Impact of thermal treatment on moisture-dependent elasto-plastic behaviour of beech

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Introduction

- **Thermally processing of wood** is recognized as **eco-friendly** technique without the use of chemical additives.

- Thermally modified wood is now an established form of modified wood product. It is observed that **dimensional stability and natural durability** are improved by increasing treatment temperature and processing time. Nevertheless, some **mechanical properties** such as toughness, strength and stiffness may decrease to an unacceptable level during treatment.

Introduction

- **Use of thermally treated (TT) wood for construction applications???**
  - **Outdoors,**
  - **harsh environment (cycling of humidity and temperature)**
- European market has till now only standardized quality control of innate / natural sawn wood (visual and mechanical CE grading). **Mechanical properties of TT wood in relation to moisture content are less researched.**

Research objectives and material

Objectives:

- To examine the impact of heat treatment on mechanical properties of wood at compressive loading under various humidity conditions.

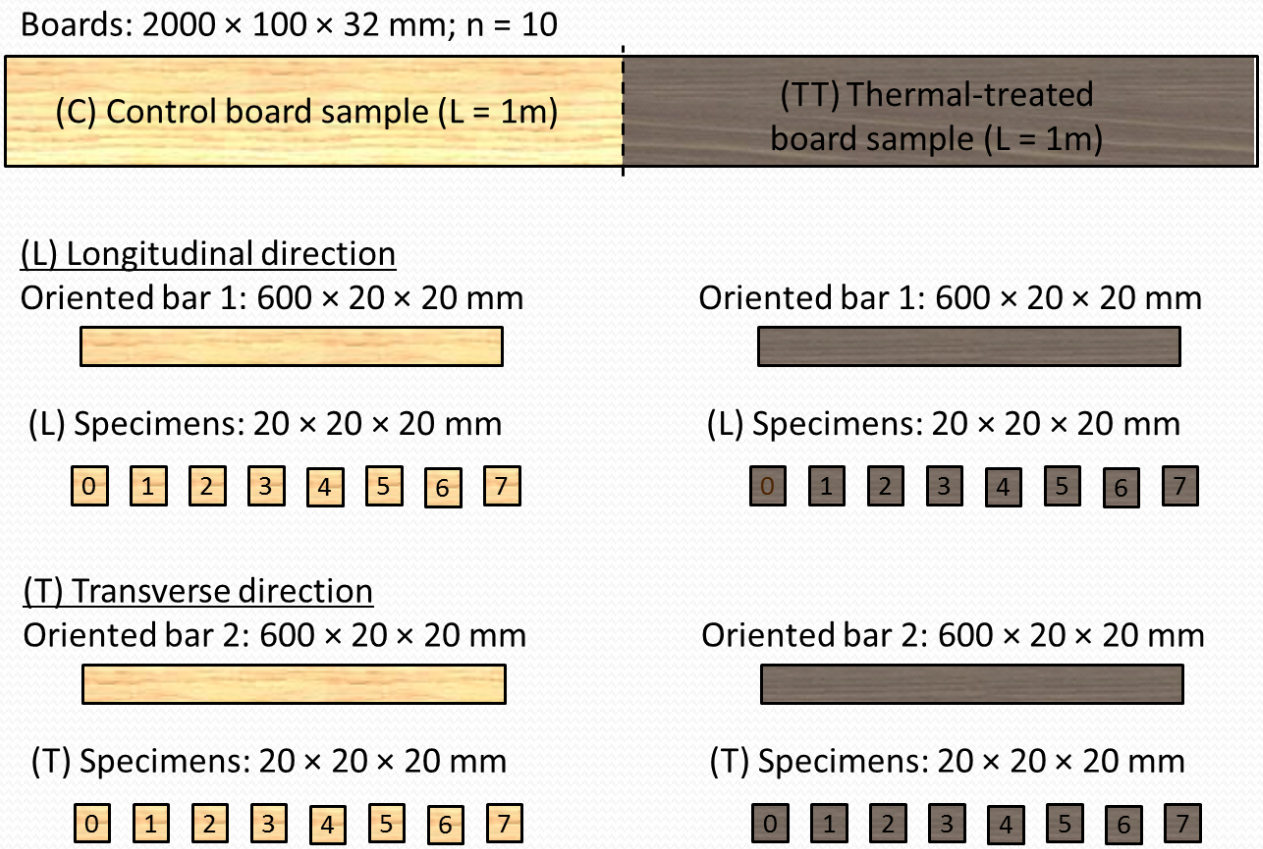
Material:

- Innate and industrially heat treated beech wood (*Fagus sylvatica* L.) in unsaturated steam conditions (up to 200 °C; t = 4 h)
- Raw wood specimens: 25 × 80 × 800 mm

