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Effect of natural aging on wood properties

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1. Introduction

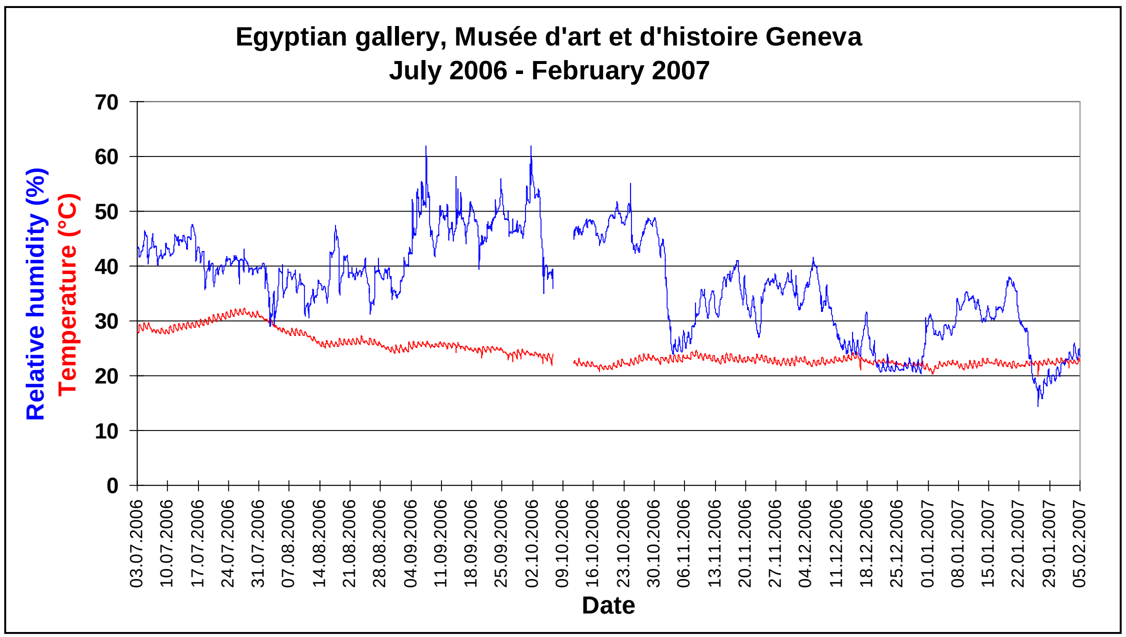
We have a lot of old wooden elements (furniture, music instruments, wooden constructions):
aged up to any hundred or thousend years

Questions:

- Impact of age on physical, mechanical and chemical properties
- Interaction of wooden cultural heritage with changing environment conditions (MOE, strength, sorption, swelling, cracks, warping)
- Influence of wood, used adhesives (animal glues), old coating systems (shellac, linseed oil)

1. Introduction

Uncontrolled relative humidity (RH) in historic buildings



RH varies between ca. 15 and over 60 % in a year

Rapid fluctuations of up to 20 % RH in 2-4 days

Day-night fluctuations

Damage of museum objects






Irreversible deformation, cracks, delaminating veneer

To what extent can RH fluctuations be tolerated?

Which is more harmful?
Slow seasonal fluctuations or rapid fluctuations within 24-48 h?

New buildings produced with wood from old constructions

Wood quality needed (MOE, strength)

New building with 200 years old wood (Chaletbau Matti/CH)

Old wooden bridge in Bad Säckingen

2. State of the art

- Initial wood quality unknown (difficult to test the aging):
- High variation in quality indicators (density, MOE, MOR)
  - E.g. requirements for spruce resonant wood [Wagenführ, Holzatlas 06]:
    - Density: 300…640 kg/m^3
    - MOR: 49…78…136 N/mm^2
    - MOE: 7300…11000…21400 N/mm^2
- Aging process is not well investigated

Wood age < 200 years: sdev. reduction of swelling and increase of MOE (~10%);

Wood age > 200 years: effects unknown, not well known (Holz-Lexikon 2003)

Colour: colour changes due to natural aging

⇨ PhD thesis K. Kranitz ETH Zurich from 2010-2014 "Effect of natural aging on wood"

Influence of aging at softwoods in different publications (PhD thesis Kranitz, ETH Zurich, 2014)

