Business from technology

Moisture-induced stresses perpendicular to grain in cross-sections of timber members exposed to different climates

M. Fragiacomo,
S.Fortino,
D. Tononi, I. Usardi,
T. Toratti
University of Sassari, Italy
VTT Technical Research Centre of Finland

Background

- In variable humidity conditions wood absorbs or desorbs moisture from the air. Unless the change in humidity is very slow, this will develop moisture gradients in the wood sections. These gradients will develop stresses: moisture-induced stresses.
- The present paper investigates the main parameters affecting such moisture-induced stresses, including the type of climate, the size of the timber cross-section, and the type of protective coating.
- An attempt to identify moisture- induced stresses in different European climate regions was made.

Factors affecting the moisture induced stresses

- Initial moisture content
- Type of exposure
- Size of the member
- Coatings

Moisture induced mechanical effects: Classes 1, 2, 3, 4

Classification

1. Restrained shrinkage is a problem in joint design and detailing
2. Fast drying is a problem in areas with surface peak perp stresses (holes, notches)
3. Long wetting is a problem where wood is under tension perp load (tapered beams)
4. Longitudinal stresses, continuous humidity cycles more important than single moisture changes.

Conclusions from previous research

Classes 1–3 →

- **Moisture induced stresses is primary reason of failure**
- **Number of cycles or duration of load not important**
- **Stress analysis shows similar stress fields in successive cycles**

Class 4 →

- **Strength is reduced in high humidities and still more reduced in cyclic humidities, duration of load is important**

1. Restrained shrinkage

Figure 115-1. Arched column with steel parts (in white).

Figure 115-2. Crack at column fitting to the steel part.

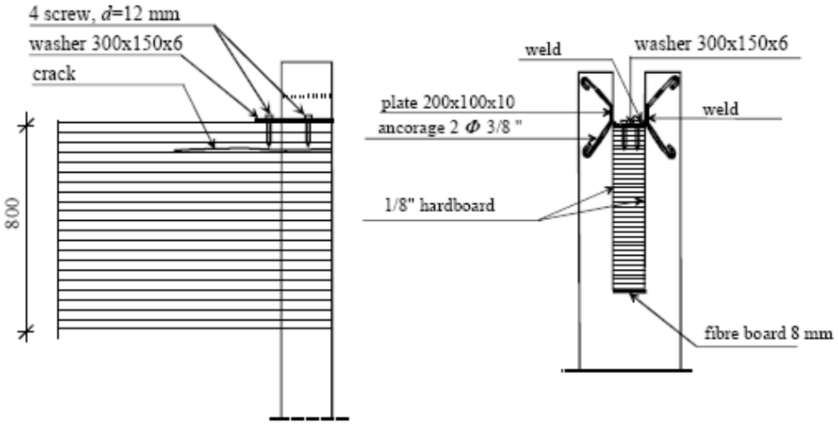


Figure 94-1: Support connection of glulam beam to concrete column.

2. Fast drying

Fig. 9. Longitudinal through crack in glulam roof girder due to shrinkage effects. Hot water piping in the vicinity of the girder contributed to fast drying. Source: Ref. [7].

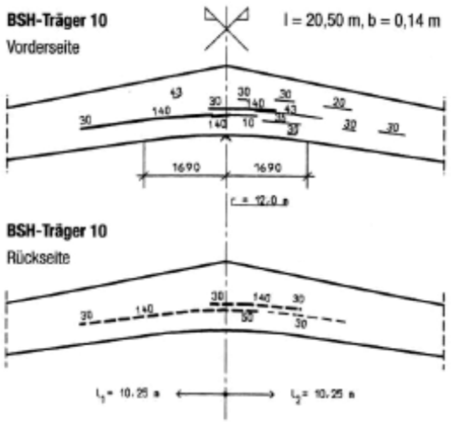
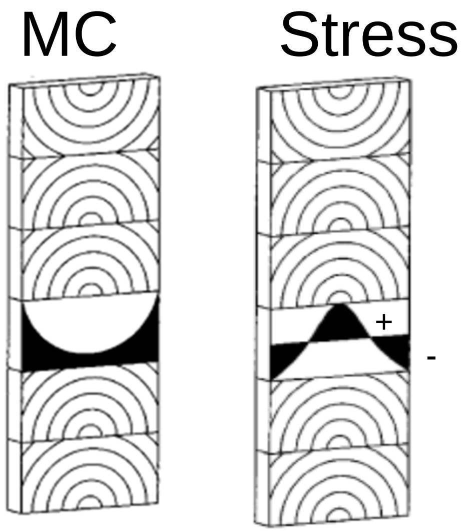


Figure 20. Cracks in pitched cambered roof beams due to restrained shrinkage. Views of both sides of a beam. Source: Ref. [7].