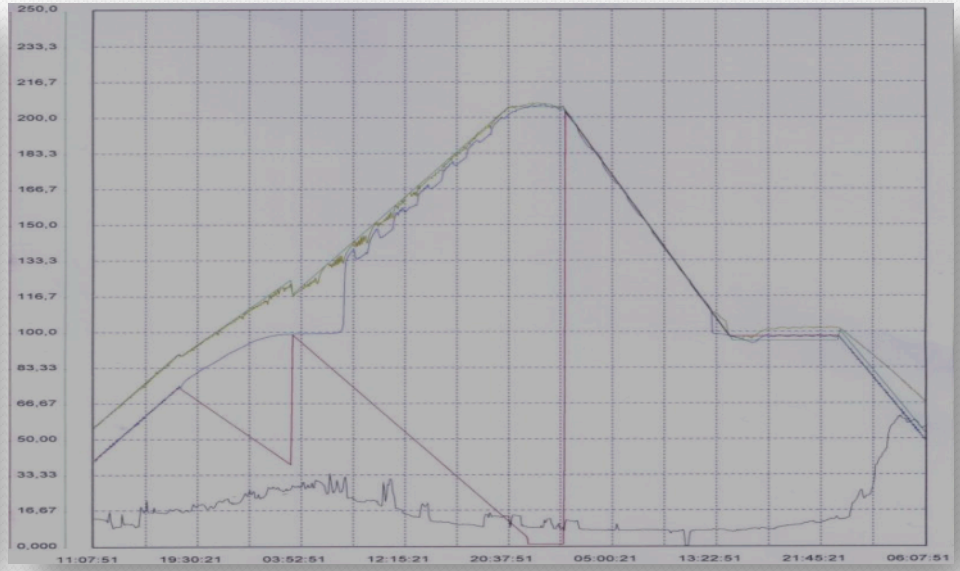
Methods

Sampling and conditioning

- Parallel sampling (two of each in L- and T-direction):



Thermal treatment



- Unsaturated steam atmosphere including pre-drying, heating, cooling and conditioning) (t = 64 h);
  - Heating / Cooling rate: 5 °C/h,
  - Ultimate HT phase: T = 200 °C, t = 4 h.
  - Post “treatment” phase: T = 20 °C, RH = 65%, t = 4 h

Methods

Sampling and conditioning

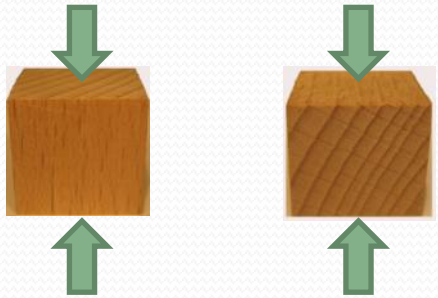
- Thermostatic conditioning chambers with saturated salt solutions (T = 20 °C).

Climate	Medium	RH [%]
0	Vacuum drier (50°C / 2 hPa)	0
1	HCOOK	20
2	$MgCl_2$	33
3	K_2CO_3	44
4	$NaNO_2$	65
5	NaCl	75
6	$ZnSO_4$	87
7	Distilled water	97

Methods

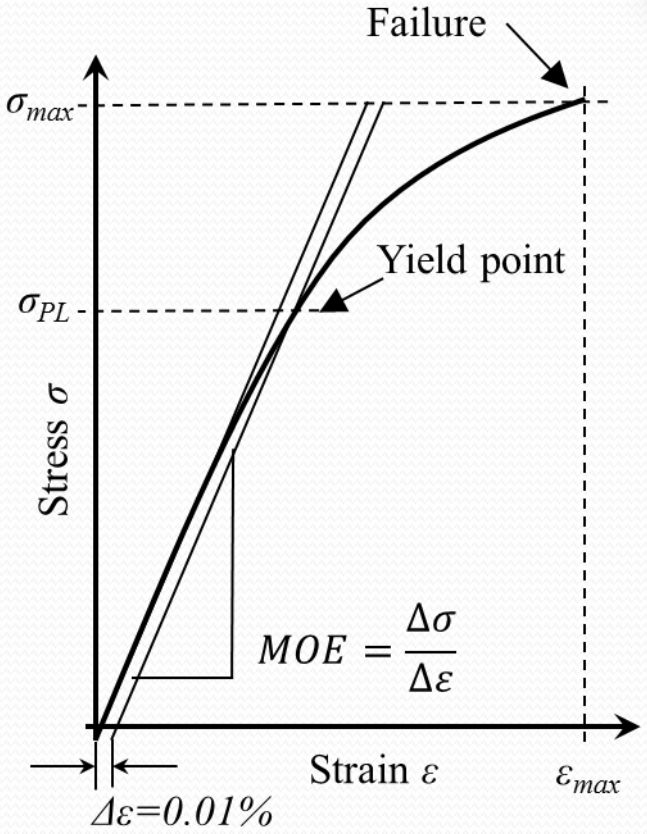
Static mechanical compression test (DIN 52185)

- Longitudinal (L) and transverse to the grain direction (T):



