H_2O and biomaterials

COST Action FP1407 Training School

4th April 2017
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BC Materials

INNOVATION IN BIO-MATERIALS FOR INDUSTRY

What happens when wood gets wet?

- The wet state is wood's natural state
- Trees are designed for fluid flow by capillary action
- Wetting reverses **some** of the processes which occurred when the wood originally dried out
- Water is adsorbed to sites on the surface, and inside the wood cell wall

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What happens when wood gets wet?

- Original drying caused the wood to contract from its native state
- Adsorption of water onto hydroxyl groups within hemicellulose re-opens micro-voids
- This can happen by two routes: wetting by liquid water & by water vapour

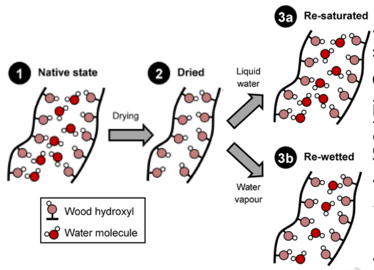

Image: Thybring et al. (2017) Cellulose

doi:10.1007/s10570-017-1278-x

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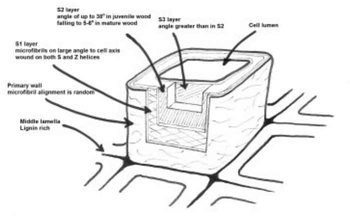
What happens when wood gets wet?

- Swelling in the regions between microfibrils causes a net swelling of the whole piece of wood



- Tangential > Radial > > Longitudinal

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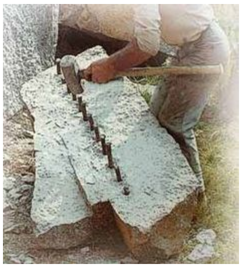
Water adsorption = power



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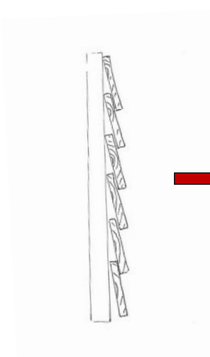
Water uptake – grain orientation



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Changing the relationship of wood and water

- Wood modification and surface treatments can change this

(Tingaut et al., 2005)

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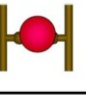
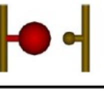
Wood modification - reminder

Lumen filling	Cell wall filling	Cross linking - internal	Cross linking	Reaction with wood polymers	Degradation of cell wall
					

Ormondroyd G, Spear M, Curling S (2015) Proceedings of ICE: Construction and Materials 168(4):187-203

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Wood modification

Modification method	Commercial	Principle
Heat treatment	X	
Acetylation (Accoya)	X	
Melamine resin	(X)	
DMDHEU (Belmadur)	X	
Furfurylation(Kebony)	X	
Silicone/Silane	(X)	
oil / wax/ parafins	X	

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How do we measure the benefit?

Altering the hemicellulose composition (thermal mod.)

Blocking the hydroxyl groups (acetylation)

- Soaking to observe swelling
- Anti-swelling efficiency (ASE)
- Conditioning experiments at elevated humidity
- Equilibrium moisture content (EMC)

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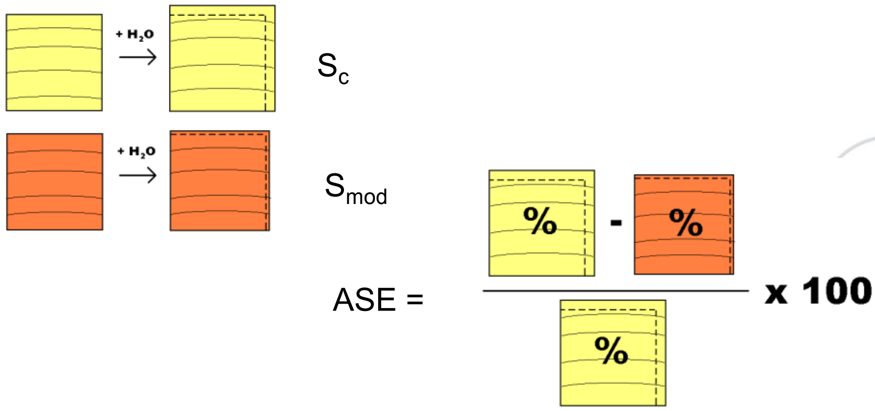
Swelling coefficient and ASE