3. Long Wetting



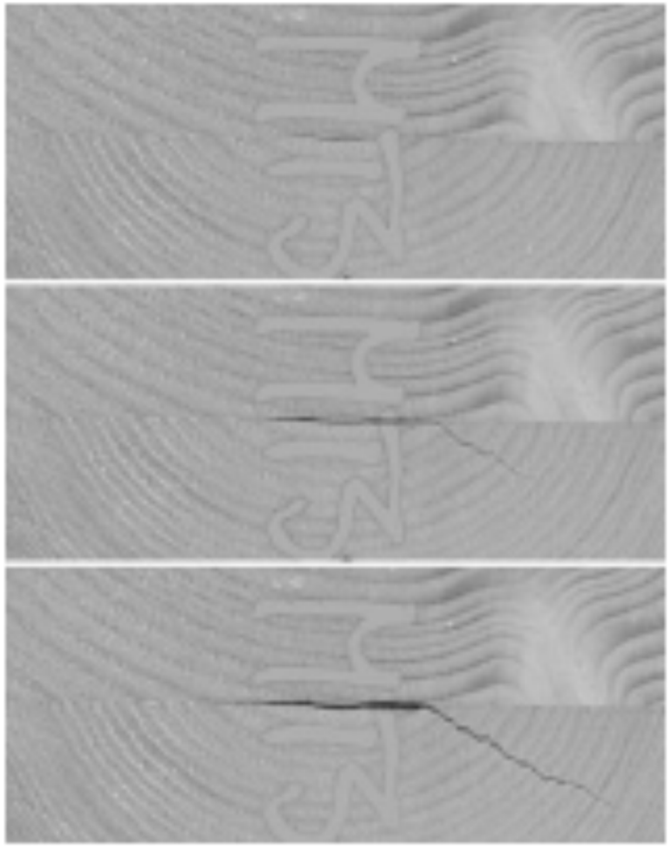
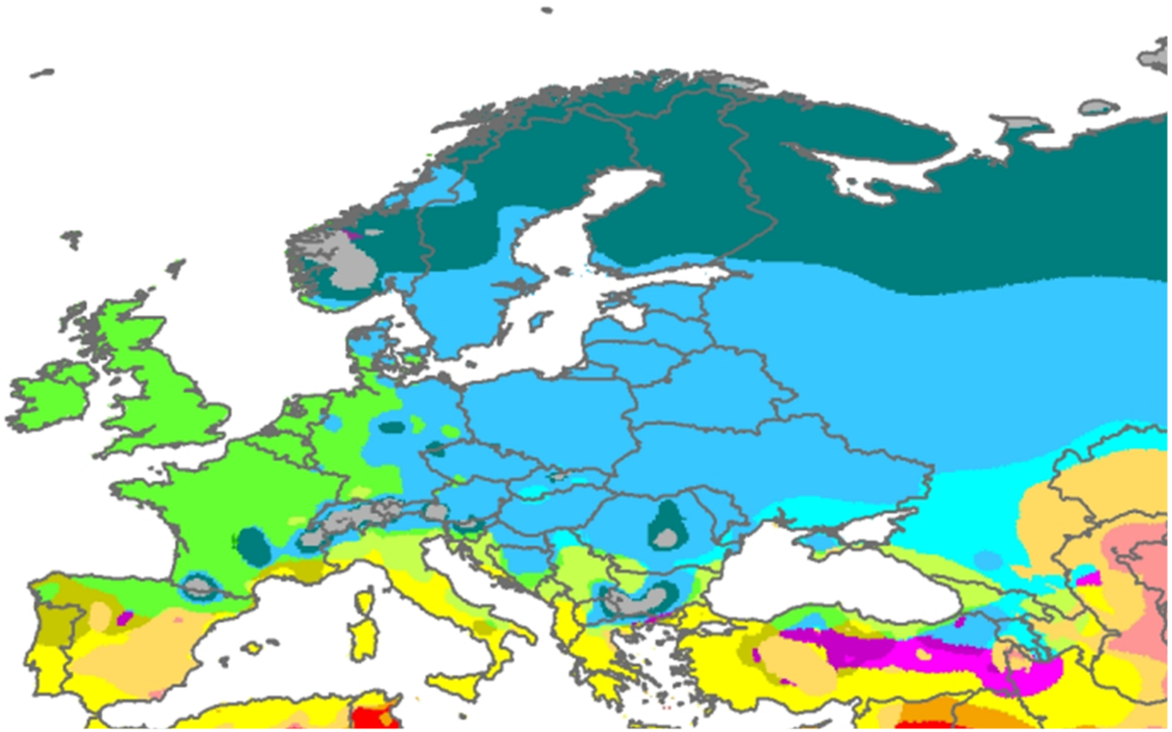