↑: increasing; ↓: decreasing; ≈ no change

Species (Scientific name / Trade name)	Age [year]	Lignin	(Holo)cellulose	Hemicellulose	Crystallinity	Extractives	Ash	EMC	Swelling	Bending strength	Compression strength	Tensile strength	Shear strength	Young's modulus	Impact bending strength	Hardness	References
Softwoods:																	
Abies alba Mill. / Silver fir	n.a.							↓									[84]
	300-800	↑	↓				↑										[61]
Chamaecyparis obtusa Endl. / Hinoki	300-1300		↓		↑	↑		↓	↓	~	~		↓	~	↓	~	[68]
	500-1600							↓						↑			[85]
	1250		↓	↓	-												[66,67]
	1400				-			↓									[64]
	<1600									↓					↓		[99]
Juniperus phoenicea L. / Phoenician juniper	4100-4400	↓	↑		↓		↑										[72,73]
Larix decidua Mill. / European larch	300-800	↑	↓				↑										[61]
Picea abies [L.] Karst. / Norway spruce	60(-180?)	-	-	-			-		-								[59]
	100							↓									[83]
	300								↑	↑	↑	↑			↓		[81]
	200-500	↓		↓		↓											[49]
	300-800	↑	↓				↑										[61]
	n.a.										↓				↓		[97]
	n.a.							↓						↓	↓		[84]
Pinus densiflora Siebold et Zucc. / Japanese red pine	270				-								-				[63]
	121-296													↑			[46]
	170-500		↓		↑												[65]

3. Material and method

- Recent and aged wood (spruce, fir, oak) with different age (up to 470 years), used in old buildings (small clear samples and boards (ultrasound))

Tests

- Sorption, swelling, mechanical properties, ultrasound, colour and others
- Chemical analysis (lignin, hemicellulose, extractives)

MOE tested on boards

Used equipment (boards): length 1,230–2,645 mm

- Sylvatest Duo (Concept Bois Technologie), 22 kHz

Small clear samples (10mm(l) x 10mm(r) x 10mm(t))

- Epoch XT

longitudinal waves: f = 2,25 MHz, shear waves, f = 1MHz

$G = c^2$ x density
$E = c^2$ x density

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Methods for the small clear samples

- Impact bending: DIN 52 189
- Dynstat: DIN 53 435
- Bending strength: DIN 52 186
- Fracture thoughness: DIN EN ISO 12737

4. Results

a) Chemical properties from recent and aged wood (results: PhD thesis Kranitz, 2014)

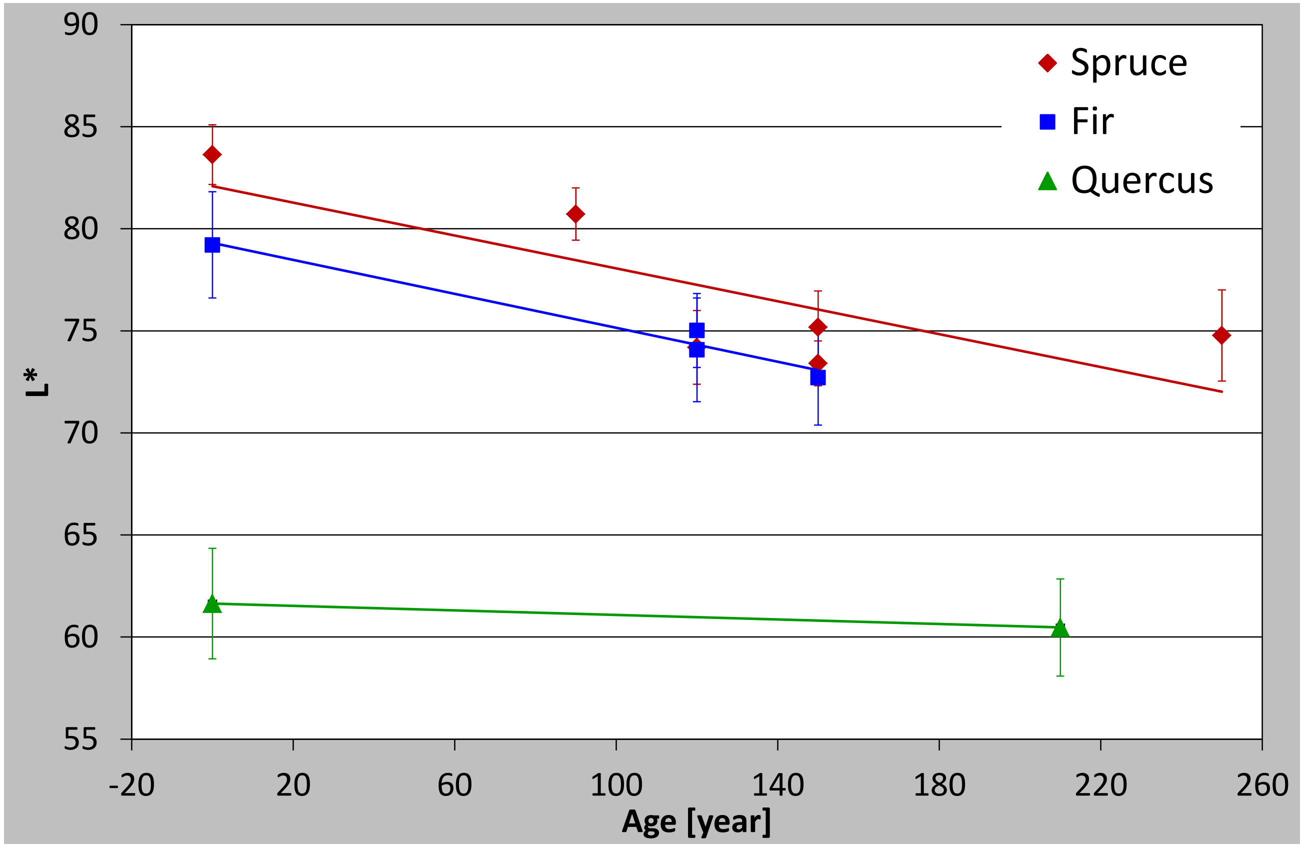
sample		age	ash	extracts	cellulose	hemicellulose	lignin	Σ
spruce	SA05	210 years	0.26%	1.29%	52.42%	19.88%	28.29%	102.14%
	SA06	150 years	0.33%	1.50%	52.95%	23.40%	29.48%	107.66%
	SA07	150 years	0.30%	1.84%	49.03%	27.11%	28.51%	106.78%
	SA08	120 years	0.32%	2.66%	49.03%	29.44%	30.50%	111.94%
	SR01	recent	0.26%	2.39%	53.01%	32.31%	29.00%	116.98%
fir	FA06	120 years	0.39%	2.95%	51.83%	19.32%	31.27%	105.76%
	FA07	120 years	0.40%	1.34%	56.43%	22.82%	29.90%	110.89%
	FR01	recent	0.29%	1.38%	52.26%	20.98%	28.14%	103.05%
oak	OA04	250 years	0.27%	5.24%	42.15%	17.37%	28.90%	93.92%
	OR03	recent	0.30%	11.96%	35.34%	29.09%	31.62%	108.31%

