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Mechanical Properties of the Chemically Modified Wood

Yanjun Xie

Qiliang Fu

Qingwen Wang

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Northeast Forestry University

東北林業大學
Northeast Forestry University

26 Hexing Road, Harbin, 150040

Structure

- Introduction: Why modify the wood? Why concern about mechanical properties?
- Review the current modification techniques and effects on the mechanical properties of wood
- Summary

Introduction: why modify wood?

From Westin, M., et al.
SP, Sweden

- Hygroscopic
- Dimensional deformation
- Develop cracks
- Weathering and fungal decay
- Insect and borer damage

Chemical modification is an alternative strategy for wood protection !

Dr. Roger Rowell (FPL, US)

Target of chemical modification

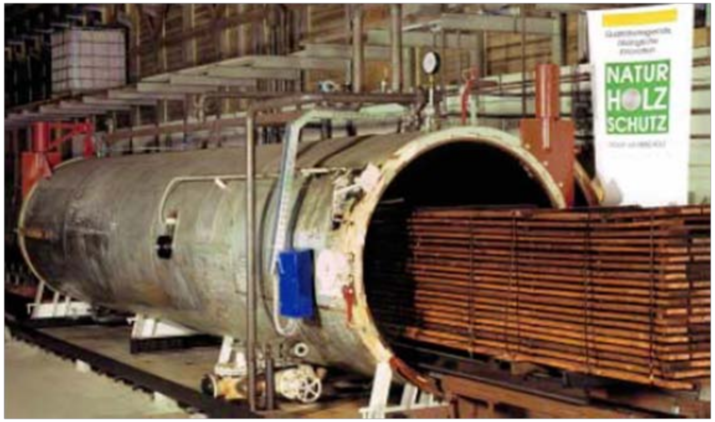
- Dimensional stability: ASE, Bulking
- Durability: white-, brown-, and soft-rot
- Resistance against weathering deterioration
- Resistance against insect···

⇨ **Mechanical properties?**
Mechanical properties is crucial for wood as a construction material!

1. Heat treatment

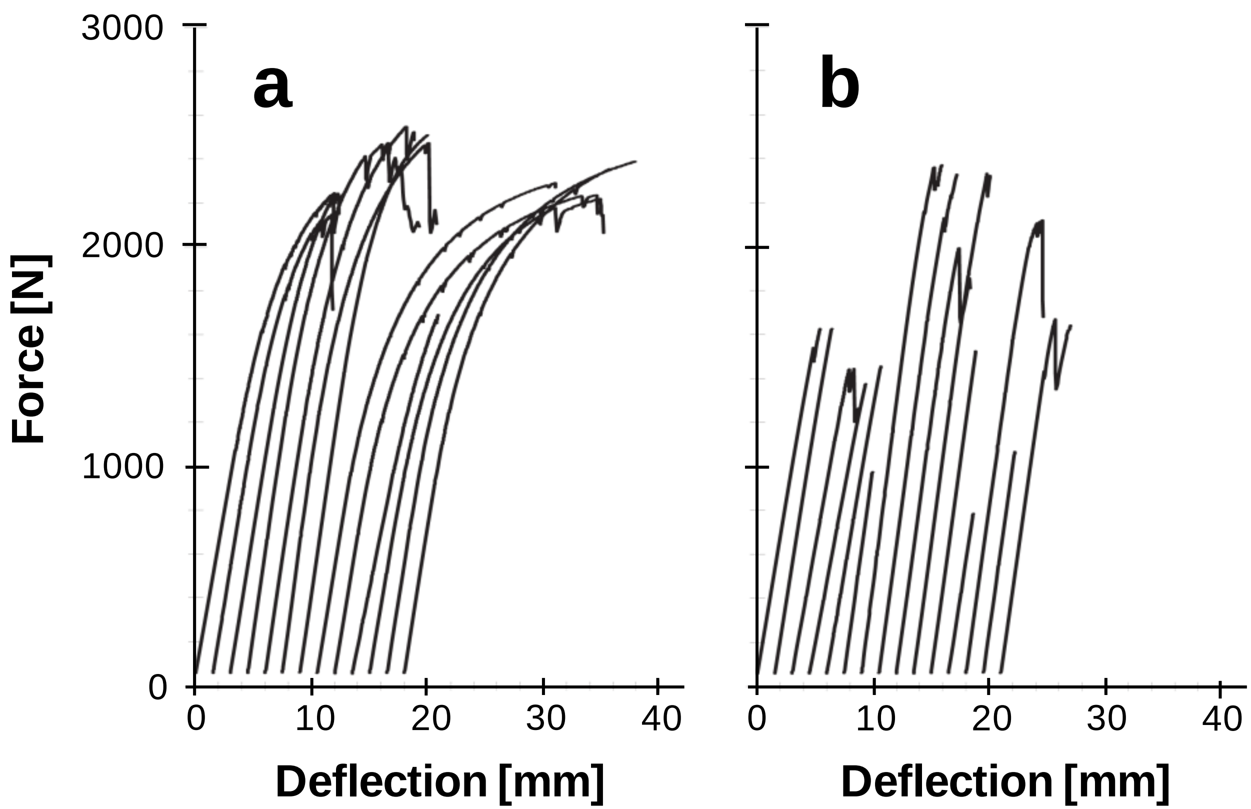
Using different shield media:

- **Water vapour:** Low cost, controllable, easy operation; but hydrolysis and oxidation, dark colour, Severe reduction in mechanical properties.
- **Natural oil (caster oil)**: good thermal conductivity, cutting off air, but difficult to coat, high cost.
- **Inert gas (nitrogen):** extinguish oxidation, costly, difficult operation.