Fig. 8. Crack propagation in gradient specimens, RH 40 to 80%, tested at day 5



Bsk: Cold semi-arid climate (Madrid, Salamanca, Albacete)

Csa: Warm Mediterranean climate (Lisbon, Cagliari, Palermo, Athens)

Csb: Temperate Mediterranean climate (Potenza, Marsilia, Coruna, Porto)

Cfa: Warm oceanic//humid subtropical climate (Zagreb, Brescia, Torino, Bologna, Roma, Foggia.)

Cfb: Temperate oceanic climate (Stuttgart, Zurich, Paris, London)

Dfa: Warm / humid continental climate (Kosice, Odessa, Zaporozhe)

Dfb: Temperate//humid continental climate (Moscow, Warsaw, Helsinki)

Dfc: Cool continental climate/subarctic climate (Rovaniemi, Lulea, Tampere)

ET: Tundra climate (Chambery, Zurich, Sofia)

Abbrev-iation	Type of climatic region	Example of cities within the climatic region
Bsk	Cold semi-arid climate	Madrid, Salamanca, Albacete
Csa	Warm mediterranean climate	Lisbon, Florence, Cagliari, Palermo, Athens
Csb	Temperate mediterranean climate	Potenza, Marsilia, Coruna, Porto
Cfa	Warm oceanic//humid subtropical climate	Zagreb, Brescia, Torino, Bologna, Roma, Foggia
Cfb	Temperate oceanic climate	Stuttgart, Paris, London
Dfa	Warm/humid continental climate	Kosice, Odessa, Zaporozhe
Dfb	Temperate//humid continental climate	Moscow, Warsaw, Helsinki
Dfc	Cool continental climate/ subarctic climate	Rovaniemi, Lulea, Tampere
ET	Tundra climate	Chambery, Zürich, Sofia

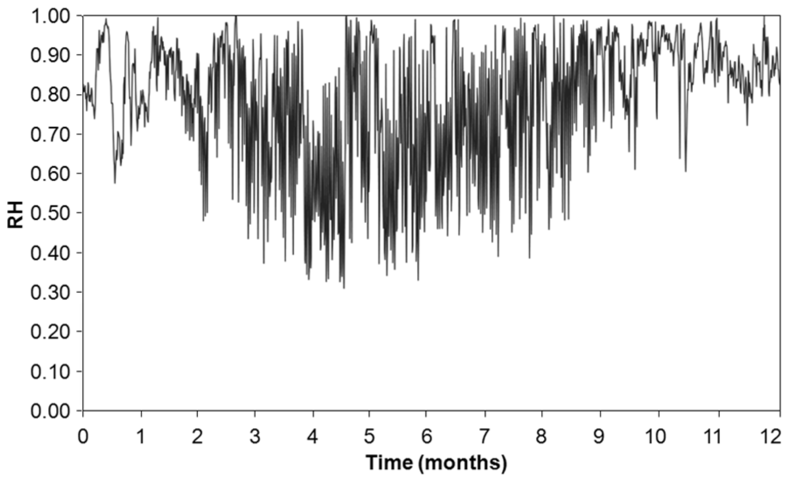
Table 1: *Köppen-Geiger climate type classification of Europe [11].*

