COST FP1303
Performance of bio-based building materials

Leibniz Universität Hannover

Durability studies in the field

Assessment and Evaluation

Training school

25 + 26 June 2014
Hannover, Germany

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The first training school in the frame of COST Action FP 1303 on "Durability studies in the field - Assessment and evaluation" will be held in Hannover on June 25-26, 2014.

Field durability studies are basic elements for performance testing of bio-based building materials. Besides traditional graveyard tests, which are well established for wood-based products, more and more new test methods are of interest. To adequately reflect the intended use conditions novel methods including moisture monitoring in various above-ground situations are required. The goal of this training school is therefore to cover various aspects of field durability testing.

<u>Program</u>

Day 1 - 25th June 2014 - 09:00-18:00

- Visual decay assessment (Ina Stephan, Pia Larsson-Brelid)
- Above ground testing - non-standard methods and moisture monitoring (Linda Meyer, Christian Brischke)

Day 1 - 26th June 2014 - 09:00-18:00

- Microscopy - introduction (sample preparation, embedding, coloring etc.) (Andreas Rapp)
- Microscopy - detection of decay types (Morten Klamer)

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1 Visual decay assessment
(Ina Stephan, Pia Larsson-Brelid)

Decay is usually assessed using a pick-test where a pointed knife is pricked into the specimens and backed out again. The fracture characteristics of the splinters as well as depth and appearance are assessed visually, referred to the different decay types (Figure 6 to Figure 8), and evaluated according to EN 252 (2012) (Table 1, Figure 1 - Figure 5). After failure specimens should be analyzed microscopically.

Table 1: Rating scale according to prEN 252 (2012)

Rating	Description	Definition
0	Sound	No change perceptible by the means at the disposal of the inspector in the field. If only a change of color is observed, It shall be rated 0.
1	Slight attack	Perceptible changes, but very limited in their intensity and their position or distribution: changes which only reveal themselves externally by superficial degradation, softening of the wood being the most common symptom.
2	Moderate attack	Clear changes: softening of the wood to a depth of at least 2 mm over a wide surface (covering at least 10 square centimeters) or by softening to a depth of at least 5 mm over a limited surface area (covering less than 1 square centimeter).
3	Severe attack	Severe changes: marked decay in the wood to a depth of at least 3 mm over a wider surface (covering at least 25 square centimeters) or by softening to a depth of at least 10 mm over a more limited surface area.
4	Failure	Impact failure of the stake in the field.

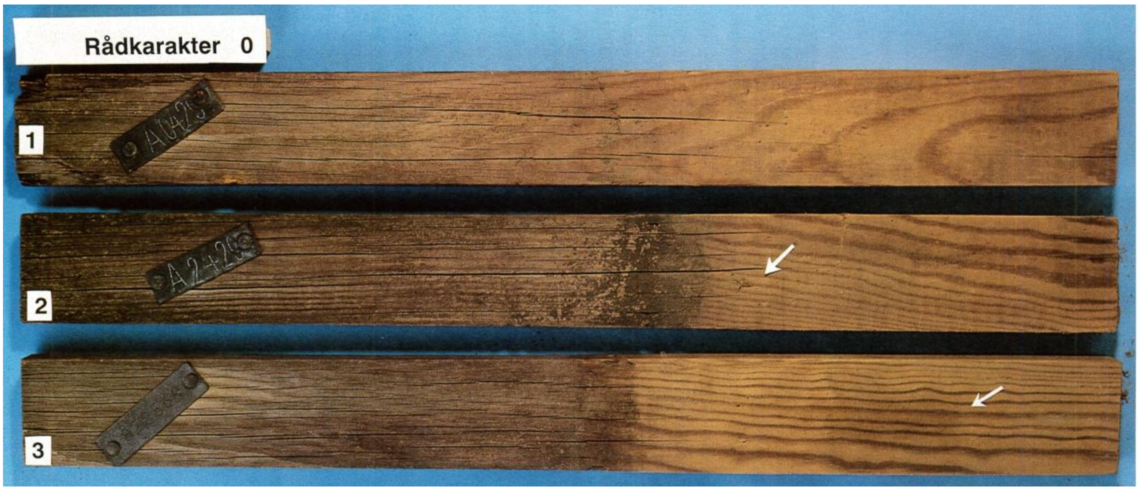


Figure 1: Examples of EN 252- stakes – Rating '0 - sound' (taken from: Borsholt and Henriksen 1992).