Rapp and sailer, 2002

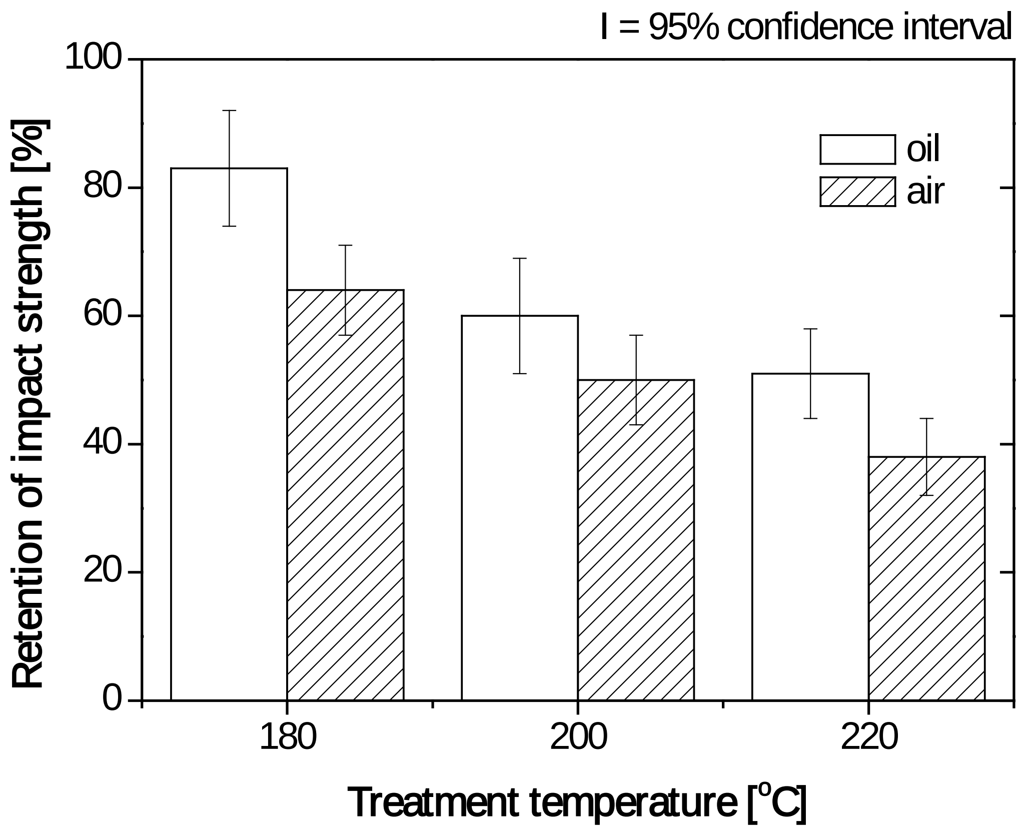
Heat treated wood



Load-deflection curves of beech specimens (a) untreated and (b) treated at 220 °C for 4 h. (Adapted from Arnold 2010).

Less tough, lower fractural force

Heat treated wood



Effect of **temperature** and **shield media** on the impact bending strength of wood. (Adapted from Rapp and Sailer 2000).

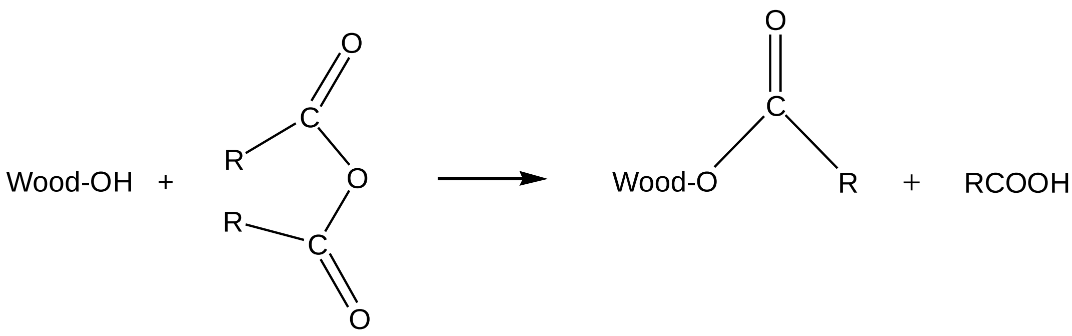
Reduction in impact strength

Heat treated wood

Wood species	Media	Temperature /duration (° C/h)	Moisture content at 20° C, 65% r.h. (%)		Change in mechanical properties based on untreated controls (%)			References
			untreated	treated	Static bending		Impact bending	
					MOE	MOR		
Pine	steam	210/6	12.6	4.5	-40	-5	--	Esteves 2007
Eucalypt			10.5	2.8	-50	-15		
Pine	$Moist/N_2$	Two stage treatment	--	--	--	-3	--	Tjeerdsma 1998
Beech						-20		
Pine	linseed oil	220/4.5	--	--	NC	-30	-49	Rapp 2000
Beech	Gas exclude O_2	220/4	11.3	4.9	11	-26	--	Arnold 2010
Spruce			12.2	5.3	10	-19		
Softwood	--	212/-	13.5	6	--	-15	--	Mayes 2002
Hardwood		200/-	10.5	6		-20		
Birch	Humid inert gas (N_2+CO_2)	230/-	--	--	-7	-43	--	Poncsák 2006
Pine	air	180/10	--	--	-32	-33	-42	Korkut 2008
Spruce	--	212/3	--	2-3	-14	-49	--	Shi 2007
Aspen		212/3			+15	-35		
Birch		200/3			+30	+6		