$$G = \frac{u_{surf} - u_{\Delta L}}{\Delta L} \left[m^{-1}\right]$$

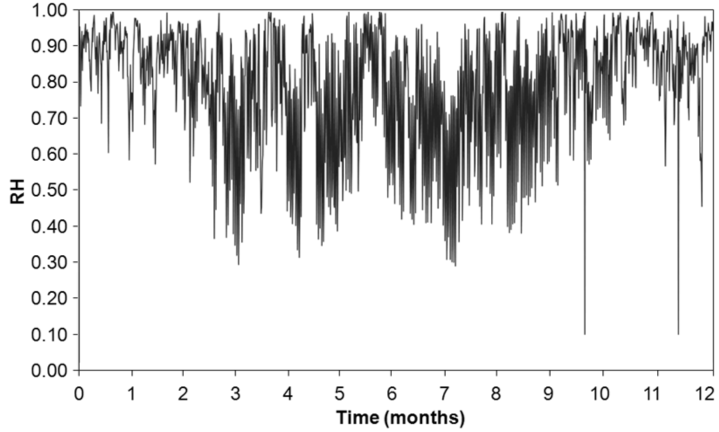
UNCOATED SECTION				
Climatic area	**City**	**ΔL = 4 mm**	**ΔL = 10 mm**	**ΔL = 30 mm**
BSK	Madrid	-5.723	-3.962	-1.379
CSA	Lisbon	-6.028	-3.955	-1.635
	Florence	-7.666	-3.657	-1.514
CSB	Potenza	-5.244	-3.159	-1.264
CFA	Zagreb	-6.744	-4.584	-1.545
CFB	Stuttgart	-8.115	-4.349	-1.880
DFA	Kosice	-6.917	-5.079	-1.606
DFB	Moscow	-6.381	-3.942	-1.954
	Warsaw	-7.959	-4.584	-1.980
	Helsinki	-9.575	-5.111	-1.789
DFC	Rovaniemi	-11.83	-5.982	-2.279
	Tampere	-11.23	-6.176	-2.593
ET	Chambery	-11.83	-3.592	-1.402

Table 3: *10-year analysis: Gradients of moisture content for different climatic regions at different depths for uncoated cross-section sizes (highest negative gradient values given which result in surface tension stresses).*