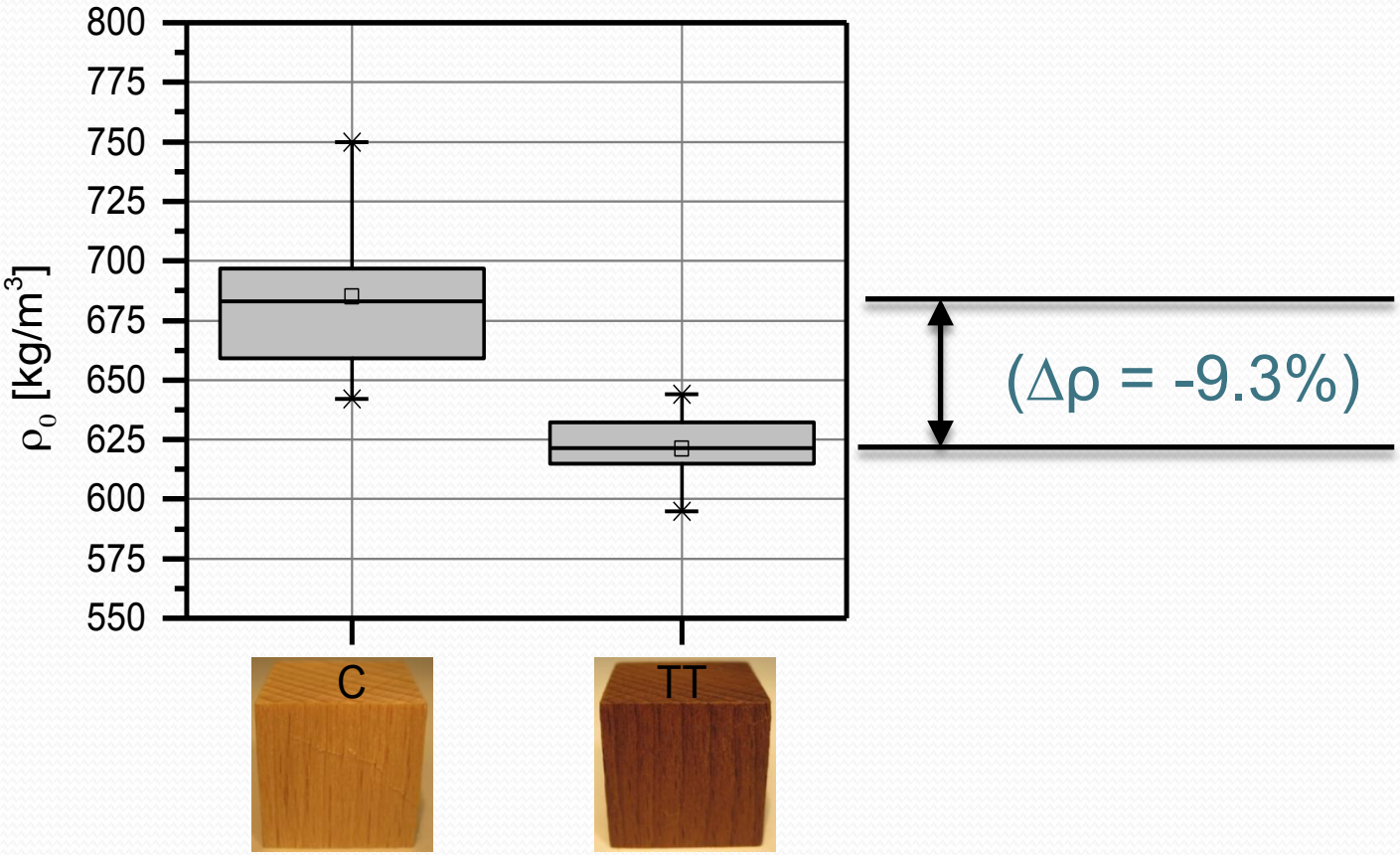
L-direction T-direction

Zwick Z100



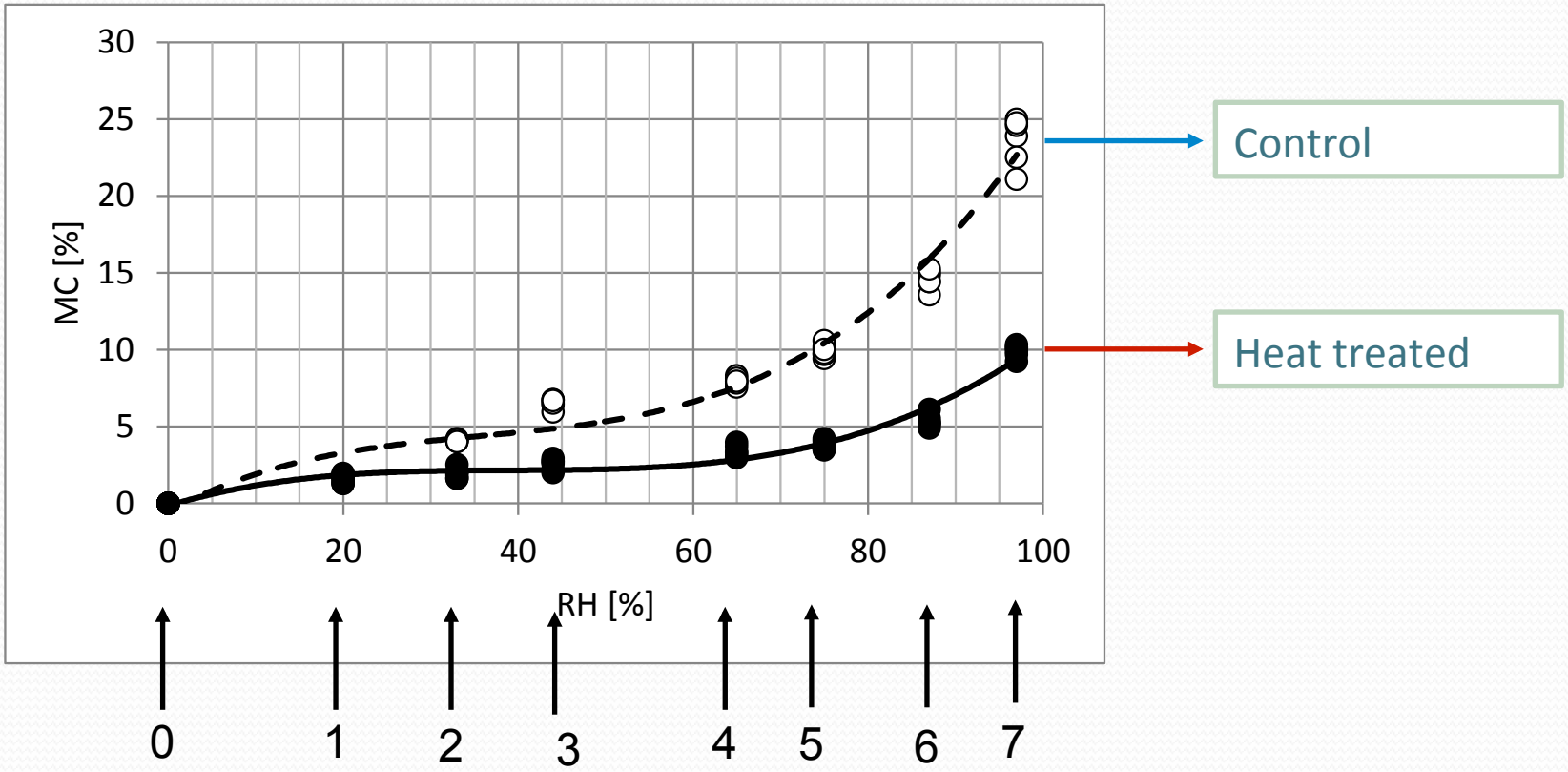
- **Determined mechanical properties:**
  - Modulus of elasticity (MOE)
  - Ultimate strength (σ_{max})
  - Proportional limit stress (σ_{PL}) "offset yield method at 0.01% plastic strain"