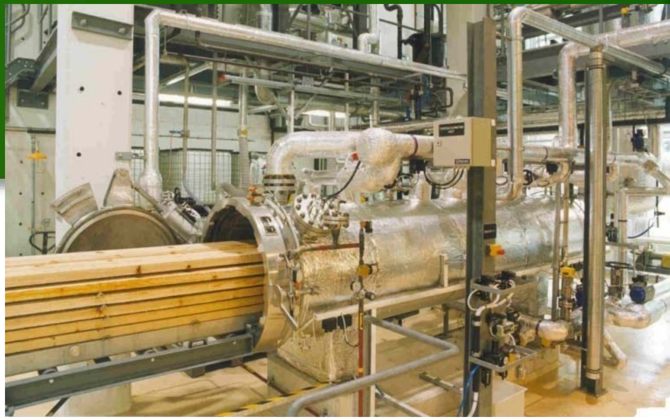
Great reduction in both the static and impact bending properties

2. Acetylation



Grafting acetic anhydride onto cell wall polymers, in the absence of water

- Better dimensional stability
- More durable
- Slightly change colour
- Smell odorously due to presence of acetic acid
- Increase in hardness



accoya the strength within www.titanwood.com

Acetylated wood

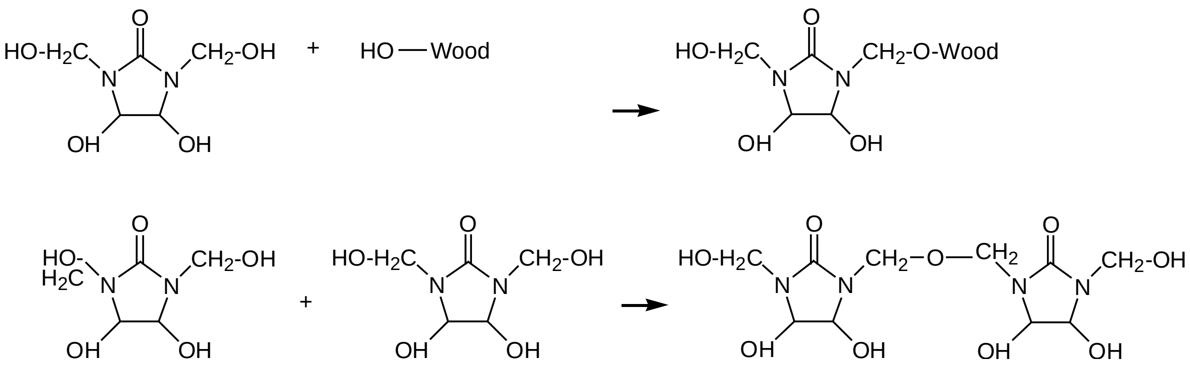
Treatment	Wood species	WPG (%)	Moisture content at 20°C, 65% r.h. (%)		Change in mechanical properties based on untreated controls (%)				References
			untreated	treated	Static bending		Impact bending	Tensile strength	
					MOE	MOR			
AA	Pine	19.1	9.8	4.1	-17.0	-5.3	--	--	Larsson 1994
	Spruce	23.3	12.0	2.8	+3.5	+7.4			
PA	Acacia mangium	--	--	--	+1.0	+2.1	--	+8.2	Bhat 2010
	Acacia hybrid				+3.6	+9.0		+10.0	
SA	Acacia mangium				+11.5	+5.5		+6.6	
	Acacia hybrid				+7.1	+2.8		+6.7	
AA, 125-130 °C	Southern yellow pine	18.0	--	--	--	--	-13.3	--	Goldstein 1961
	Ponderosa pine						+15.6		
AA, 125-130 °C	Ponderosa pine	20.7	9.1	4.0	+2.0	+10.9	+17.5	--	Dreher 1964
	Red oak	21.2	8.4	4.6	-5.8	-8.3	-6.9		
	Sugar maple	21.4	9.2	3.4	-4.3	-8.1	-1.4		
AA, $MgCl_2$	Sugi	25	--	--	-2%	-1.5%	--	--	Li 2009
AA	Sitka spruce	Up to 30	9.5	8.5-3.0	(-20)-(+10)	(-20)-(+30)	--	--	Minato 2003
AA		20	--	--			+1		Epmeier 2003
AA	Radiata pine	--	13.1	5.2	-9.1	-9.3	--	--	Jorissen 2005

Note: '--': unknown, 'AA': acetic anhydride, 'PA': propionic anhydride, 'SA': succinic anhydride

Almost NOT change the bending, tensile, and impact properties

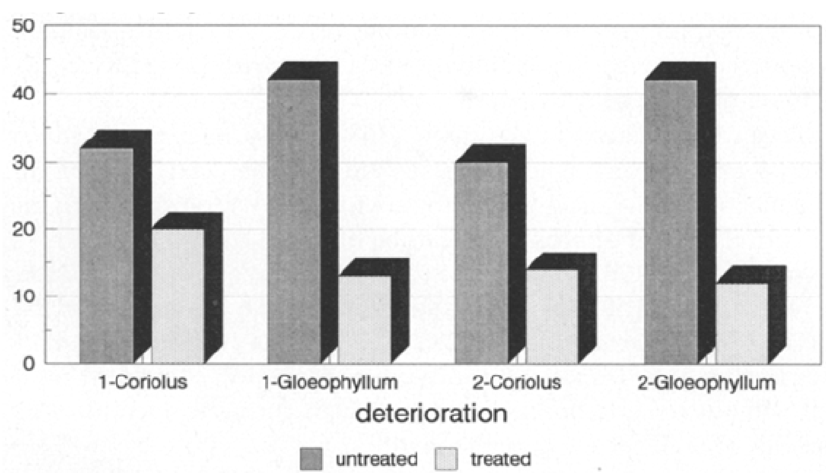
3. Methylolation of wood

- Dimensional stability
- Durability
- Reduced rate of moisture sorption and water uptake