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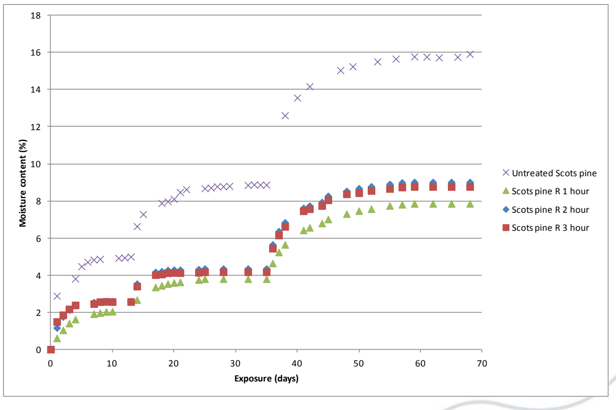
Conditioning study – oil heat treated wood

Spear et al. 2012 ECOWOOD



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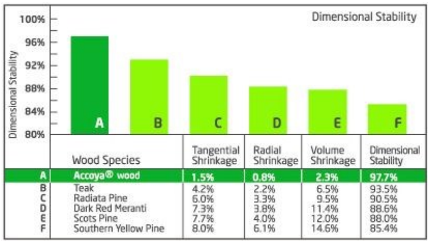
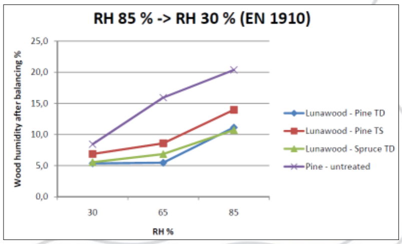
What can we achieve?

	Accoya	Kebony	Belmadur	Thermowood
ASE	70-80%	40-60%	60%	Up to 90%
EMC (20°C 65% r.h.)	3.3%	0.1%	7.8%	6 to 8%





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Dimensional stability changes with species

- Just as moisture movement relates to wood anatomy
- The inhibition of moisture movement on thermal treatment does also
- Restriction of movement in tangential direction is generally greater than radial

	ASE_r	ASE_t
Beech	10	13
Birch	13	23
Spruce	11	40
Scots pine	33	41
Radiata pine	35	40

Tjeerdsma B. (1998) IRG/WP 98-40124

Militz H. (2002) IRG/WP 02-40241

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Equilibrium moisture content on conditioning

- Uptake of water vapour in salt talks
- Oil heat treated wood

	33% rh	58% rh	90% rh
UT pine	4.99	8.87	15.92
1 hour	2.05	3.80	7.86
2 hour	2.59	4.35	9.01
3 hour	2.57	4.17	8.77
ASE 1h	47.43	50.57	34.79
ASE 2h	49.13	58.21	34.83
ASE 3h	40.33	54.80	33.72

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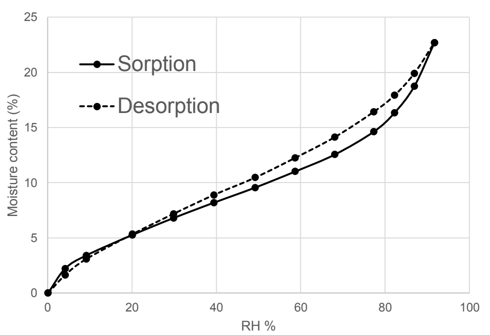
Typical isotherm of wood



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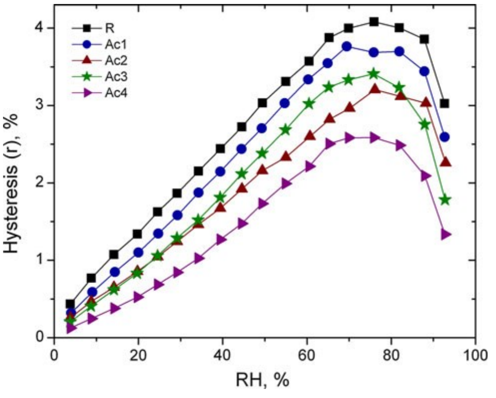

At 0, 3, 7, 10 and 16% WPG

From Popescu et al (2014) J Mat Sci 49

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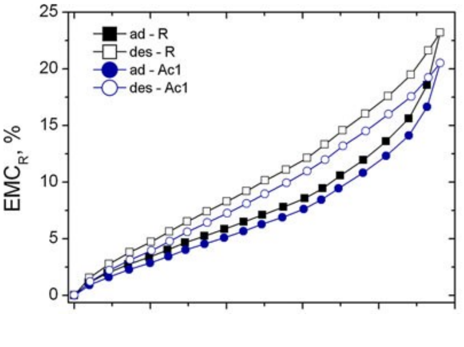