Results: Density / mass loss



- Significant decrease of wood density after thermal treatment.

Results: Sorption properties (EMC)

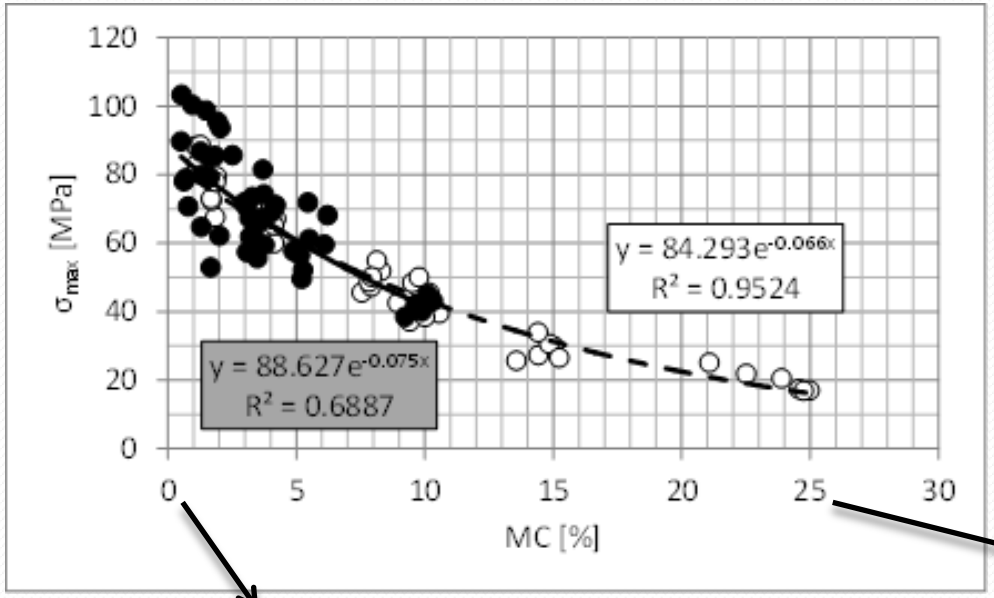


Tested equilibrium moisture content states

- Significant reduction of hygroscopicity of wood after thermal treatment, greater in upper hygroscopic range.

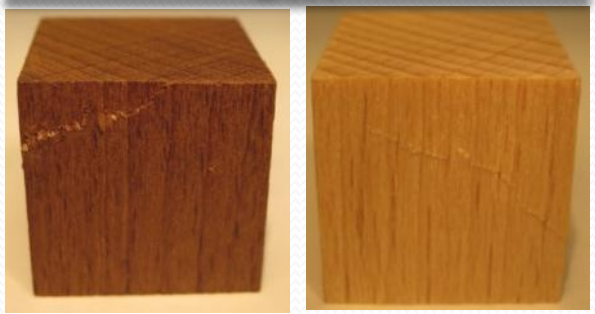
Results: Ultimate strength

- **Longitudinal direction:**



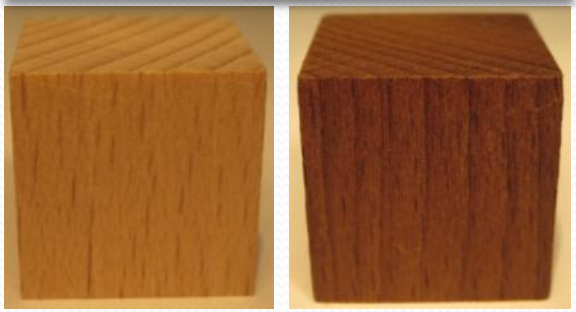
innate (○)
thermal-treated (●)