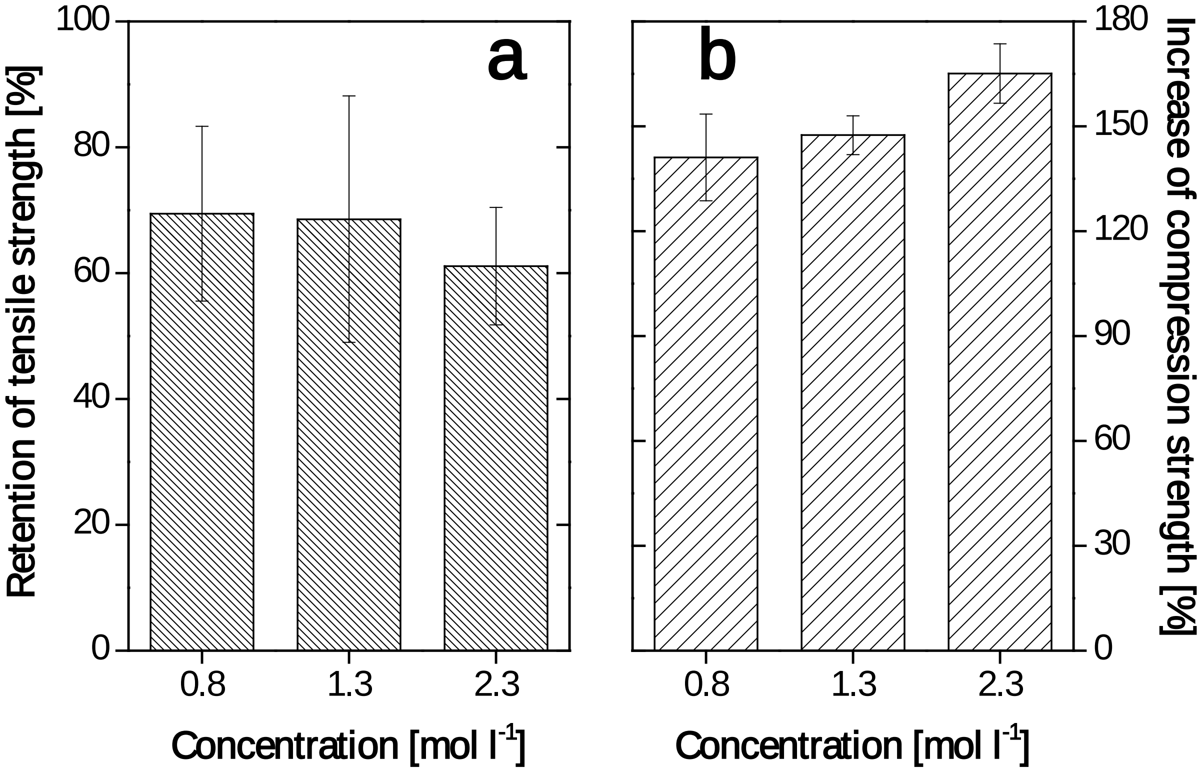


Dimethylol dihydroxy ethyleneurea (DMDHEU)