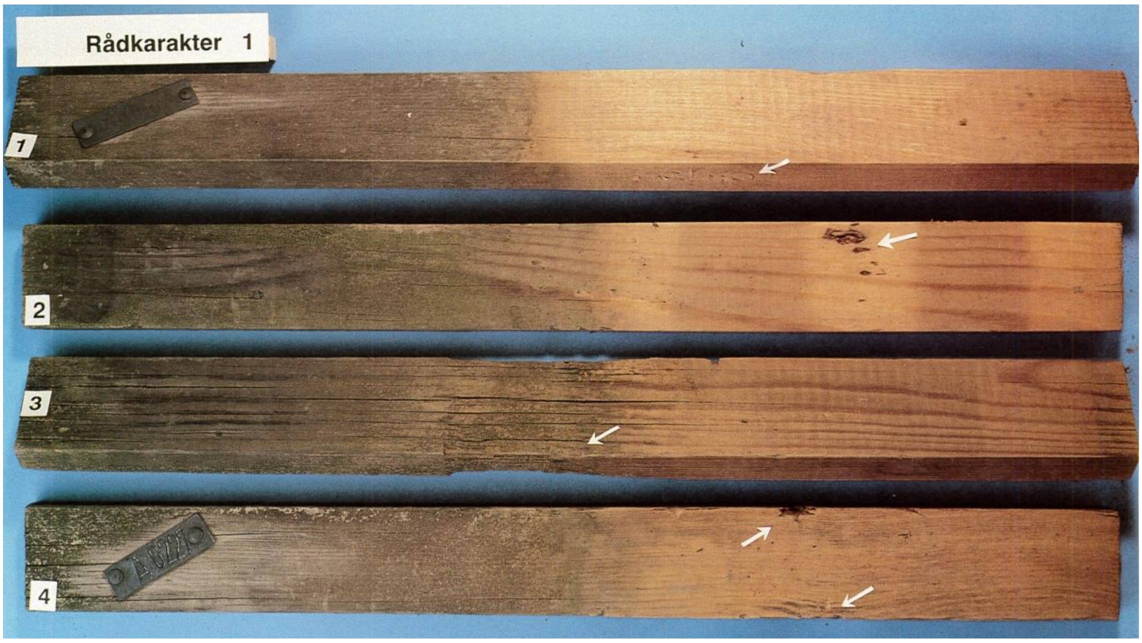


Figure 2: Examples of EN 252- stakes – Rating '1 – slight attack' (taken from: Borsholt and Henriksen 1992).

Figure 3: Examples of EN 252 - stakes – Rating '2 – moderate attack' (taken from: Borsholt and Henriksen 1992).

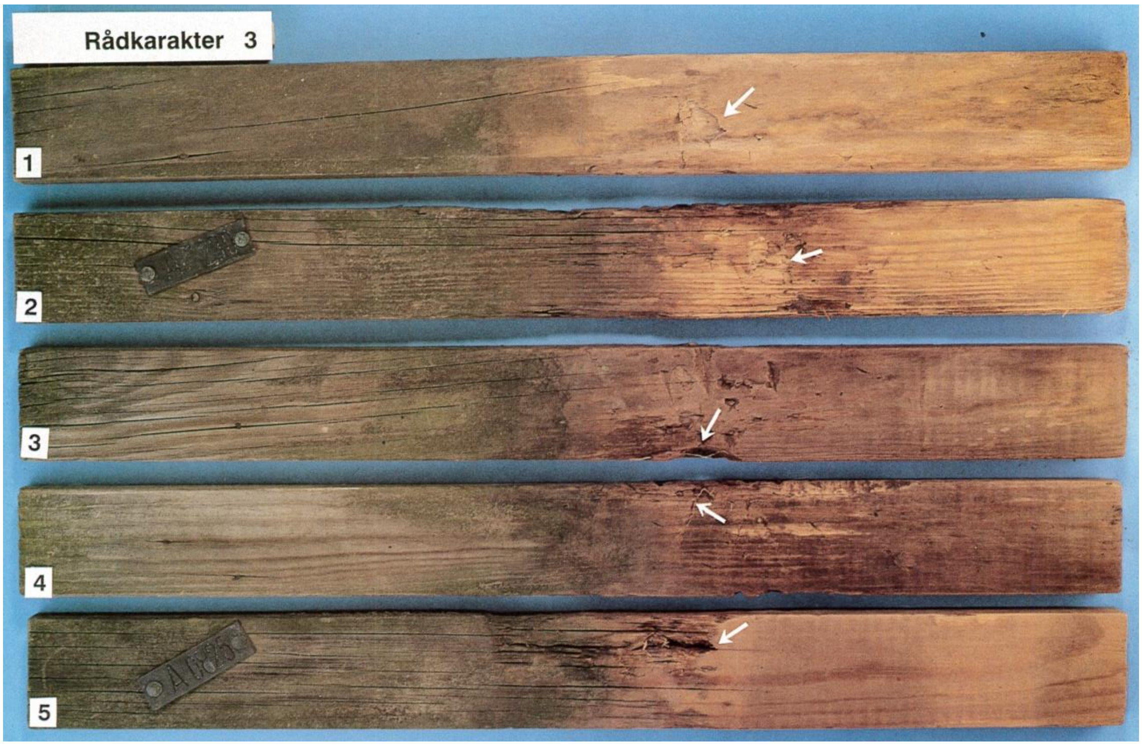


Figure 4: Examples of EN 252 - stakes – Rating ‘3 – severe attack’ (taken from: Borsholt and Henriksen 1992).

