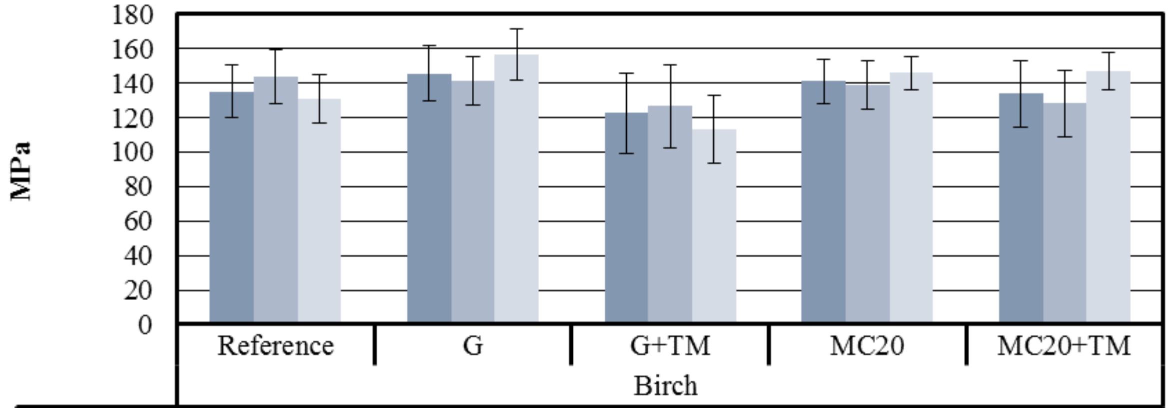
Results: MOR of European aspen wood



	Reference	G	G+TM	MC20	MC20+TM
Average	97,3	112,7	101,3	103,3	83,9
Tangential	101,1	112,3	102,8	105,4	78,5
Radial	86,7	113,7	98,2	98,2	95,9

- Significant differences between green and 20% initial moisture contents (**) and between non-thermal and thermal treatments (***)
- Compression at green state increases and thermal treatment decreases MOR on aspen wood
- No sig. differences between tangential and radial direction in any group

Results: MOR of Silver birch



	Reference	G	G+TM	MC20	MC20+TM
Average	135,3	145,7	122,8	141,1	133,8
Tangential	144,0	141,3	126,6	138,7	128,4
Radial	131,0	156,9	113,4	146,0	146,9

- Sig. difference between non-thermally and thermally treated groups (***)
- Thermal treatment clearly reduces MOR
- A difference between grain directions in the treatments with initial moisture of 20% MC (**) and in non-thermal treatments (**)

Discussion

- Compression compensates loss of mechanical properties caused by thermal degradation especially in case of aspen.
- MOE and MOR of the compressed and thermally modified aspen were clearly lower than those of birch.
- Standard deviation in MOE and MOR was lower in birch specimens

Discussion

- Likely compression took place mostly in lumens of earlywood. Improving the mechanical properties in greater extent would need the compression of latewood, as well.
- For birch, modification increased MOE and MOR more in radial direction.
- Possible reason: equal densification of both early wood and latewood layer during compression in birch?

CONCLUSIONS

- In general, MOE increases and MOR decreases in the TMTM[TM] modification process
- Joint effect of initial moisture content, compression, thermal modification and species-specific mechanical properties are complex
- Effect of grain orientation on MOE and MOR in birch and aspen were divergent

CONCLUSIONS

- Compression as a part of the TMTM™ method is a potential method to compensate the decreased strength of wood caused by thermal modification especially in aspen
- Combined compression and thermal treatment can improve strength properties of wood while improving other mechanical properties such as hardness and dimensional stability

Thank you!

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