Crosslinking cell wall polymers/condensation,
in the presence of water



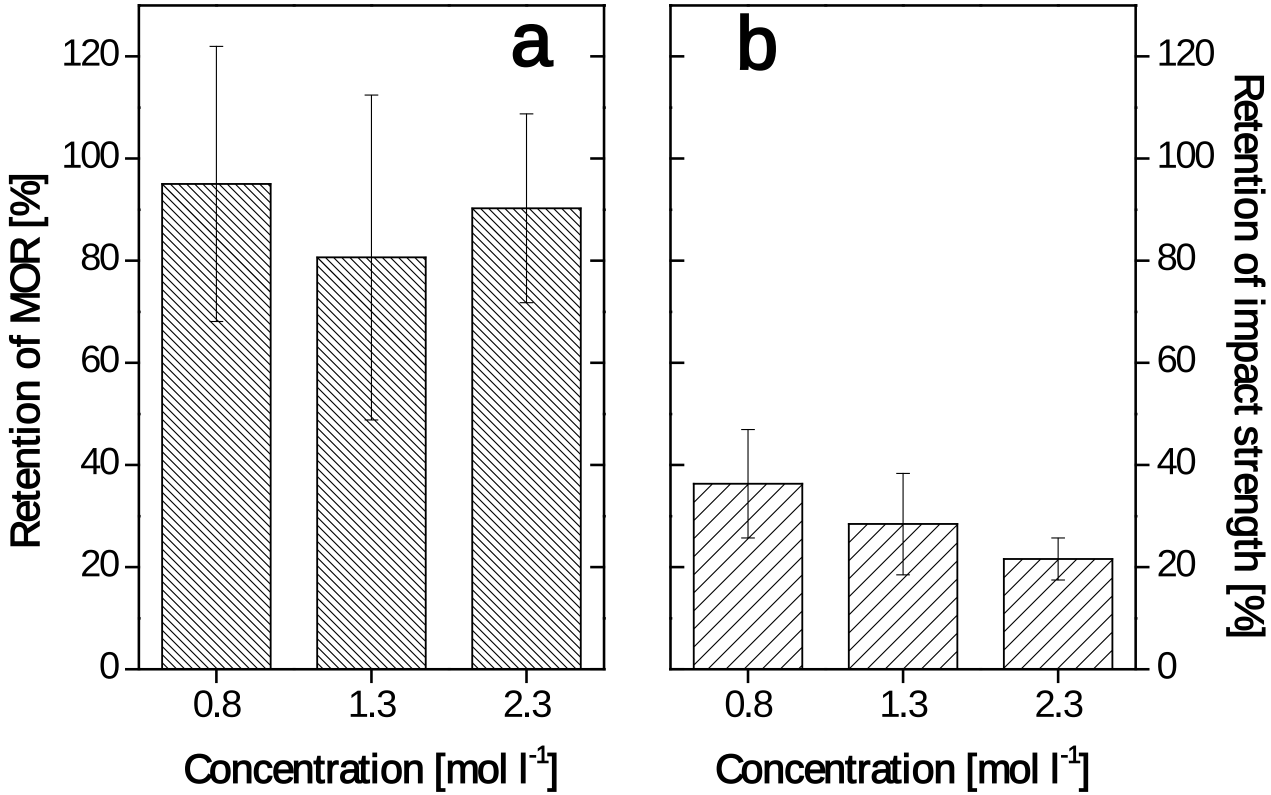
Methylolated wood



Retention of tensile strength (a) and increase of compression strength (b) of wood modified with various concentrations of DMDHEU. (Adapted from Bollmus et al. 2010.)

Reduction in tensile strength
Increase in compression strength

Methylolated wood

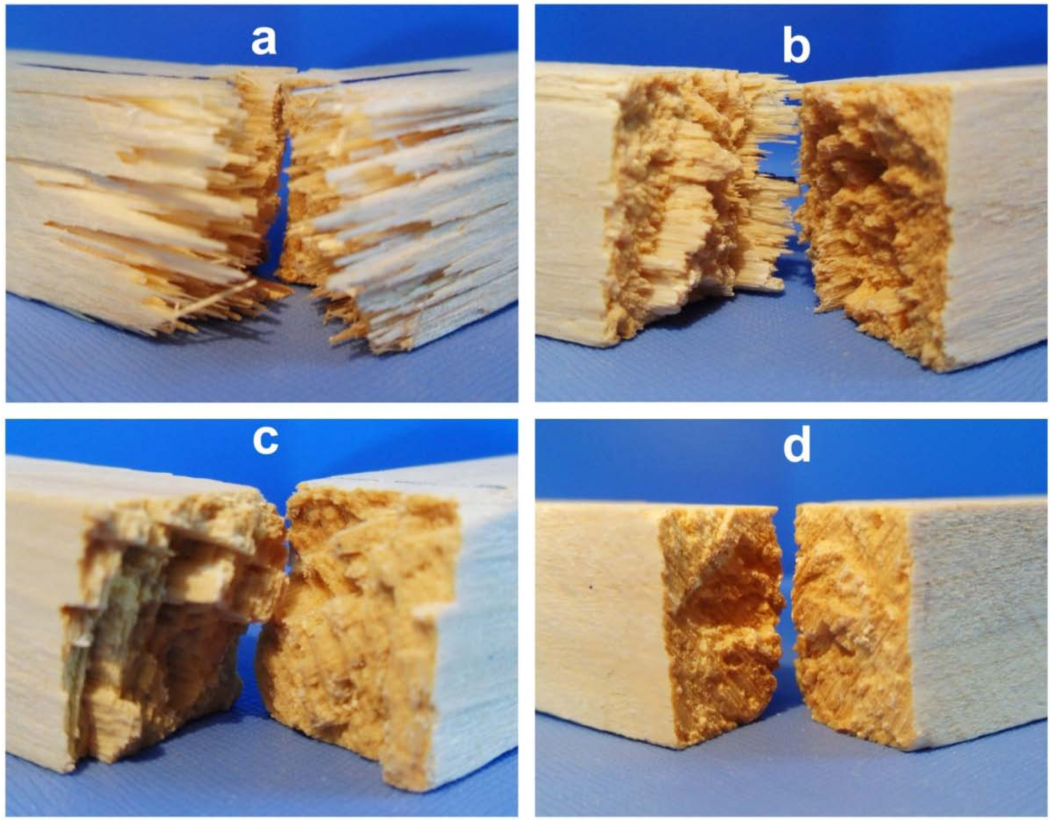


Retention of MOR in bending (a) and impact strength (b) of wood modified with various concentrations of DMDHEU. (Adapted from Bollmus et al. 2010).