Hemicellulose ⇩
extracts ⇩
Colour change visible

b) Colour as a function of wood age

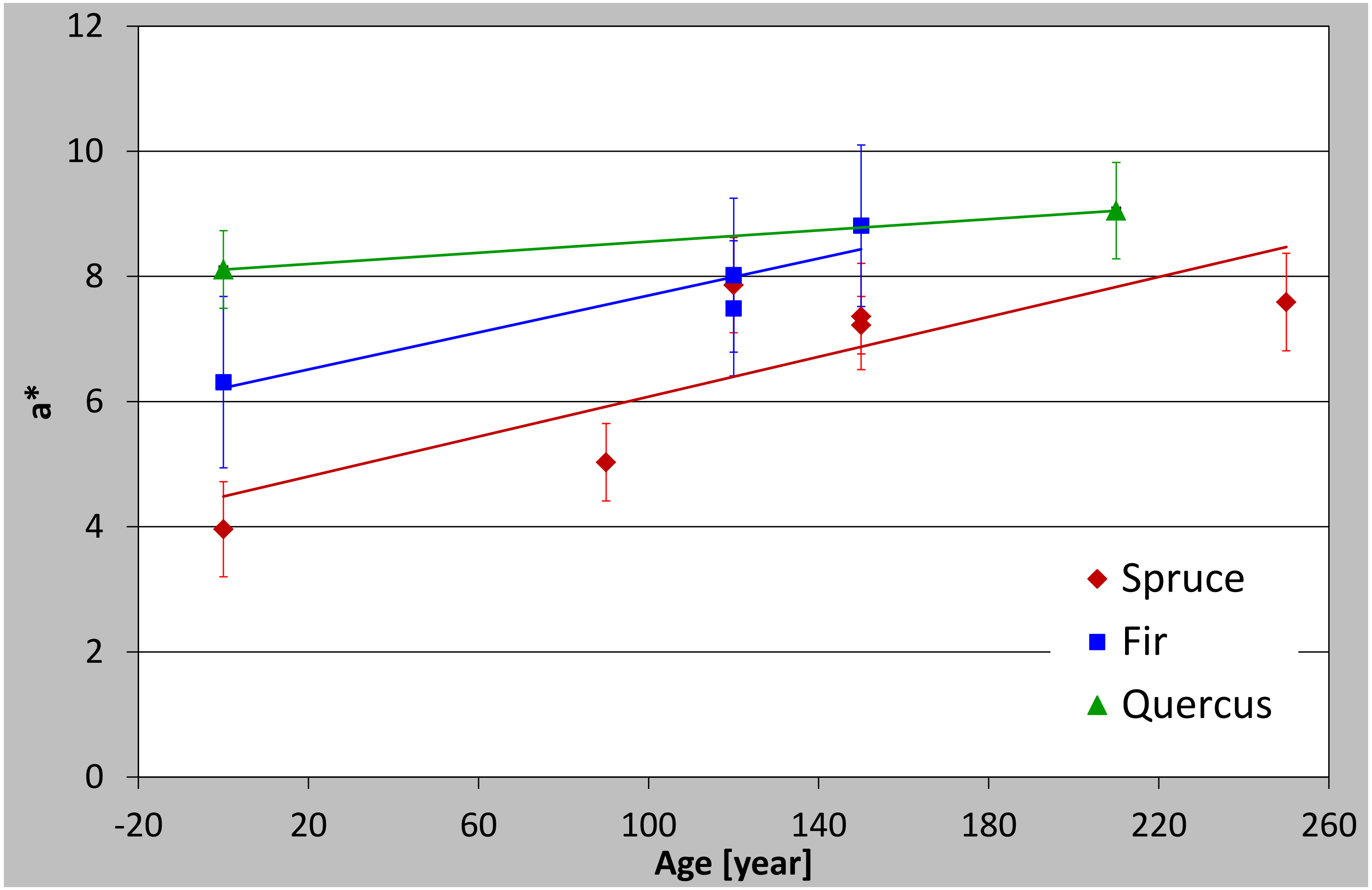
(mean values from all tested samples, Sonderegger et al., 2014)