DRY



- **Brittle**
- **Brittle**

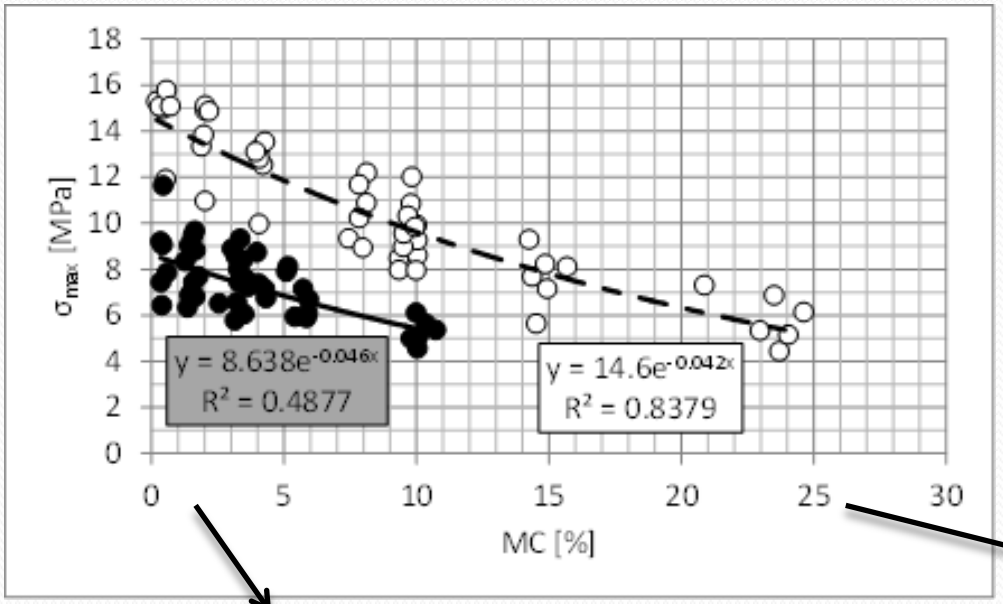
WET



- **Brittle**
- **Brittle**

Results: Ultimate strength

- **Transverse direction:**



innate (○)
thermal-treated (●)

DRY

- **Ductile**

- **Brittle**

WET

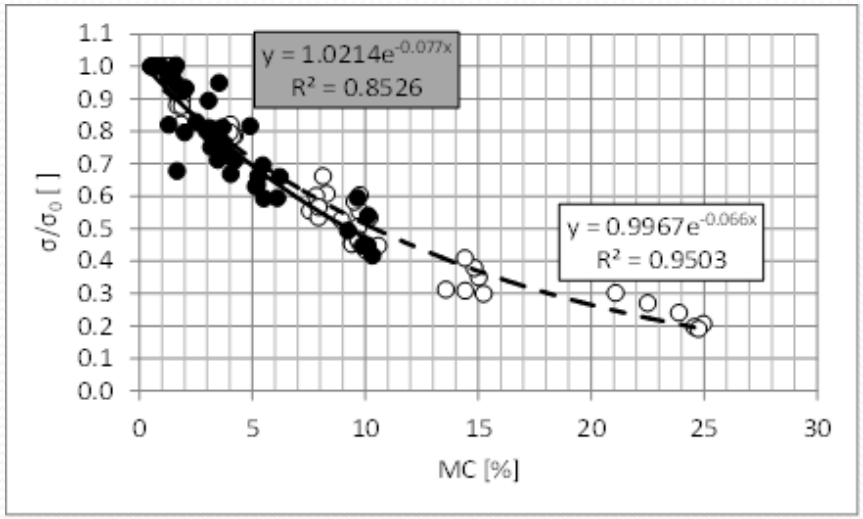
- **Ductile**

- **Brittle**

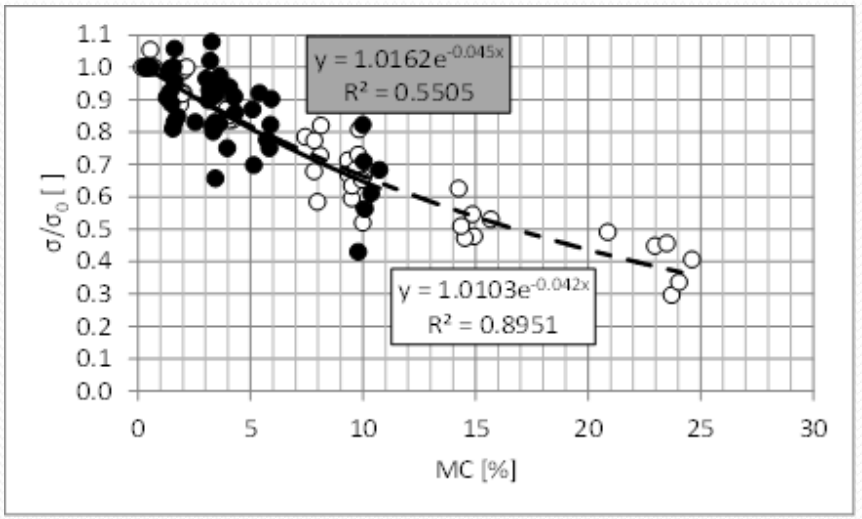
Results: Ultimate strength – relative scale

- σ/σ_0 - ratio between strength at single moisture content (σ) and strength at absolute dry condition (σ_0)