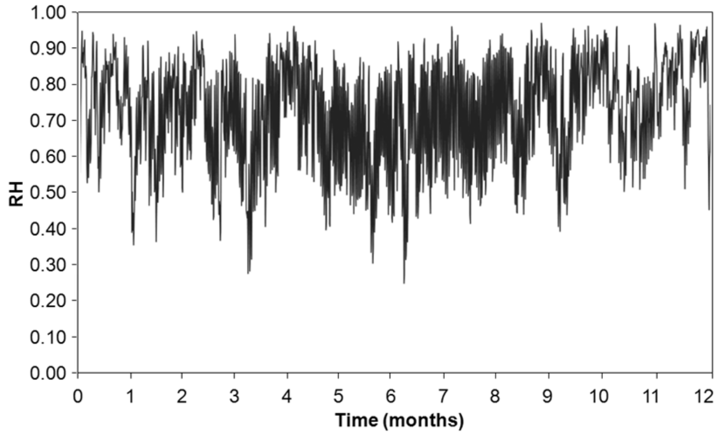
Rovaniemi

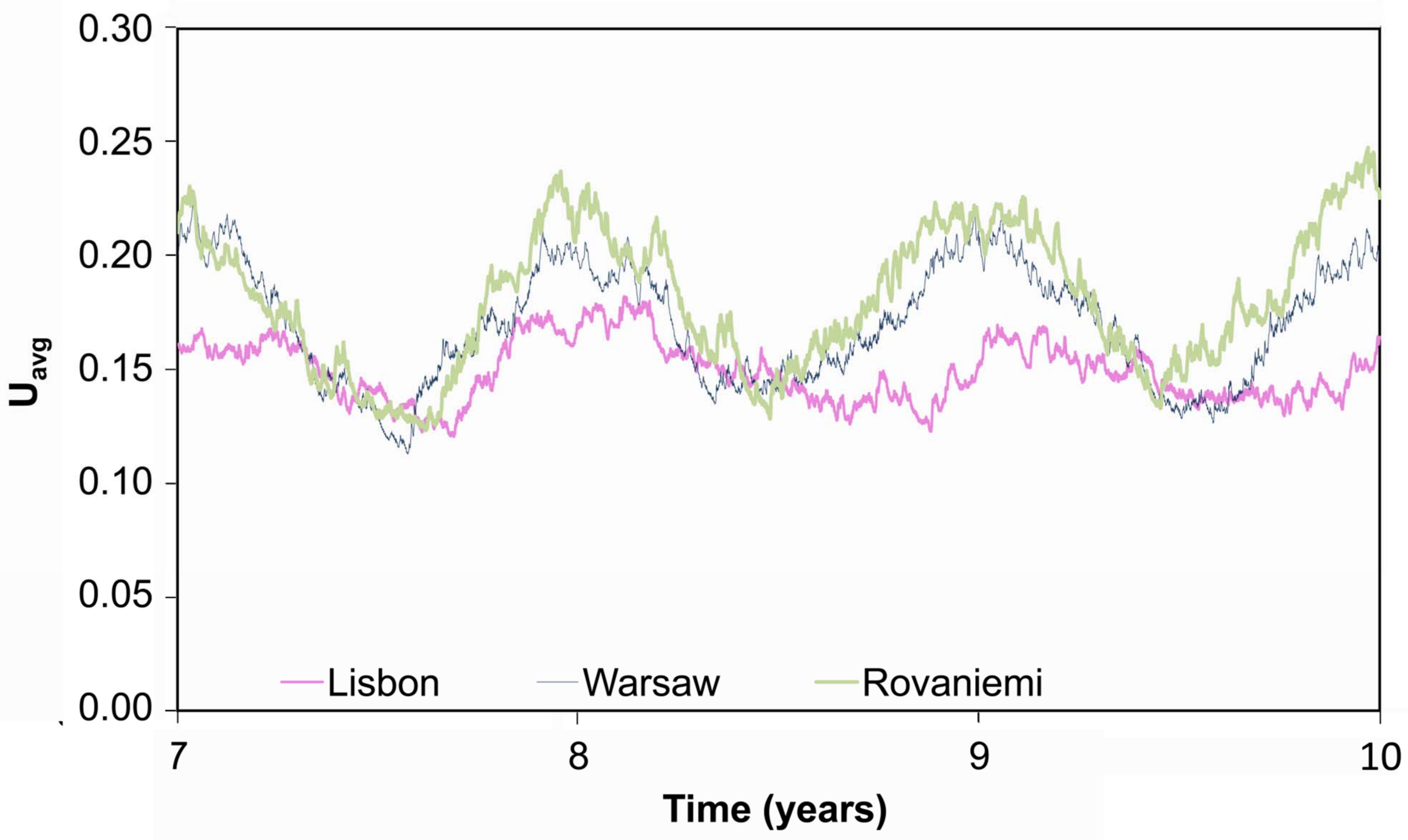


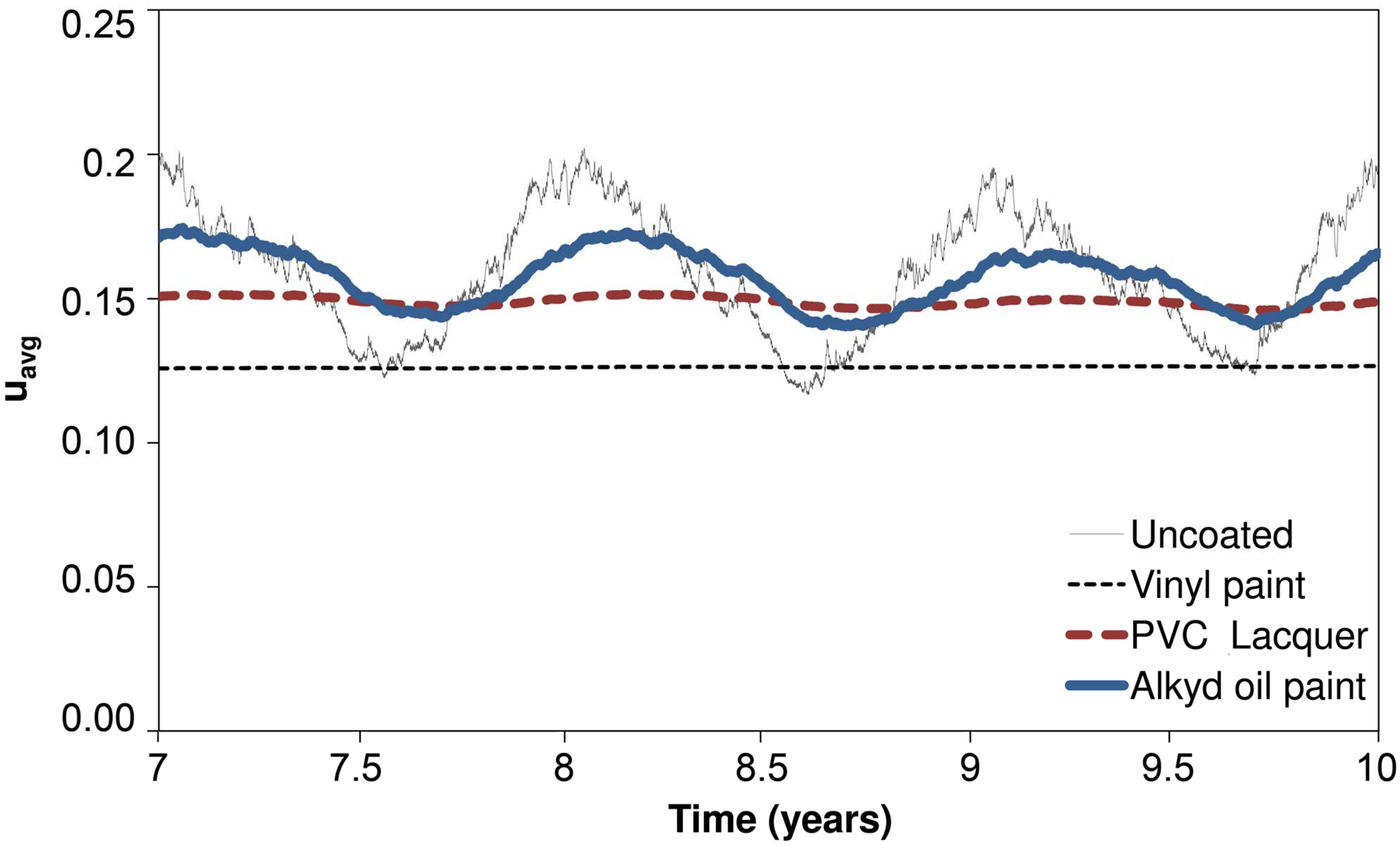
Warsaw

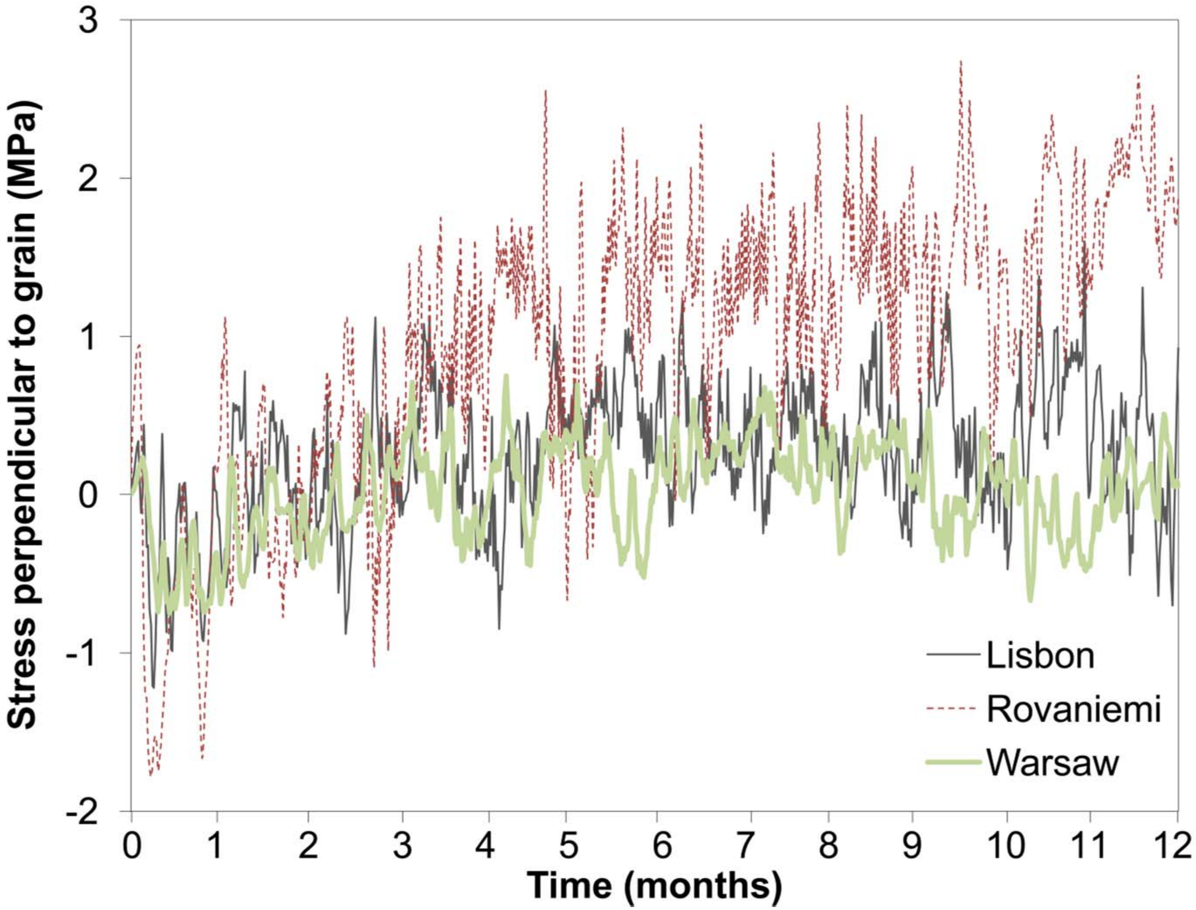


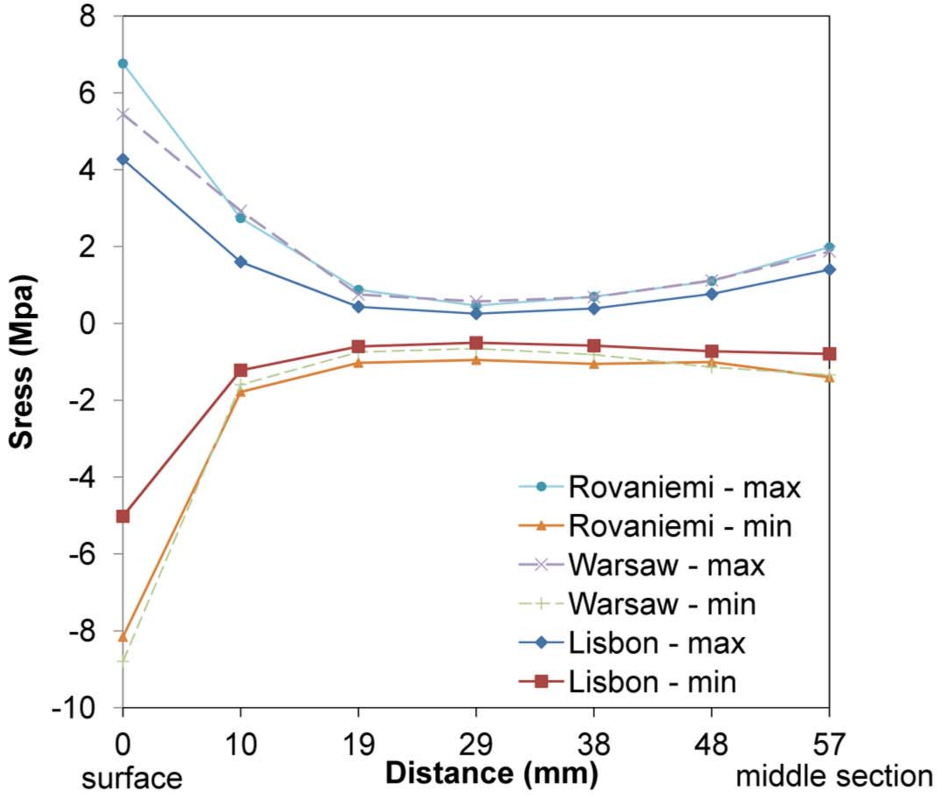
Lisbon

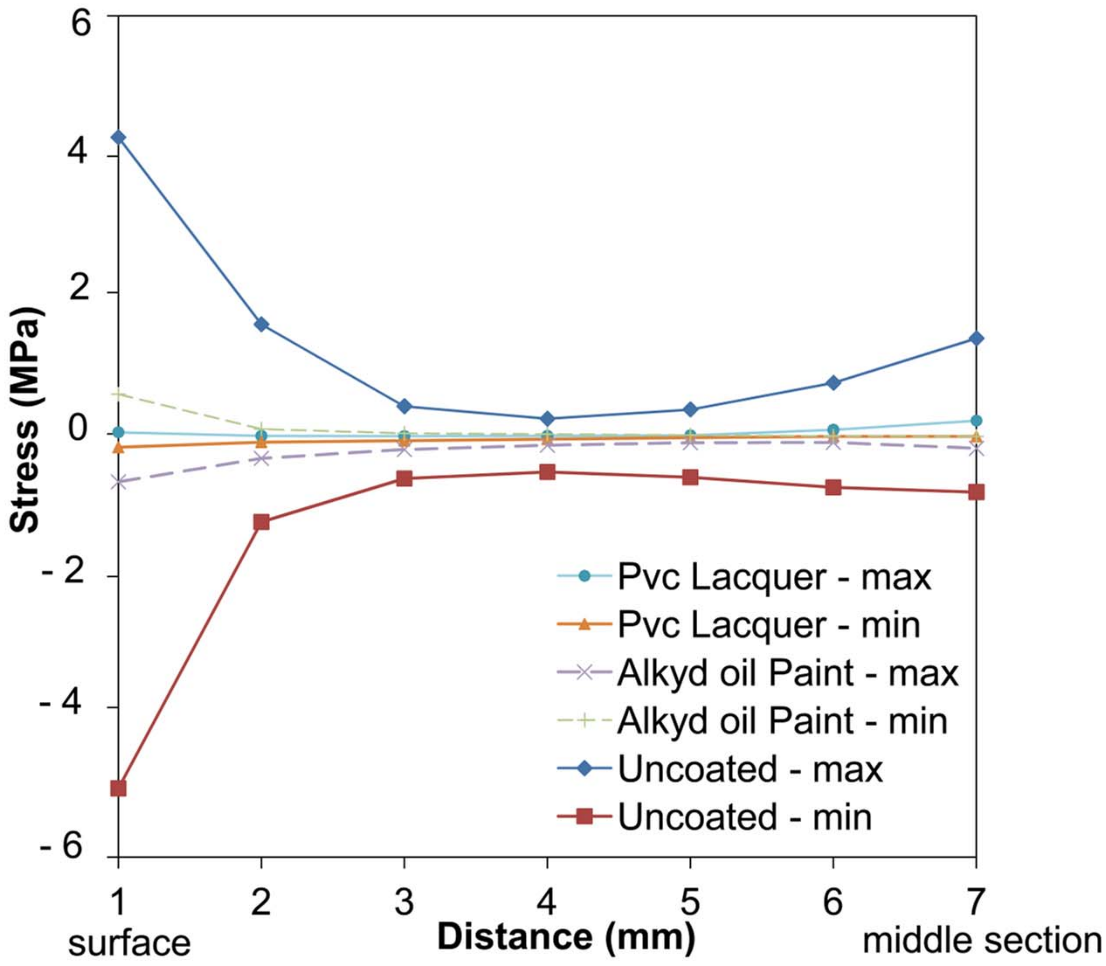



0.30
0.25
0.20
0.15
0.10
0.05
0.00
U_{avg}
7
8
9
10
Time (years)
Lisbon
Warsaw
Rovaniemi


0.25
0.2
0.15
0.10
0.05
0.00
u_avg
7
7.5
8
8.5
9
9.5
10
Time (years)
Uncoated
Vinyl paint
PVC Lacquer
Alkyd oil paint


3
2
1
0
-1
-2
Stress perpendicular to grain (MPa)
0 1 2 3 4 5 6 7 8 9 10 11 12