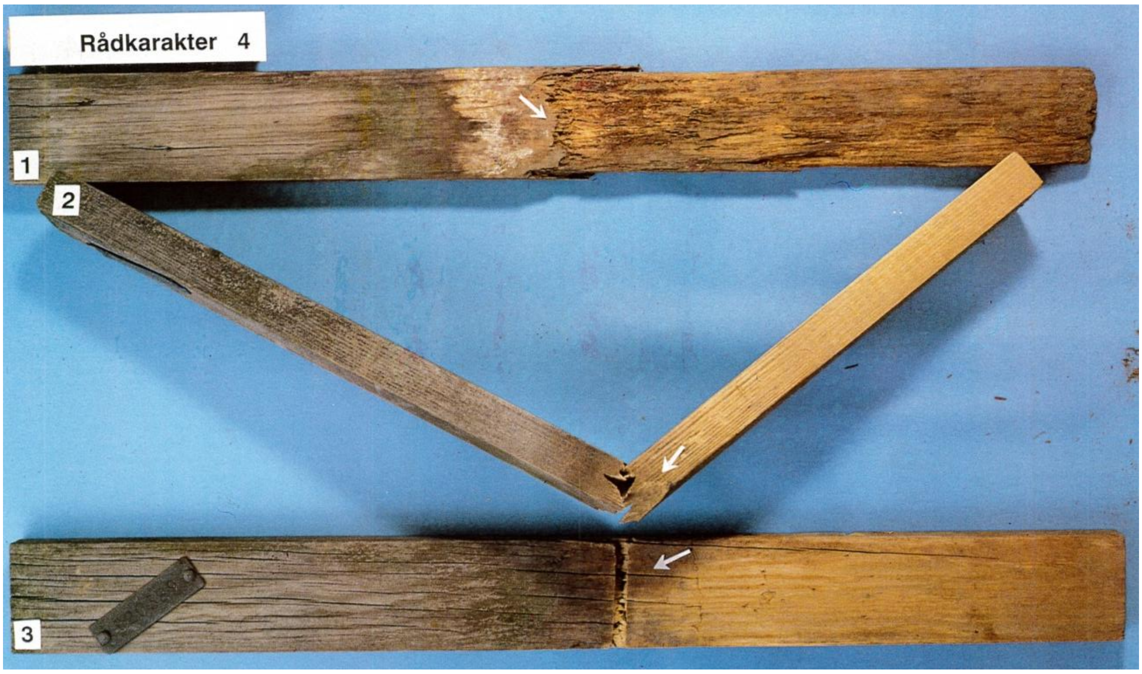


Figure 5: Examples of EN 252 - stakes – Rating ‘4 - failure’ (taken from: Borsholt and Henriksen 1992).

Figure 6: European ash. Failure after 0.5 years exposure. Visual inspection showed typical signs of soft rot: shell-shaped splinter, attack on the outer wood shell, clean fracture

Figure 7: Beech. Failure after 0.5 years exposure. Visual inspection showed typical signs of white rot: whitish discoloration, long-fibred splinter, fibred fracture

Figure 8: Beech. Failure after 0.5 years exposure. Visual inspection showed typical signs of soft rot: small cubic breaks, softened surface, dark discoloration.

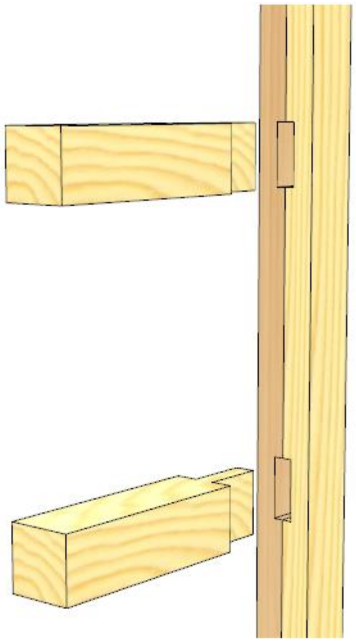
2 Above ground testing - Test methods and moisture monitoring

(Linda Meyer & Christian Brischke)

2.1 Test methods

Numerous test methods to determine the durability of timber and timber products have been described in relevant literature. However, only some of these methods have been standardized and thus only very few are regularly used for resistance tests in the field. Since results from extensive comparative field studies have shown differences in moisture performance between different test methods, one might consider further test designs to adequately the variation of moisture loads that can be expected within use class 3.

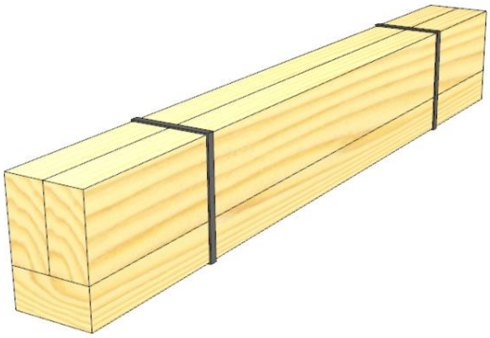
In the frame of this training school in total 27 different test methods containing long term moisture recordings will be presented. The test set up covers established tests (e.g. L-joint test, decking test, ground proximity test) as well as some new alternative test methods (Figure 9 - Figure 27).



- Specimen size:
  195 (ax.) x 38 x 38 mm^3
- Distance to ground: 100 cm
- Mortise containing of beech and pine sap feeder material
- Supported at 10° to vertical

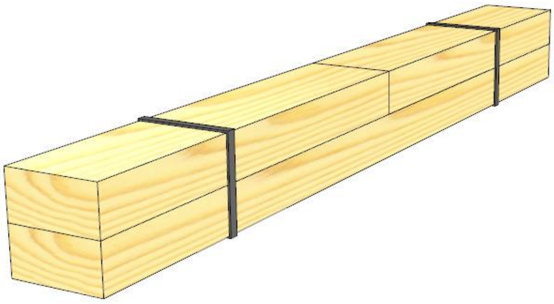
<u>Painted:</u>
- Defect painting at the joint

Figure 9: Accelerated L-Joint test (painted and unpainted), according to Van Acker & Stevens (2003).



- Specimen size:
  195 (ax.) x 38 x 38 mm^3
- Distance to ground: 100 cm
- Bottom segment with two upper segments edges faced upward
- Segments held together with cable straps

Figure 10: Bundle test I according to Brischke et al. (2011).