L* value



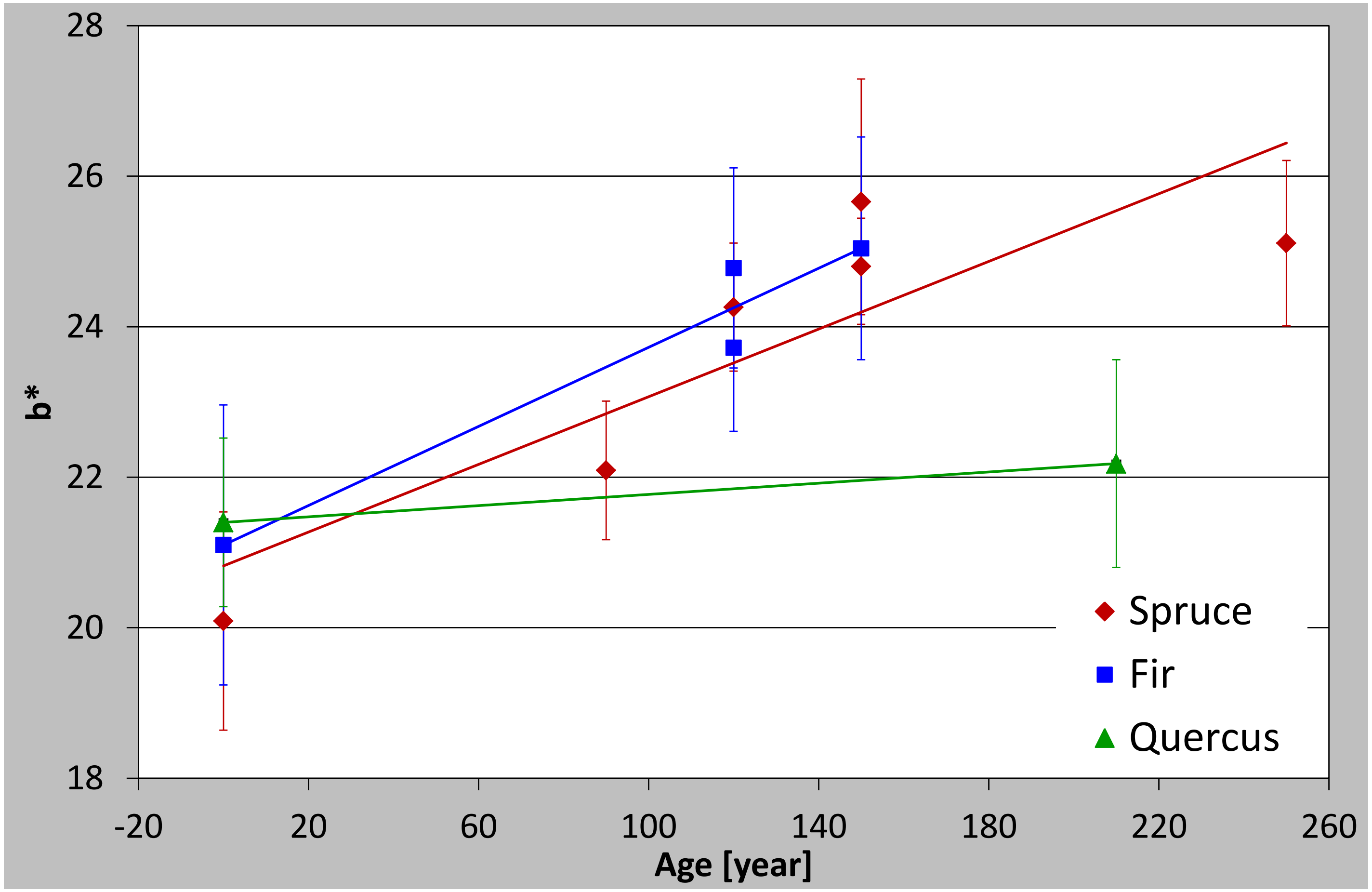
b) Colour as a function of wood age

a* value



b) Colour as a function of wood age

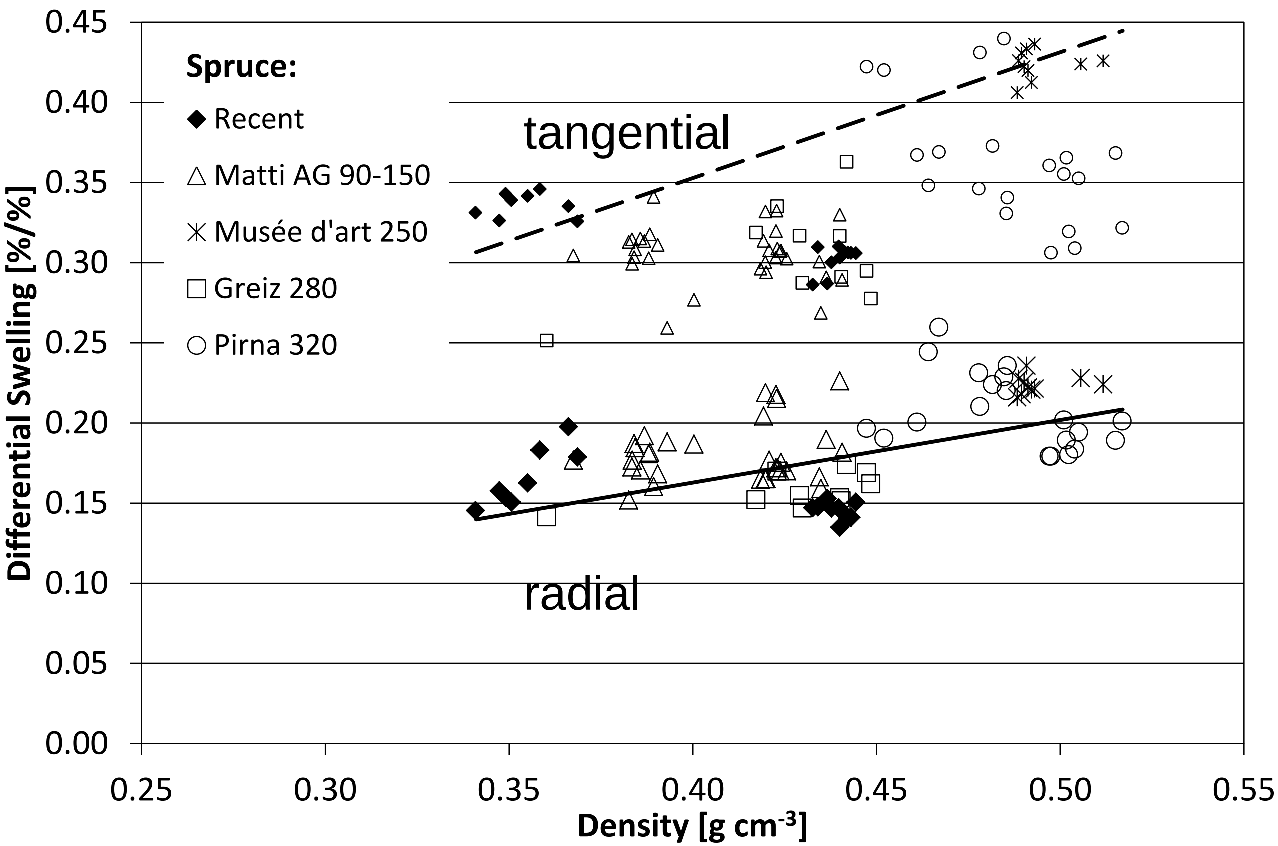
b* value



c) Sorption and Swelling

	Age [years]	n	ρ_0 [g cm^{-3}]	q_r [%/%]	q_t [%/%]	q_l [%/%]	u_{35} [%]	u_{50} [%]	u_{65} [%]	u_{80} [%]	u_{93} [%]
Spruce	recent	18 (10)	0.402 ± 0.044	0.154 ± 0.016	0.317 ± 0.019	0.010 ± 0.003	6.3 ± 0.2	8.0 ± 0.5	10.4 ± 0.2	13.8 ± 0.7	19.4 ± 0.9
	90-320	72 (30)	0.445 ± 0.043	0.191 ± 0.027	0.338 ± 0.050	0.010 ± 0.004	6.5 ± 0.6	8.2 ± 0.8	10.6 ± 0.5	13.9 ± 0.8	19.1 ± 0.16
Fir	recent	18 (10)	0.434 ± 0.041	0.178 ± 0.032	0.374 ± 0.034	0.011 ± 0.002	6.4 ± 0.010	8.1 ± 0.015	10.6 ± 0.13	14.1 ± 0.7	19.5 ± 0.4
	120-470	65 (20)	0.431 ± 0.023	0.145 ± 0.038	0.324 ± 0.056	0.011 ± 0.003	6.1 ± 0.6	7.7 ± 0.009	10.1 ± 0.6	13.6 ± 0.8	18.9 ± 0.16
Oak	recent	18 (12)	0.651 ± 0.033	0.189 ± 0.007	0.378 ± 0.054	0.014 ± 0.003	6.7 ± 0.12	8.6 ± 0.12	10.9 ± 0.9	14.2 ± 0.11	19.3 ± 0.6
	210-470	28 (8)	0.668 ± 0.064	0.205 ± 0.015	0.345 ± 0.014	0.009 ± 0.003	6.0 ± 0.11	7.8 ± 0.12	10.1 ± 0.09	13.4 ± 0.4	18.7 ± 0.7