- **L-direction**



- **T-direction**

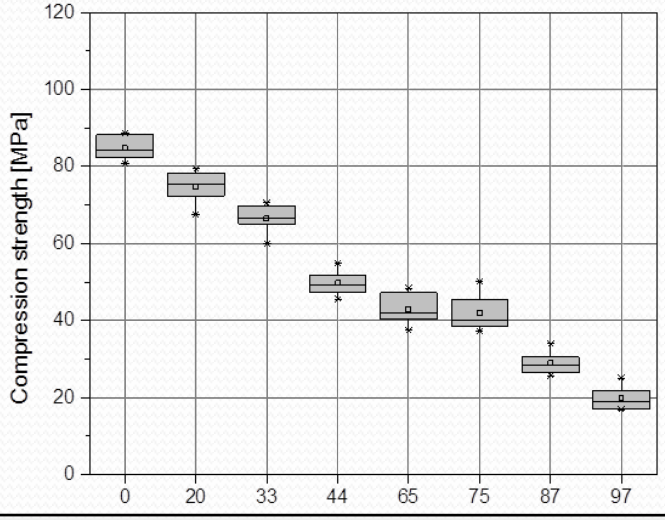


- Greater reduction of ultimate strength is present in longitudinal wood direction,
- no difference between C- and HT-samples.

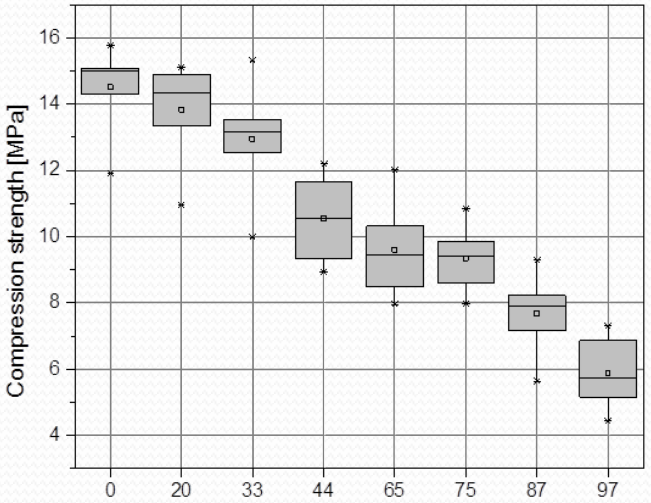
Results: Ultimate strength – humidity perspective