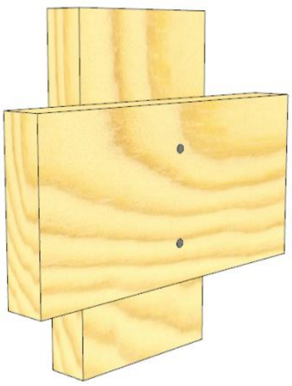


- Specimen size:
  195 (ax.) x 38 x 38 mm^3
- Distance to ground: 100 cm
- Bottom segment with two smaller (half length) upper segments edges faced sideward
- Segments held together with cable straps

Figure 11: Bundle test I according to Brischke et al. (2011).

- Specimen size:
  200 (ax.) x 20 x 8 mm^3
- Distance to ground: 15 cm
- Mini stakes placed on concrete, covered with polyethylene stick

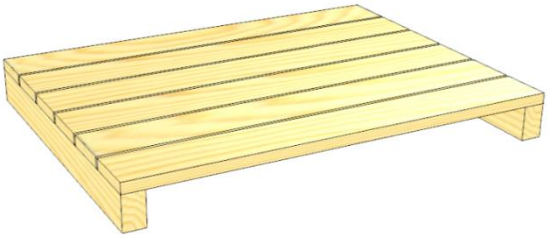
Figure 12: Close to ground mini-stake according to Westin et al. (2004).



- Specimen size:
  152 (ax.) x 76 x 19 mm^3
- Distance to ground: 15 cm
- Boards screwed together at mid-length

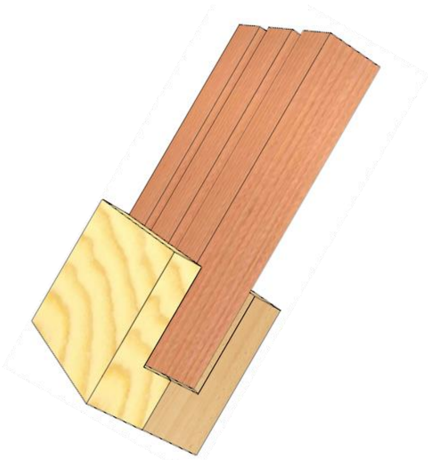
According to Highley (1995)

Figure 13: Cross brace test according to Highley (1995).



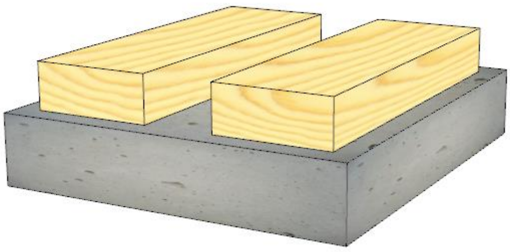
- Specimen size:
  500 (ax.) x 20 x 100 mm^3
- Distance to ground: 16 cm
- Decking boards horizontally fixed on supports from the same wood species
- Distance between boards: 20 mm

Figure 14: Decking test ('close to ground') according to Laks et al. 2008).



- Specimen size:
  200 (ax.) x 35 x 35 mm^3
- Distance to ground: 100 cm
- Specimens embedded in feeder boards (Beech, Scots pine sap-wood)
- Supported at 45°

Figure 15: Embedded test according to Cookson and Carr (2009).



- Specimen size:
  150 (ax.) x 50 x 20 mm^3
- Distance to ground: 15 cm
- Specimens exposed directly on concrete blocks

<u>Shaded:</u>

- Specimens placed in a shade box

Figure 16: Ground proximity test (shaded and unshaded) according to AWPA E 18 (2004).

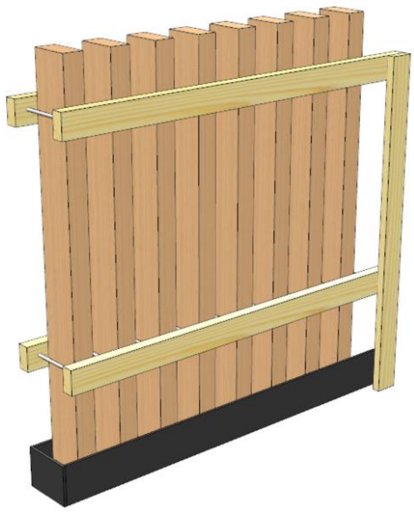
Façade:

- Specimen size:
  500 (ax.) x 100 x 20 mm^3
- Distance to ground: 100 cm
- Board on board cladding
- Upper end-grains protected by tin roof
- South oriented

Decking:

- Specimen size:
  500 (ax.) x 100 x 20 mm^3
- Distance to ground: 57 cm
- Single layer screwed to beam supports
- Distance between boards: 20 mm

Figure 17: Combined façade and decking – element according to Bornemann et al. (2012).

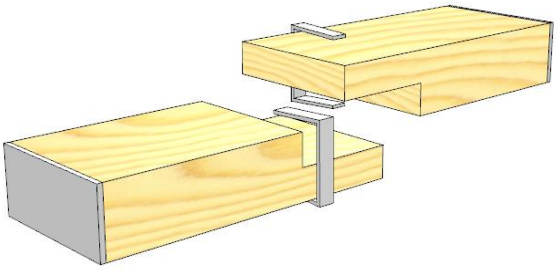


- Specimen size:
  500 (ax.) x 50 x 25 mm^3
- Distance to ground: 100 cm
- Vertically exposed in a gutter
- Gutter size: 1000 x 50 x 65 mm^3
- Laterally draining of water not possible

Figure 18: Gutter test modified after Fougerousse (1976).