Swelling: spruce



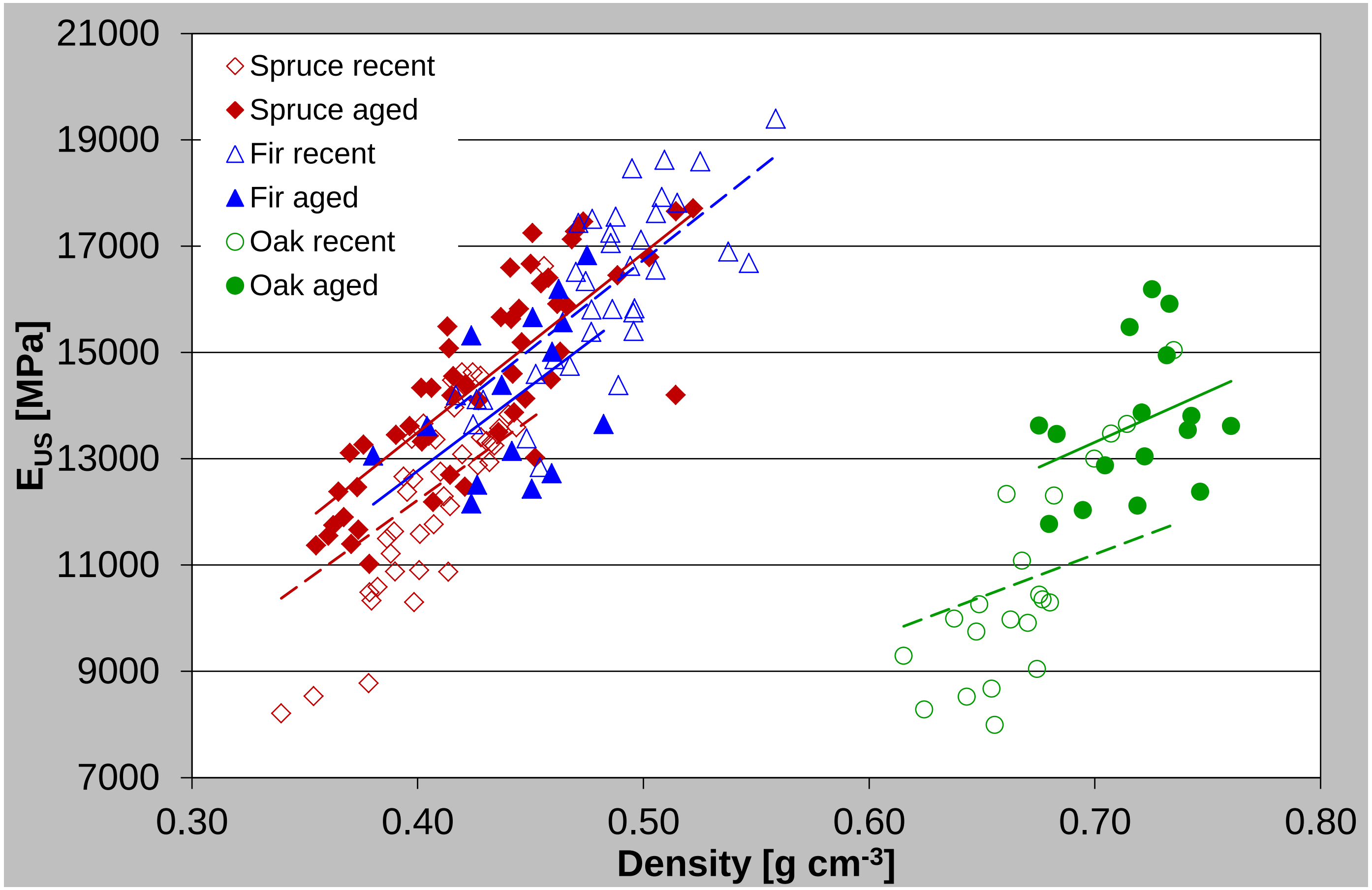
d) Mechanical properties

- Dynamic MOE and bending strength

	Age [years]	n	ρ [g cm^{-3}]	E_{Us} [MPa]	E_{Ef} [MPa]	E_b [MPa]	σ_{bB} [MPa]
Spruce	recent	45	0.411 ± 0.022	12800 ± 1840	11000 ± 1570	11000 ± 2170	75.6 ± 9.5
	120-150	44	0.428 ± 0.033	14700 ± 1650	12700 ± 1490	11900 ± 1500	81.2 ± 9.6
Fir	recent	27	0.475 ± 0.023	16300 ± 1380	13700 ± 1090	14800 ± 1660	86.6 ± 8.9
	120-150	14	0.441 ± 0.025	14800 ± 1090	12800 ± 1030	13900 ± 2100	76.9 ± 16.0

d) Mechanical properties

Dynamic MOE (US)



d) Mechanical properties

- MOE$_{US}$, MOE$_{Ef}$, impact bending strength (w)