No change in MOR
Reduction in impact strength

Methylolated wood

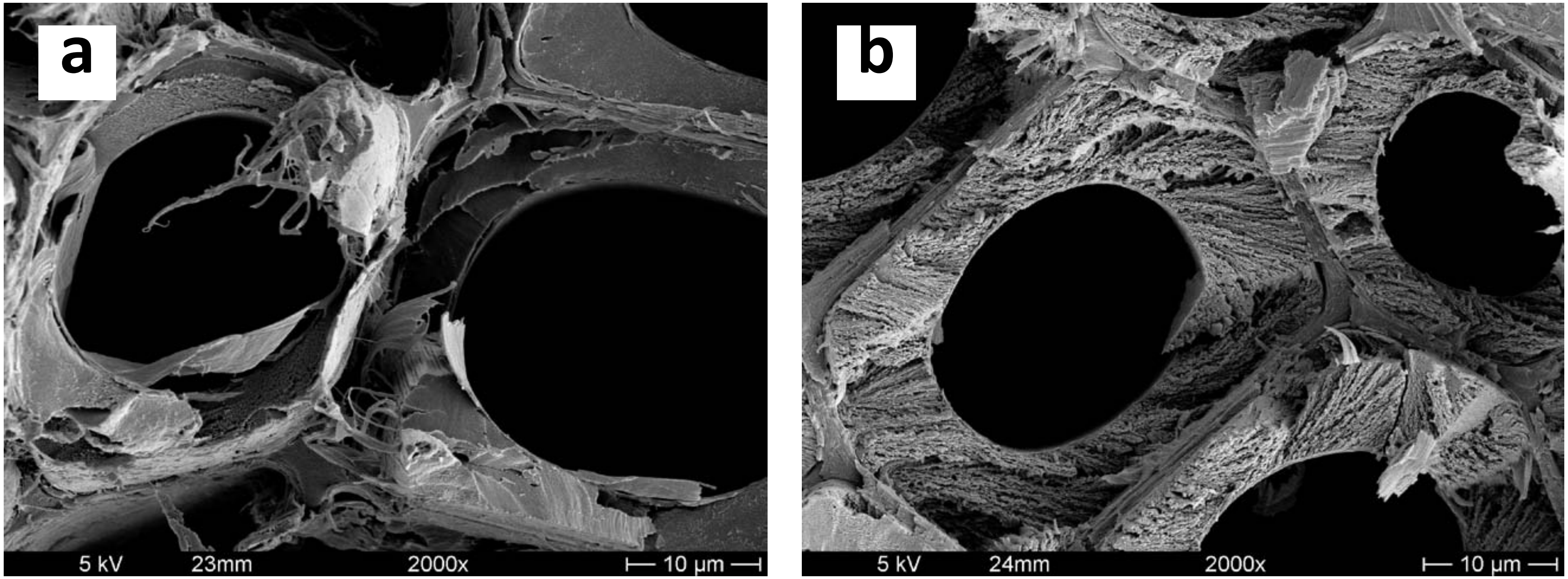
Jagged breakage line



Straight breakage line

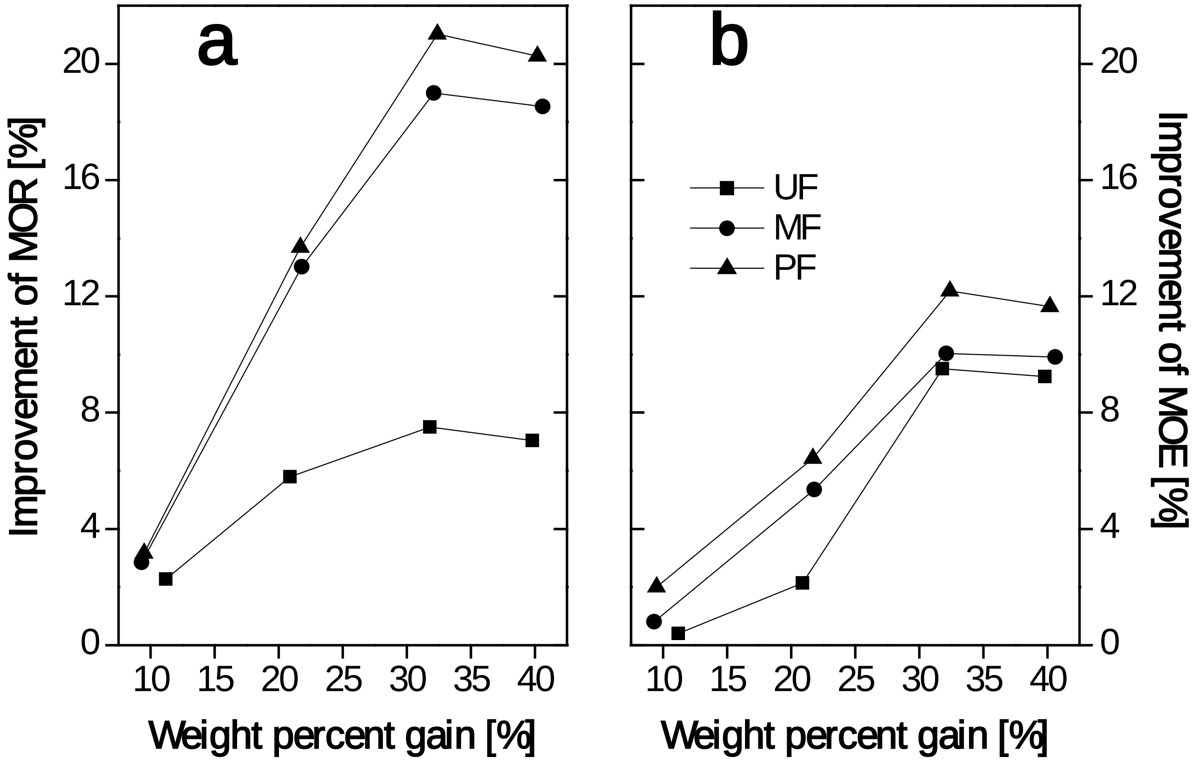
Impact fractural wood untreated (a) and treated with 0.4 (b), 1.2 (c), and 2.0 mol l^{-1} DMDHEU.

Methylolated wood



SEM graphs of fractured cross sections of latewood untreated (a) and treated with DMDHEU to 28% WPG (b). Untreated: microfibril bundles are pulled out and treated: regular fracture surface.

4. Formaldehyde-based resins

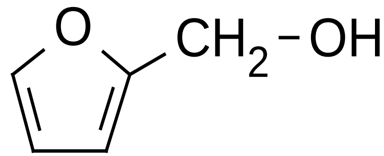


Improvement of MOR (a) and MOE (b) of wood treated with urea formaldehyde (UF), melamine-formaldehyde (MF), and phenol formaldehyde (PF) to different WPGs, respectively. (Data adapted from Deka et al. 2002).