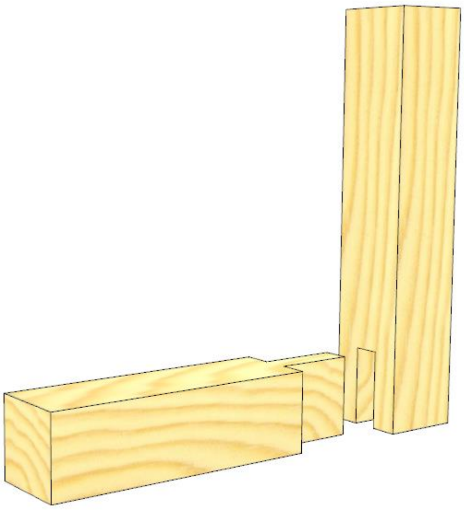
- Specimen size:
  500 (ax.) x 50 x 25 mm^3
- Distance to ground: 20 cm
- Upper layers displaced laterally by 25 mm
- Supports made from aluminum PE spacers for segmentation,
  3 specimens serve as one replicate

Figure 19: Horizontal double layer test modified after Augusta (2007).



- Specimen size:
  180 (ax.) x 85 x 40 mm^3
- Distance to ground: 100 cm
- Two segments with lap-joint held together by metal clamp
- Supports made from aluminum
- End-grains PU-sealed

Figure 20: Lap-joint test according to CEN/TS 12037 (2003).

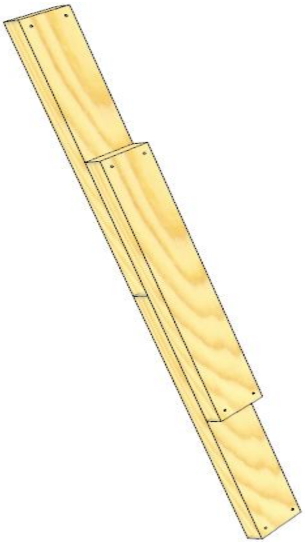


- Specimen size:
  203 (ax.) x 38 x 38 mm^3
- Distance to ground: 100 cm
- Tenon-mortise bond
- Supported at 10°
- Specimens placed on supports made from plastics

<u>Painted:</u>

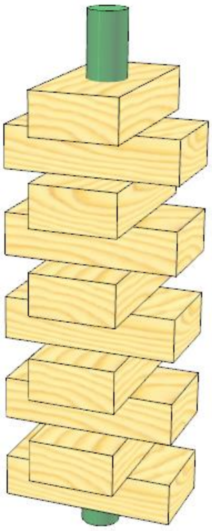
- Defect painting at joint

Figure 21: L-joint test (painted and unpainted) according to EN 330 (1993).



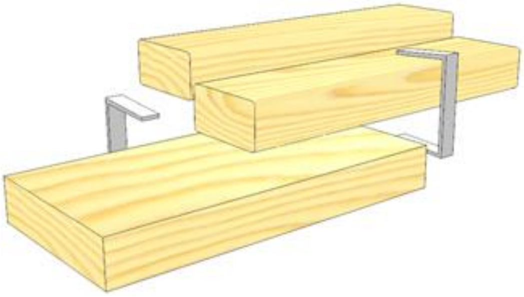
- Specimen size:
  500 (ax.) x 95 x 22 mm^3
- Distance to ground: 100 cm
- Three specimens overlapping each other and screwed together
- Supported at 60°

Figure 22: Johansson test according to Johansson (2001).



- Specimen size:
  100 (ax.) x 50 x 25 mm^3
- Distance to ground: 0 cm
- Specimens turned by 90° to each other and piled up on a plastic coated rod

Figure 23: Rod test.



- Specimen size:
  a) 200 (ax.) x 49 x 25 mm^3
  b) 200 (ax.) x 100 x 25 mm^3
- Three segments held together by a steel clamp
- Supports made from aluminum
- Distance to ground: 20 or 100 cm
- Specimens placed in a shade box

Figure 24: Sandwich test modified after Zahora (2008) with different heights above ground and shading.

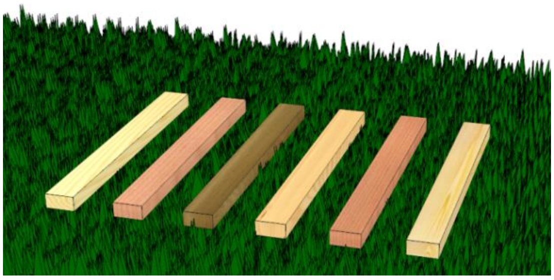
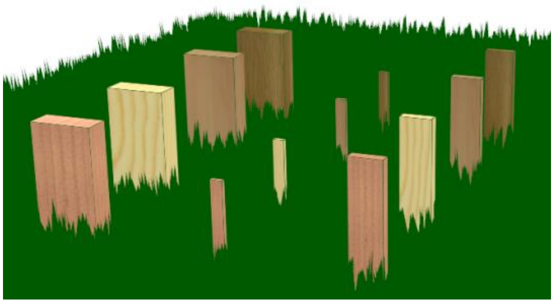


Figure 25: On-ground test.

- Specimen size:
  500 (ax.) x 50 x 25 mm3
- Distance to ground: 0 cm
- Specimens directly placed on ground



- Three different specimen sizes:
  EN 252
  500 (ax.) x 50 x 25 mm^3

  Double sized

  500 (ax.) x 100 x 50 mm^3

  Mini stake
  200 (ax.) x 20 x 8 mm^3
- Stakes buried to half of their length

Figure 26: In-ground stake tests with different specimen dimensions according to prEN 252 (2012).