	Age [years]	n [-]	ρ [g cm^{-3}]	MC [%]	E_{US} [MPa]	E_{Ef} [MPa]	w [kJ m^{-2}]
Spruce	recent	41	0.408 ± 0.024	12.4 ± 0.4	12400 ± 1790	10500 ± 1530	36.9 ± 10.7
	120-150	52	0.428 ± 0.043	12.2 ± 0.5	14400 ± 1890	12000 ± 1670	35.2 ± 11.3
Fir	recent	35	0.484 ± 0.033	13.2 ± 0.3	16200 ± 1660	12900 ± 1260	41.2 ± 6.8
	120-150	15	0.443 ± 0.027	12.5 ± 0.4	14200 ± 1520	11300 ± 1240	38.6 ± 9.3
Oak	recent	21	0.668 ± 0.029	15.8 ± 0.4	10600 ± 1950	8600 ± 1570	35.7 ± 13.0
	210	16	0.719 ± 0.025	13.4 ± 1.3	13700 ± 1360	11200 ± 1240	32.2 ± 12.2

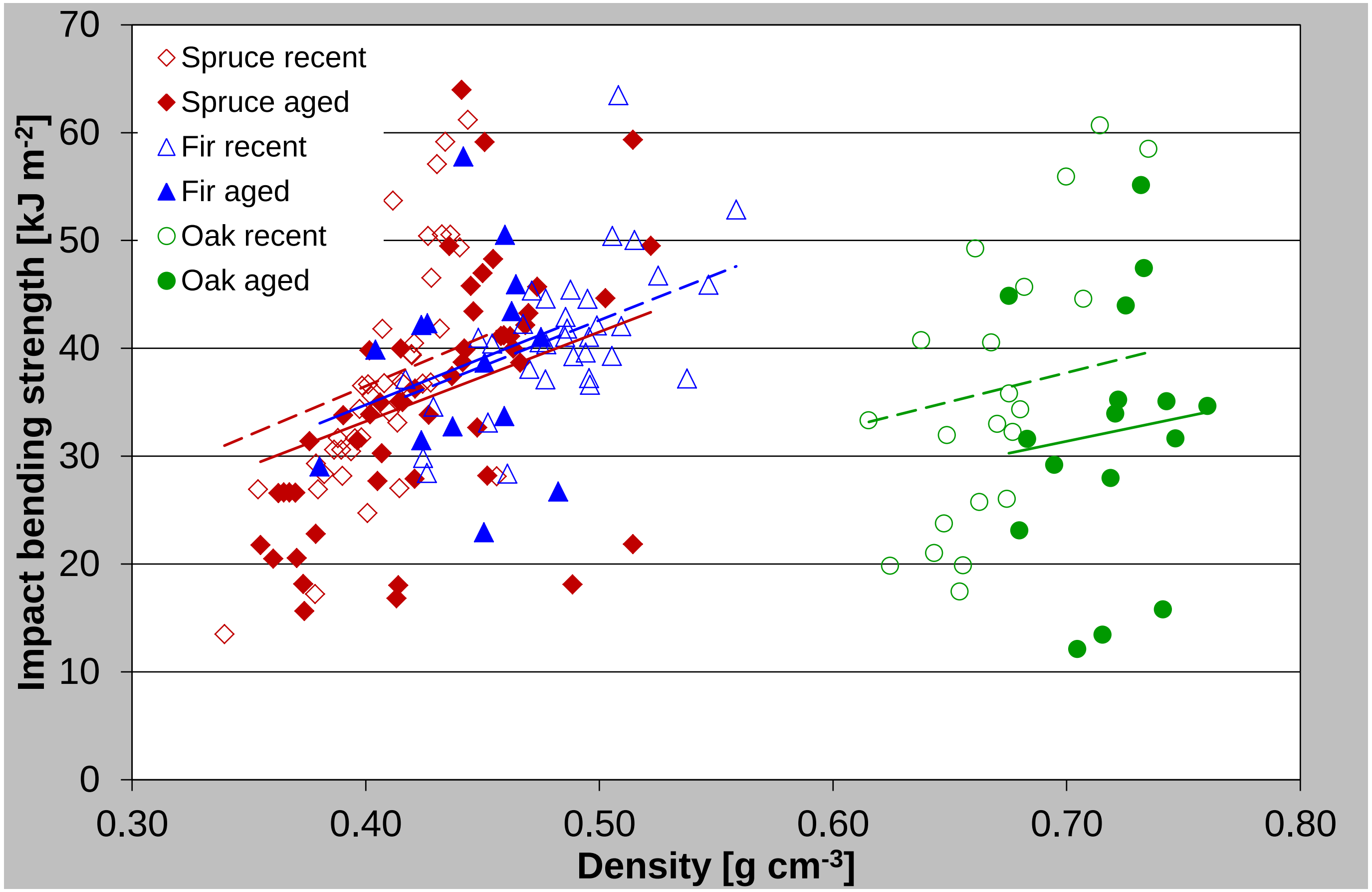
d) Mechanical properties

- Impact bending strength (w) determined by the Dynstat device; n = number of specimens, ρ = density