Increase in MOE and MOR with the WPG

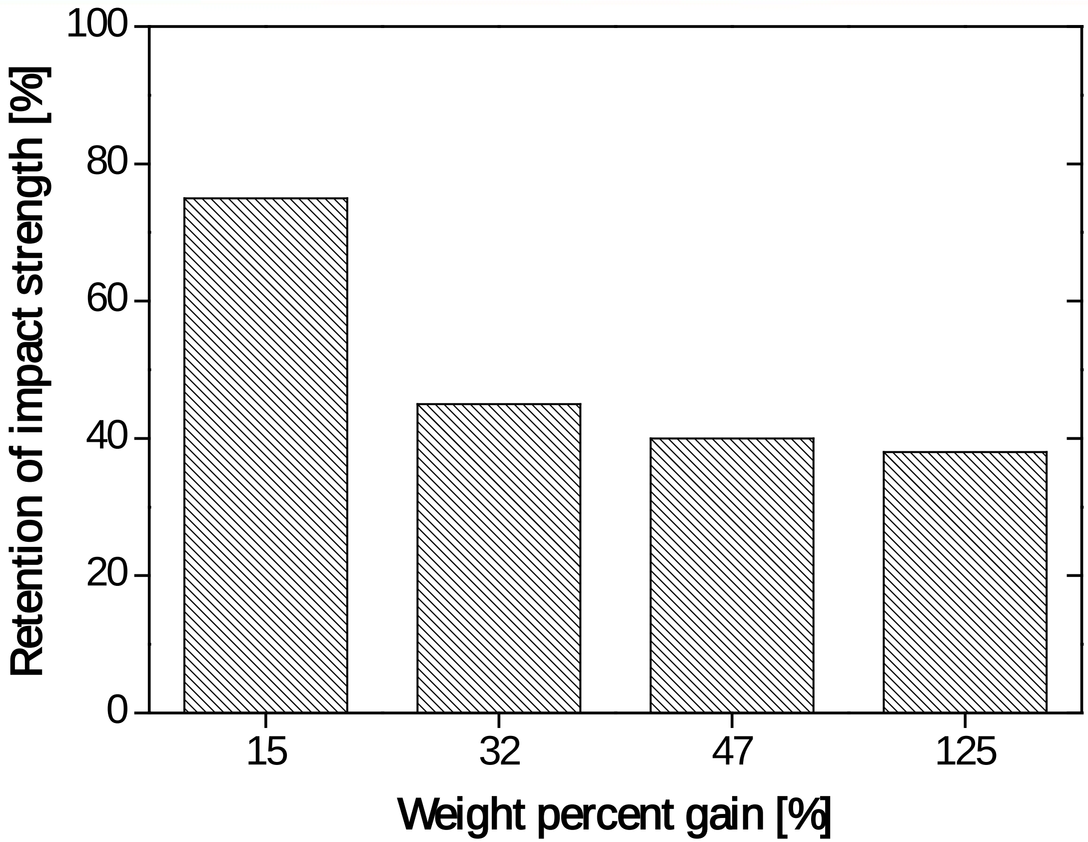
5. Modification with furfuryl alcohol

- Improved dimensional stability
- Improved Durability
- Dark surface
- Uneven for large timber