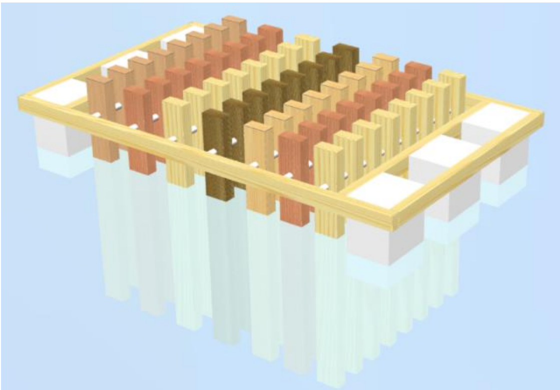


Figure 27: Freshwater test.

- Specimen size:
  500 (ax.) x 50 x 25 mm^3
- Pontoon with specimens, vertically exposed in a lake
- Specimens submerged in freshwater to half of their length

2.2 Decay assessment

Due to deviating size and shape of the test specimens the rating schemes of the two European standard above ground methods are similar, but not identical with the in-ground test assessment according to prEN 252 (2012). A description of the decay assessment schemes for lap-joint and L-joint specimens is given in Table 2 and Table 3.

Please note the differences in the description of the grading systems, even though it is a five-step scale for all three tests.

Table 2: Rating scale according to EN 330 (1993) – L-joint method.

Rating	Description	Definition
0	Sound	No evidence of deterioration.
1	Slight attack	Slight discoloration, often dark and in streaks: no significant softening or weakening of the wood.
2	Moderate attack	Distinct discolorations, but in discrete patches and streaks, with small areas of decay (softened, weakened wood); typically no more than 25% of the visible area affected.
3	Severe attack	Marked softening and weakening of the wood typical of fungal decay and in extensive patches or streaks; distinctly more than 25% of the visible area affected
4	Failure	Very severe and extensive rot; tenon often capable of being easily broken.

Note: Observations made on specimens for non-destructive inspection will often yield a lower rating than when surfaces created by sawing are available for evaluation.

Table 3: Rating scale according to CEN/TS 12037 (2003) – Lap-joint method.

Rating	Description	Definition
0	Sound	No evidence of decay.
1	Slight attack	Visible signs of decay, but no significant softening or weakening of the wood.
2	Moderate attack	Areas of decay (softened, weakened wood); typically not more than 3 cm³ and to a depth of 2 to 3 mm
2+	Moderate attack	Approaching 3, severe attack
3	Severe attack	Marked softening and weakening of the wood typical of fungal decay; distinctly more than 3 cm² affected and to a depth of 3 or 5 mm or 5 to 10 mm over a few cm²
3+	Severe attack	Approaching 4, failure
4	Failure	Very severe and extensive rot, joint member(s) often capable of being easily broken..

Note 1: Discoloration obviously due to the attack of wood destroying Basidiomycetes and/or soft rot fungi shall be recorded and mentioned in the test report. If recommended by the sponsor of the test discoloration due to staining fungi should be rated according to Annex C, Table C.1

Note 2: Due to physic-chemical lignin degradation defibration of the wood cells may occur at the upper surface of the lap-joints. Together with checks originating from differing wood moisture contents in different layers of the specimens their upper surface may be softened, especially when the lap-joints are wet. This has to be distinguished carefully from fungal decay.

Note 3: In certain climatic areas with predominantly high relative humidity and frequent precipitation soft rot may occur in a thin layer of the upper surface, leading to softening of this layer.

3 Microscopy - detection of decay types

(Andreas Rapp & Morten Klamer)

3.1 Diagnostic microscopy of exposed samples

Some guidance on the macroscopic and microscopic appearance of the different decay types is provided in annex D of CEN/TS 15083-2 (2005), where the following text has been taken from.

3.1.1 Introduction

In unsterile soil, wood can be degraded by a large number of different decay types. The following are the most commonly encountered decay types: brown rot, white rot, soft rot and attack by tunneling bacteria. […] In addition, wood can be degraded by erosion bacteria and a number of decay forms where the causal micro-organisms remain unknown. These types of decay are not described.

3.1.2 Macroscopical appearance

It is often helpful to start by looking at the macroscopic appearance of the samples. This will indicate where sections should be taken in case of uneven attack of the sample and will provide some clues to the major decay types.

3.1.3 Preparation of test specimens for microscopy

An ordinary light microscope using brightfield is adequate. Equipment for polarized light is a great advantage. Sections of a thickness of approximately 20 µm are cut using a microtome. Hand sections cut with a razor blade are also appropriate. In order to avoid misidentifications, it is strongly recommended to cut transverse as well as longitudinal sections. Radial longitudinal sections are better than tangential longitudinal sections. Decay patterns are more easily identified in softwoods than in hardwoods. It should be noted that preservatives may cause changes to the micro-morphology of the decay types.

The sections are placed on a glass slide in a solution of safranine (mass fraction of 0.1 % in water), then a cover glass is put on top of the section. The sec-

tions are viewed at magnifications from x 250 to x 400. Transverse sections are best viewed without polarized light although polarized light may be used to check transverse sections for brown rot. For viewing longitudinal sections, polarized light should normally be used. A solution of aniline blue (mass fraction of 0.1 % in a mass fraction of 50% lactic acid) can be used to stain fungi and bacteria.