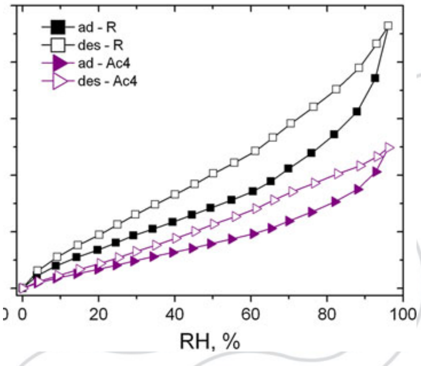

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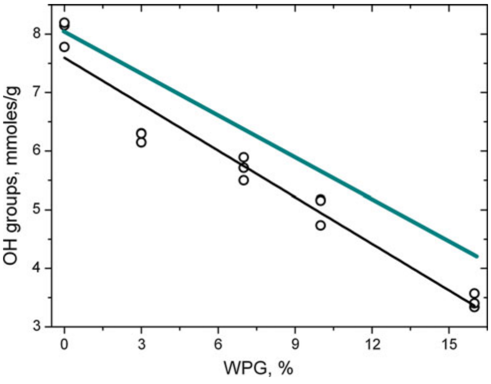

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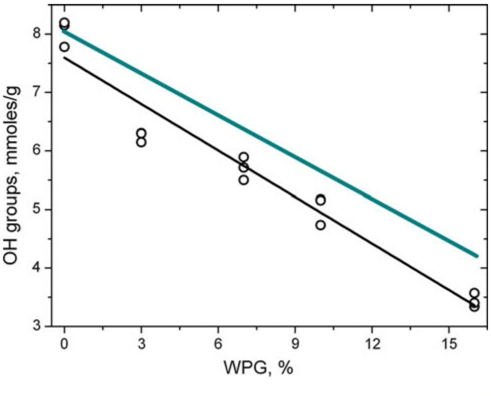
Associated hydroxyl groups with WPG



- Determined by deuteration

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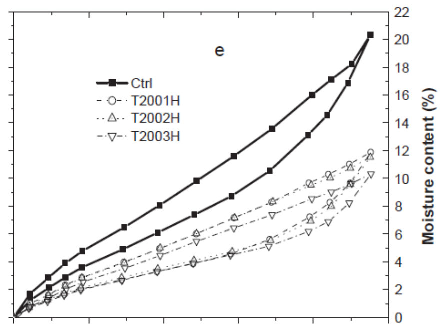
Effect of thermal modification on Sessendok



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How much water will the wood be exposed to?

Use class	Conditions	Wood moisture content
1	Interior, dry	Under 20%
2	Interior, occasional wetting or humidity	Occasionally above 20%
3.1	Exterior, above ground, covered	Frequently above 20%
3.2	Exterior, above ground, exposed to weather and frequent wetting	Frequently above 20%
4	Exterior, ground contact	Permanently above 20%
5	Marine or fresh water	Permanently above 20%

Use classes according to BS EN 335:2013

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Water uptake and retention

- Study on plywood moisture content in outdoor exposure by Li et al. (2016) European Journal of Wood and Wood Products 74: 211- 221
- Average moisture content correlates well with rainfall
- Ply 2 shows peak moisture content which coincides with solar irradiation

[redacted]

[redacted]

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Time of wetting data

- Days with MC higher than 20%

[redacted]

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Predicting duration above 20% m.c.

- Long running research by Brischke and co-workers stared with double layer test – at sites across Europe
- Temperature and m.c. measured within the wood
- Moisture content can be related to relative humidity (u_{Φ})
- And related to rainfall events (u_r)
- For the proposed model

$$u_{\phi} = 0.7\phi^3 - 0.8\phi^2 + 0.42\phi + 0.0077$$

$$u_r t_i = u_{\phi} t_i \, [1+k_r]$$

- where k_r is a factor for species and rainfall duration

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Mapping decay potential

- Decay potential, as mapped by Hansson et al. (2012) WCTE Auckland, New Zealand, Timber Engineering Challenges and Solutions, pp. 295-303
- Values are relative to the decay potential at Uppsala, Sweden
- For this model k_r of 0.8 was used, but different species interact differently with moisture

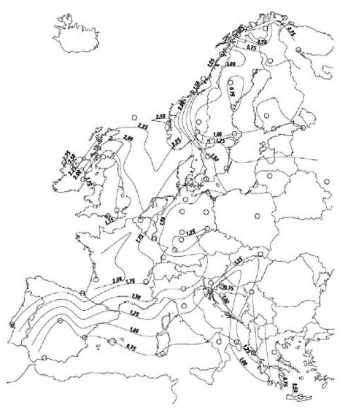

Figure 1: *Example of relative decay potential for Europe indicated as relative doses for 60 European sites (circles) calculated with a performance model based on data from Meteonorm and ECA & D. Relative dose compared to Uppsala, Sweden.*