INNATE

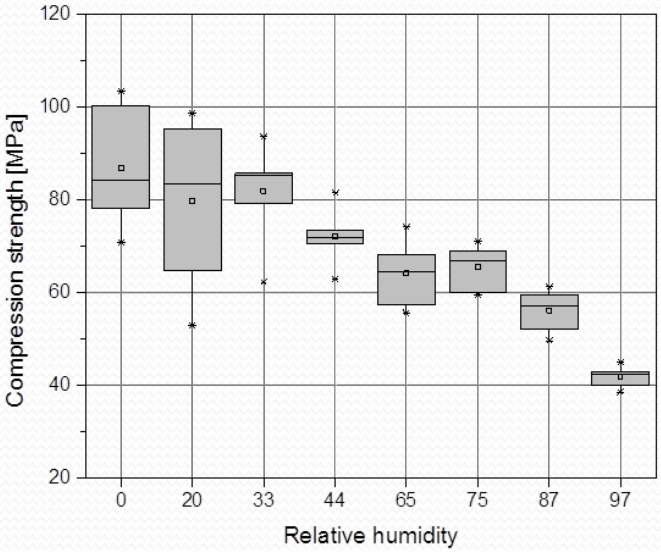
- L-direction

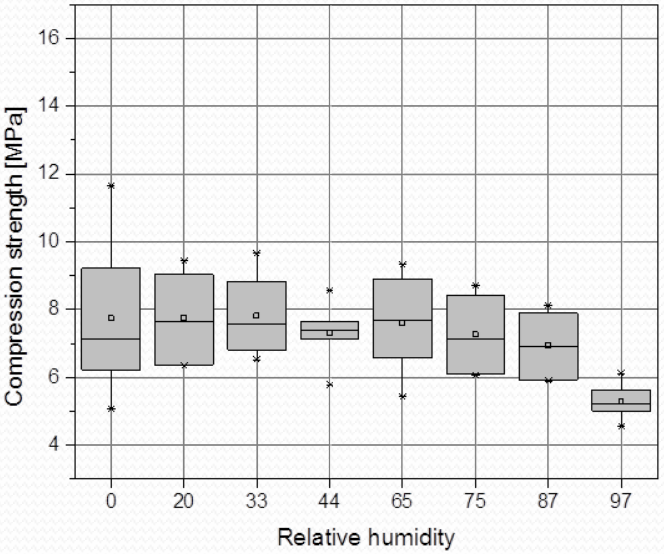


- T-direction



THERMALLY TREATED

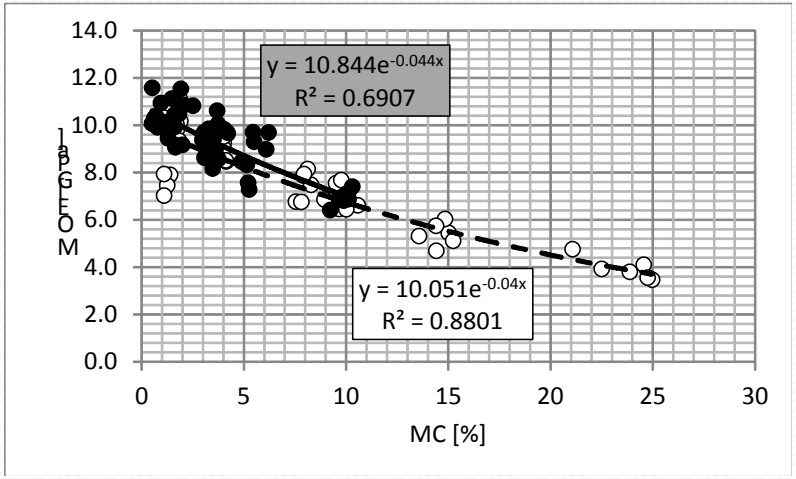




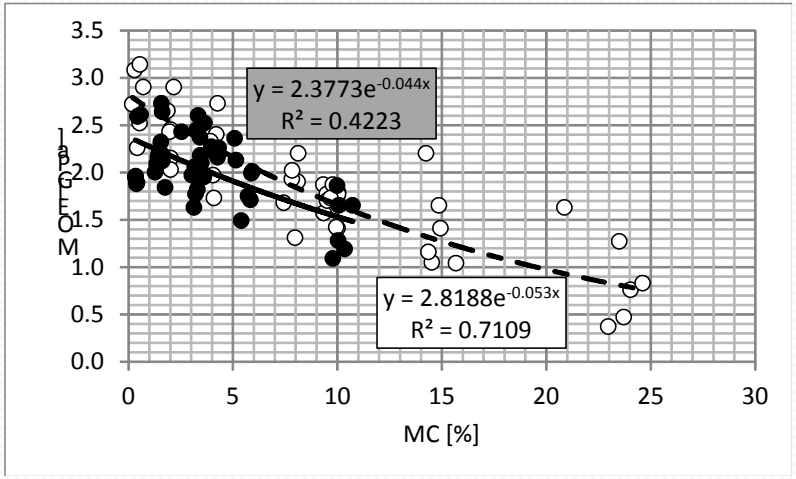
Results: Modulus of elasticity

innate (○)
thermal-treated (●)

- **L-direction**



- **T-direction**

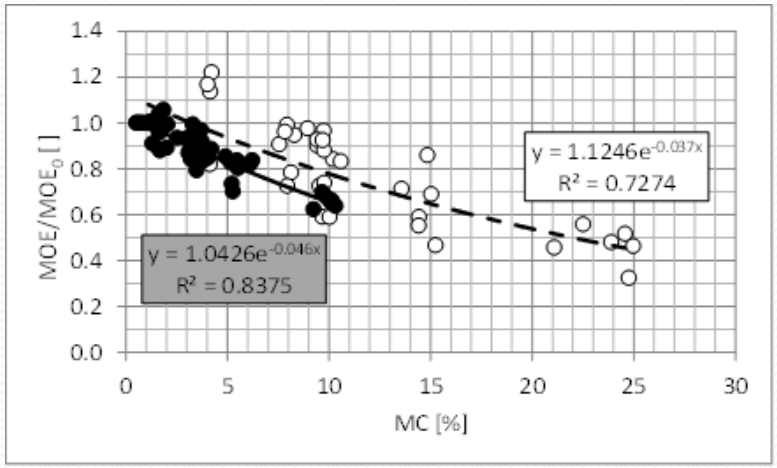


- Unchanged stiffness-moisture relation in L-direction,
- Slight reduction of stiffness in T-direction after thermal treatment.

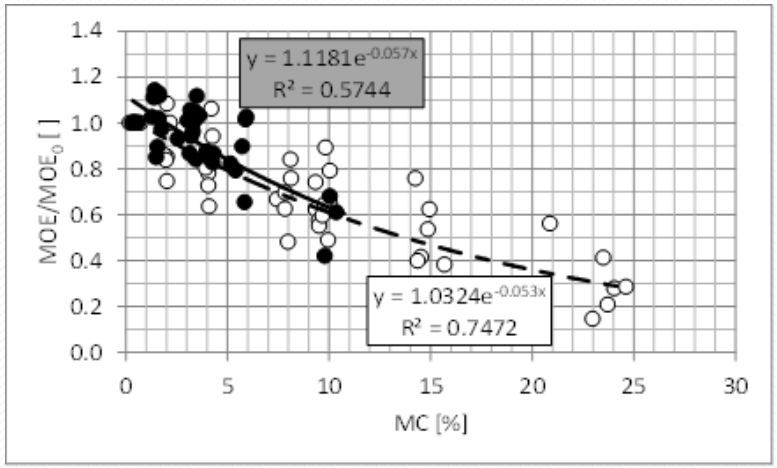
Results: Modulus of elasticity – relative scale

- MOE/MOE$_0$ - ratio between strength at single moisture content (σ) and strength at absolute dry condition (σ_0)

- **L-direction**



- **T-direction**

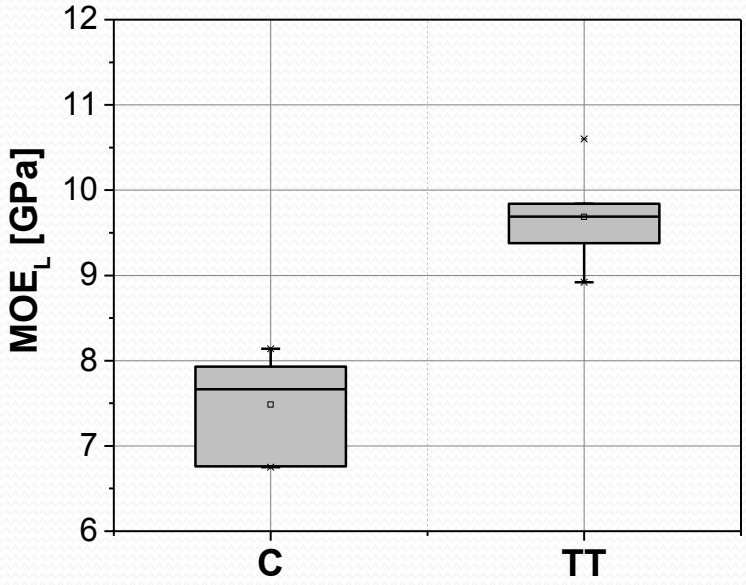


- The relative reduction of stiffness with increase of wood moisture content remains unchanged after the thermal treatment.