3.1.4 Description of decay types

3.1.4.1 Brown rot

Early stages of brown rot are difficult to detect even using microscopy. More advanced attack is characterized by extremely high strength losses and by a dark brown color. Samples with advanced brown rot can be difficult to remove without breaking.

A typical feature of brown rot is that complete removal of parts of the cell wall is very rarely observed. Thus the outlines of the fibers are generally well preserved. Transverse sections in polarized light are less brilliant than sound wood and the color of the section when using safranine is a dull reddish brown. A closer look at fibers with thick cell walls shown that the smooth surface of sound fibers has changed to a more amorphous structure. Longitudinal sections of advanced stages show that the fiber outlines and pits are well preserved despite a drastic loss of birefringence. The presence of hyphae with clamp connections supports the identification of brown rot.

3.1.4.2 White rot

A light brown discoloration is often observed in the early stages of white rot especially in softwoods. More advanced attack is characterized by bleaching which may be patchy. The wood often becomes fibrous and smaller or larger parts of the samples may be missing.

There are two basically different types of white rot. The first type is characterized by a simultaneous degradation of the main chemical components of the wood, whereas the second type is characterized by preferential removal of lignin. The attack of the first type is generally seen in transverse sections as a *more or less uniform erosion of the cell walls. Sometimes distinct troughs can be seen. Through the erosion the cell walls become thinner and in the later stages only the middle lamella will remain. Eventually, the middle lamella will also disappear. This is a unique feature of white rot attack. (Soft rot Type 2 leads to erosion of cell walls in several hardwoods, but in this case the middle lamella will not be degraded).*

The second type of attack leads to a gradual disappearance of lignin from the cell walls. In transverse sections stained with safranine this is seen as non-stained areas starting at the inner arts and progressing towards the middle lamella, which eventually will disappear.

In addition large bore holes are often common and the pit borders in the earlywood of softwoods become eroded resulting in large round holes in the cell wall. Hyphae with clamp connections support the identification.

3.1.4.3 Soft rot

Soft rot fungi cause two different types of attack. Type 1 is characterized by cavity formation within the wood cell walls and Type 2 by erosion of the cell walls resulting in thinner walls. Type 2 is only significant in hardwoods (like beech and birch). The middle lamella will always remain intact. Cavity formation (Type 1) is the most typical form of soft rot attack and also the only form of importance in softwoods. The cavities are discrete and often elongated, forming sequentially along hyphae growing within the S_2 layer of cell walls. The longitudinal axis of the cavities in relation to the longitudinal axis of the fiber. In some cases, particularly in compression wood of softwoods, cavities may also be formed in the S1 layer, resulting in a perpendicular orientation with respect to the fiber axis.

The cavities are best observed in longitudinal sections using polarized light. The cavities are then seen as rhombic to elongated dark areas with pointed ends. The cavities are often arranged in a chain-like way. A hypha can usually be seen within each cavity. The hypha is very thin in the early stages but later becomes broader, often darkly colored and heavily segmented. (Other fungi may form longitudinal bore holes within the wood cell walls, but such bore holes are not as regularly oriented as soft rot cavities).

In transverse sections the cavities are seen as rounded holes, staring as a very minute hole which then grows larger. A transverse section of a hypha can often be seen in the larger holes. (Other micro-organisms, such as tunneling bacteria and some fungi, also attack the wood cell walls in a way that results in small bore holes visible in transverse sections, but these bore holes remain minute in most cases).

3.1.4.4 Tunneling bacteria

These bacteria are very common in fertile soils and they are known to attack treated wood which is resistant to most forms of fungal decay. Very advanced attack results in a granular structure of the outermost layers. The green color of samples containing copper is often "bleached" in patches to a light yellow/brown color.

The bacteria penetrate into the wood cell walls where they increase in numbers through division. There are different forms of attack. Some types are characterized by long tunnels spreading through the wood cell walls whereas other forms are seen as more compact colonies resulting in a honeycomb structure. The bacteria may be seen within the tunnels after staining with aniline blue. Very advanced attack y tunneling bacteria results in a granular appearance of the fibers when observed in longitudinal sections.

The first signs of attack in transverse sections are seen as minute bore holes which never enlarge. Areas of the cell wall then become granulated. Tunnels perpendicular to the longitudinal axis of the fibers are sometimes observed. Such tunnels may traverse through the middle lamella into adjacent fibers.

3.2 Decay types – Example photographs

Typical features of the different decay types are illustrated in the following figures.