Time (months)
Lisbon
Rovaniemi
Warsaw


8
6
4
2
0
-2
-4
-6
-8
-10
Sress (Mpa)
Rovaniemi - max
Rovaniemi - min
Warsaw - max
Warsaw - min
Lisbon - max
Lisbon - min
0
10
19
29
38
48
57
surface
Distance (mm)
middle section


6
4
2
0
- 2
- 4
- 6
Stress (MPa)
1
2
3
4
5
6
7
surface
Distance (mm)
middle section
Pvc Lacquer - max
Pvc Lacquer - min
Alkyd oil Paint - max
Alkyd oil Paint - min
Uncoated - max
Uncoated - min

Summary

- The moisture-induced stresses perpendicular to grain depend on the moisture content distribution over the cross-section and, hence, on
  - the type of exposure, the size, initial moisture content, coatings.
- For timber members exposed to outdoor conditions with timber sheltered from rain, the most influencing quantities were found to be the type of climate, and the presence of a protecting coating.
- Climates characterized by larger yearly variations of relative humidity induce higher stresses, northern European climates were found to result in higher moisture gradients and thus in higher moisture induced stresses when compared with southern European climates.
- Natural variations of relative humidity were found in several cases to induce stresses perpendicular to the grain exceeding the tensile and compressive strength perpendicular to the grain.
- The presence of a protective coating is an effective measure to reduce moisture variations and, therefore, moisture-induced stresses and the consequent cracking.

Possible reasons for the rather high calculated internal stresses

- the use of a Fickian diffusion model,
- the omission of hysteresis effects of sorption,
- and possibly higher actual mechano-sorptive properties perpendicular to grain than predicted