Kebony

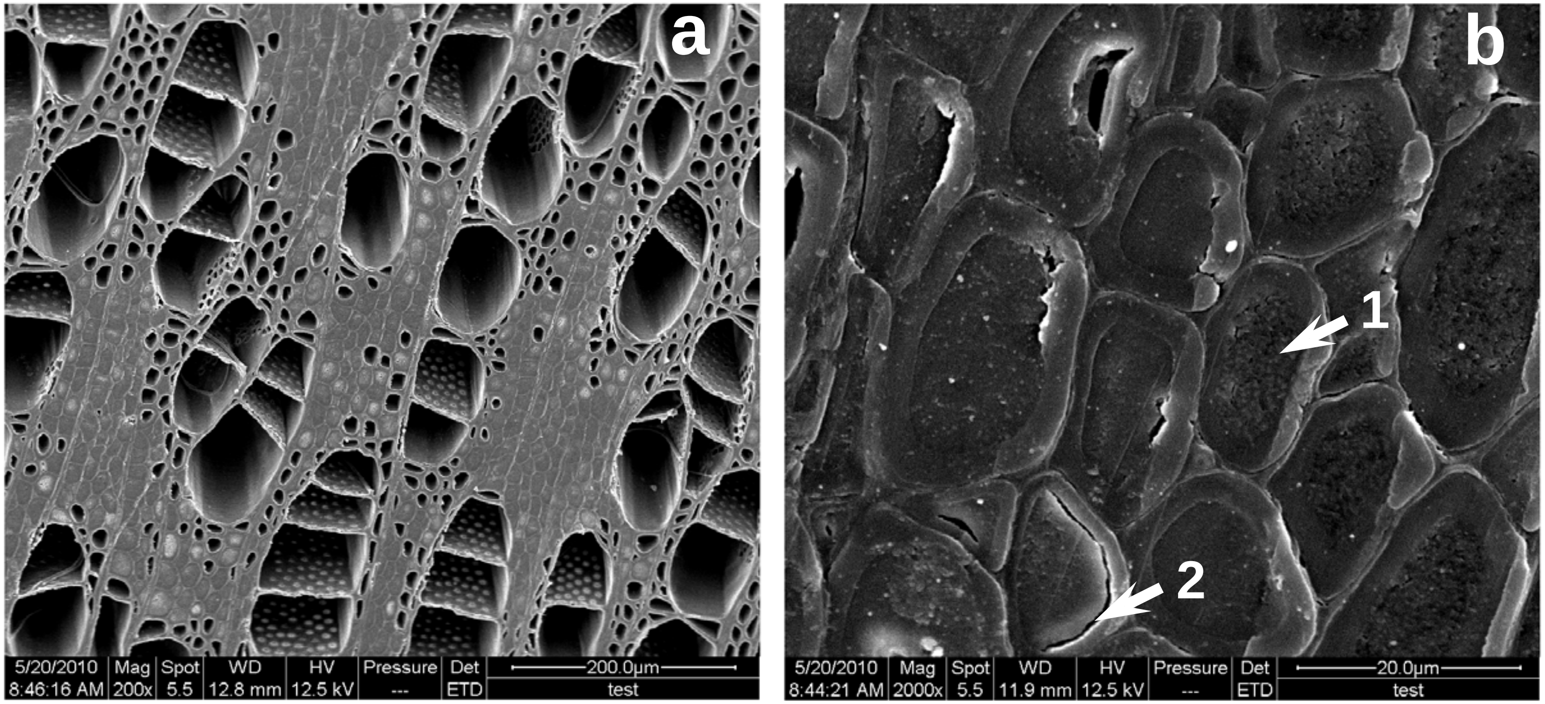
Furfurylated wood



Retention of impact strength of Scots pine wood treated with furfuryl alcohol to various weight percent gains. (Data adapted from Westin et al. 2003).

⇨ Decrease in impact strength with increasing the WPG

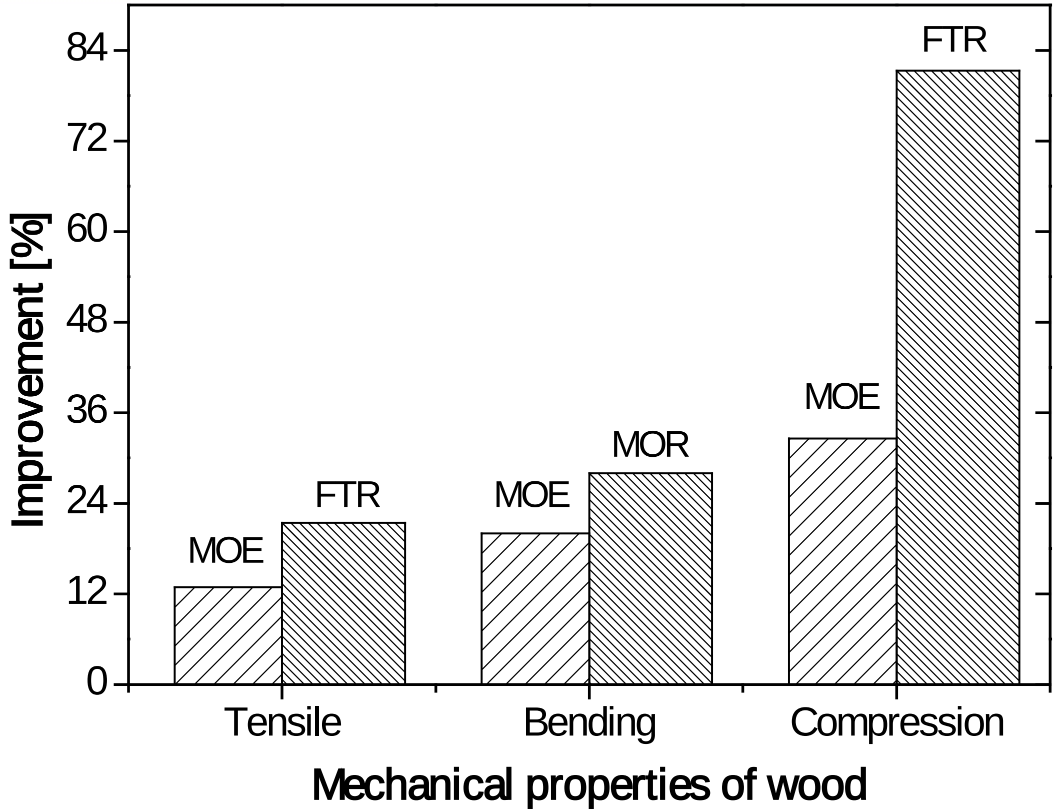
6. Grafting with vinyl monomers



Micrograph of cross-section of poplar wood treated with methylmethacrylate. (a) 200x and (b) 2000x.

Mostly exist in cell lumens and lack of interfacial bonding

Grafting with vinyl monomers



Improvement in the mechanical properties of sugar maple wood treated with a vinyl-type monomers to WPG of approximately 50%. Legends: MOE, modulus of elasticity; MOR, modulus of rupture; FTR, force to rupture. (Data adapted from Schneider et al. 1990).

⇨ Improve the mechanical strength

Summary

- Heat treatments cause **a general reduction** in the mechanical properties, but highly depending on temperature, time, and shield media.
- Modification by incorporating chemicals in wood structures forming **stiff crosslinking network** will reduce the **dynamic strength** such as impact strength. **Hydrolysis** of cell wall polymers is the other reason for such reduction.
- Incorporation of chemicals will increase the surface **hardness and compression strength**.
- Changes in mechanical properties are associated with **wood species** mostly due to their different solution **permeability.**
- There may be a limitation to use most chemically modified wood as **load-bearing elements**.

Ice Lanterns

snow carving

Thanks for your attention!

Welcome to visit Harbin!

東北林業大學
Northeast Forestry University

26 Hexing Road, Harbin, 150040