	Age [years]	n [-]	ρ [g cm^{-3}]	w [kJ m^{-2}]
Spruce	recent	110	0.414 ± 0.020	16.4 ± 4.9
	120-150	114	0.443 ± 0.041	23.8 ± 4.2
Fir	recent	42	0.506 ± 0.016	32.6 ± 2.9
	120	65	0.476 ± 0.021	27.5 ± 2.9
Oak	recent	42	0.681 ± 0.028	14.1 ± 6.2
	210	35	0.733 ± 0.024	12.9 ± 3.7

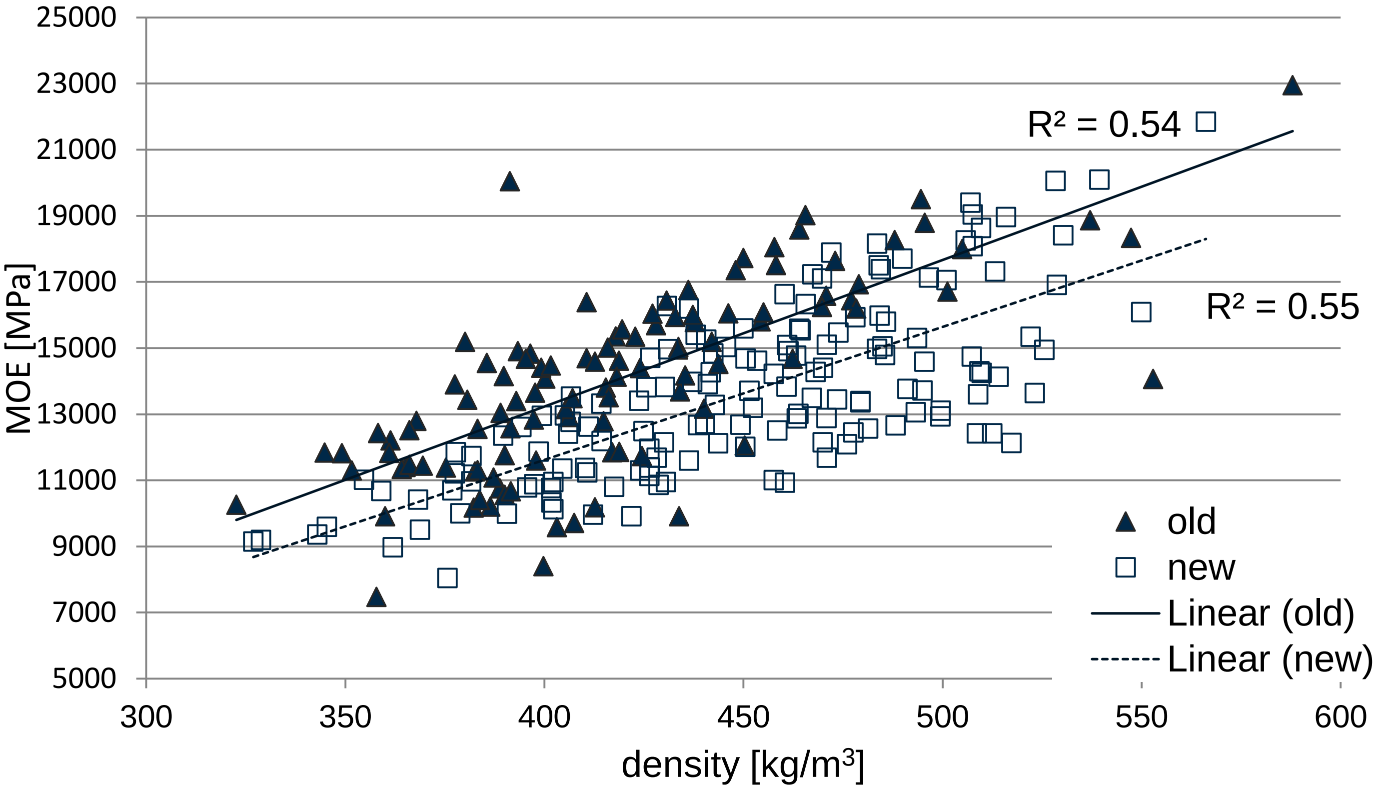
d) Mechanical properties

Impact bending strength (DIN 52 189)



d) Mechanical properties

Dynamic MOE (boards) (Kranitz: Materials and structures, 2013)



5. Summary and conclusions

- The changes are mainly found regarding the chemical composition, colour changes and a reduction of impact bending strength.
- In contrast, sorption and swelling as well as bending and fracture toughness not or only partly show an aging effect.
- One problem is the high variation of the physical and mechanical properties within a species which superimpose some possible aging effects.
- Therefore, more investigations are necessary.

Thank you very much!