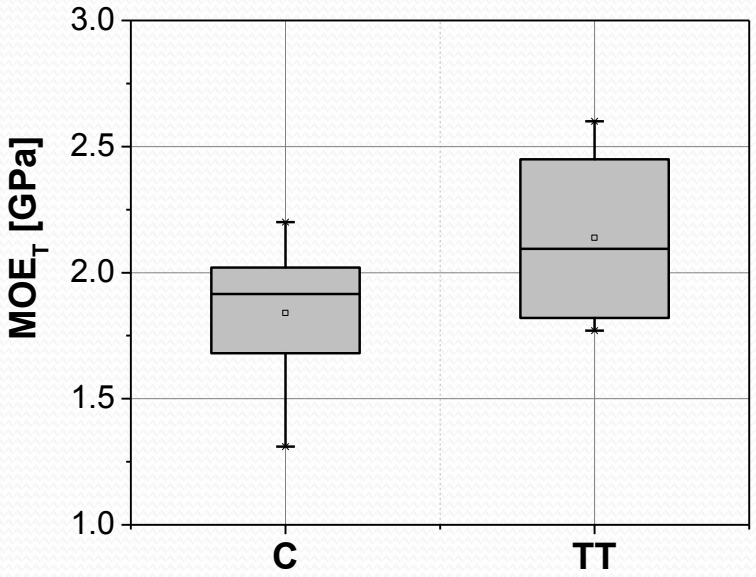
Results: Modulus of elasticity – humidity perspective

Comparison of stiffness at normal climate (T = 20 °C; RH = 65 %)

- L-direction



- T-direction

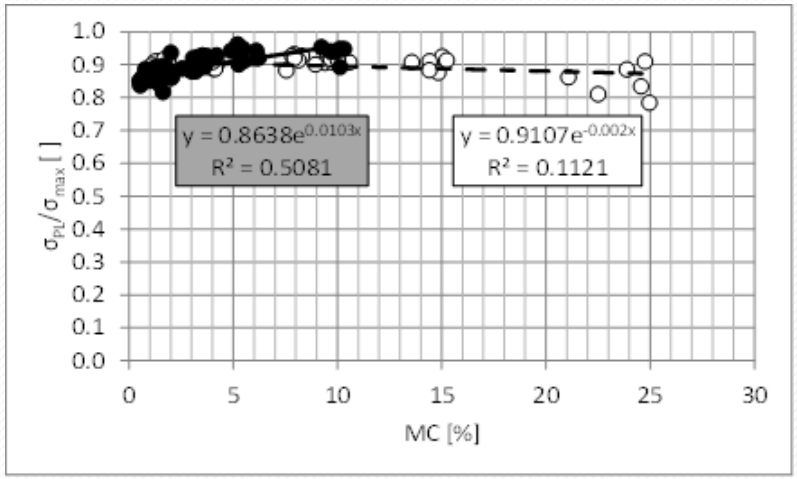


- Apparent (“fictive”) increase of stiffness of wood after thermal treatment.

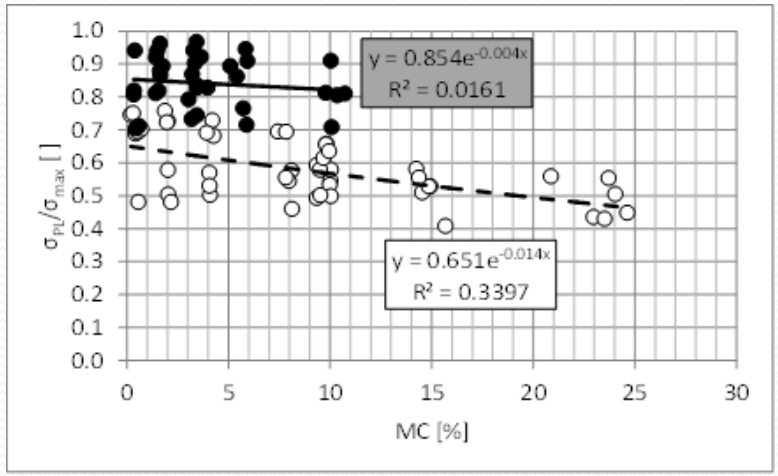
Results: Proportional limit stress

- σ_{PL}/σ_{max} - ratio between proportional limit stress (σ_{PL}) and ultimate strength (σ_{max}) of single specimen

- **L-direction**



- **T-direction**



Concluding remarks

- Heat treatment significantly impacts ultimate strength, stiffness and elasto-plastic properties of wood (proportional limit stress).

- The mechanical response of wood in relation to the present moisture content (EMC) remains mostly unchanged after the treatment
  - Relative change of ultimate strength and modulus of elasticity in relation to the moisture of wood is unchanged,

- The wood structure is more brittle after the thermal treatment (the lost of visco-elastic character was confirmed in transverse wood direction).