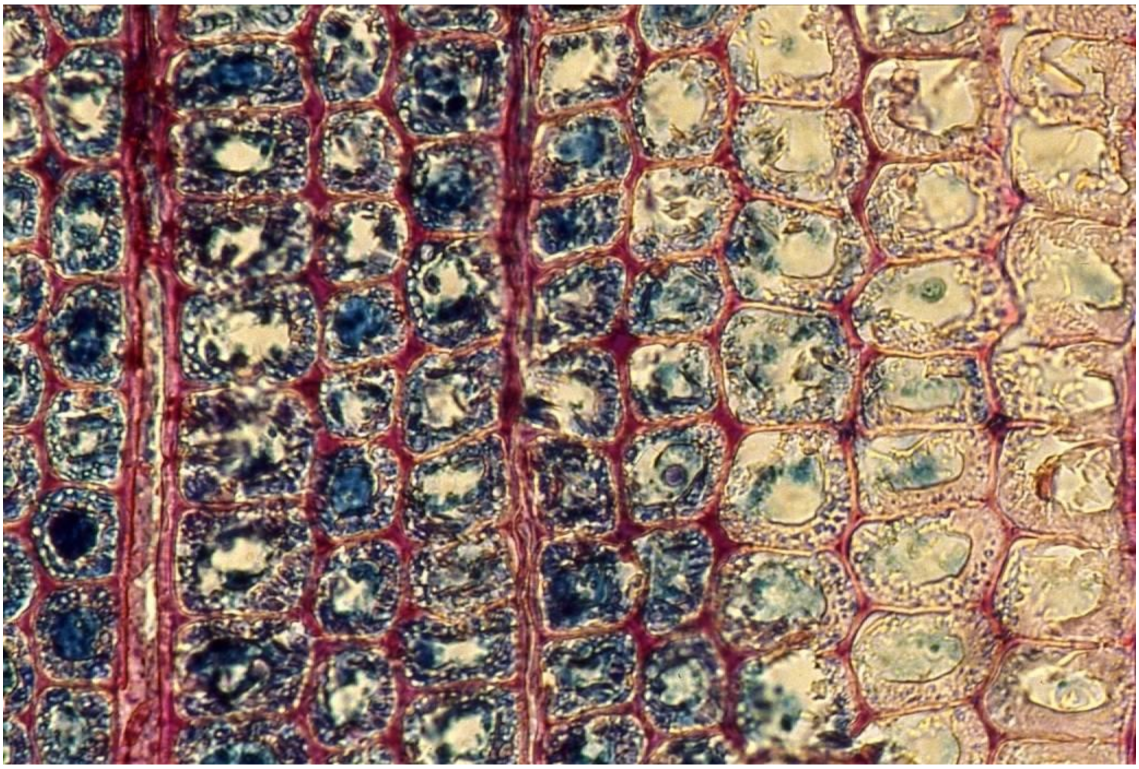


Figure 28: Soft rot decay on Scots pine. Transverse section colored with safranine – basic blue; Brightfield: Caverns in S_2 layer (Photo: A. Rapp).

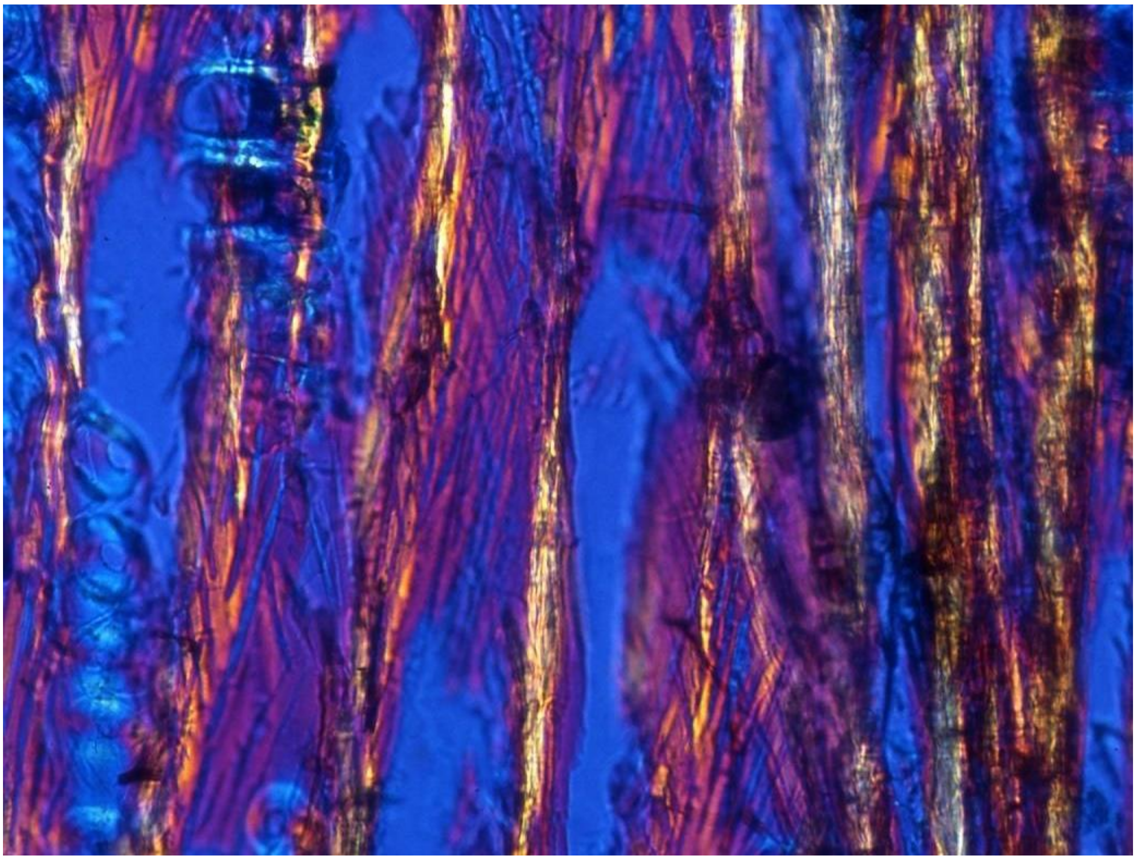


Figure 29: Soft rot decay on Scots pine. Radial section colored with safranine –basic blue, polarized light. Note: Angle between caverns and cell axis = stem axis (Photo: A. Rapp).

Figure 30: Soft rot decay on Scots pine. Radial section colored with VCA (basic violet – chrysoidine – basic blue), Brightfield (Photo: A. Rapp).

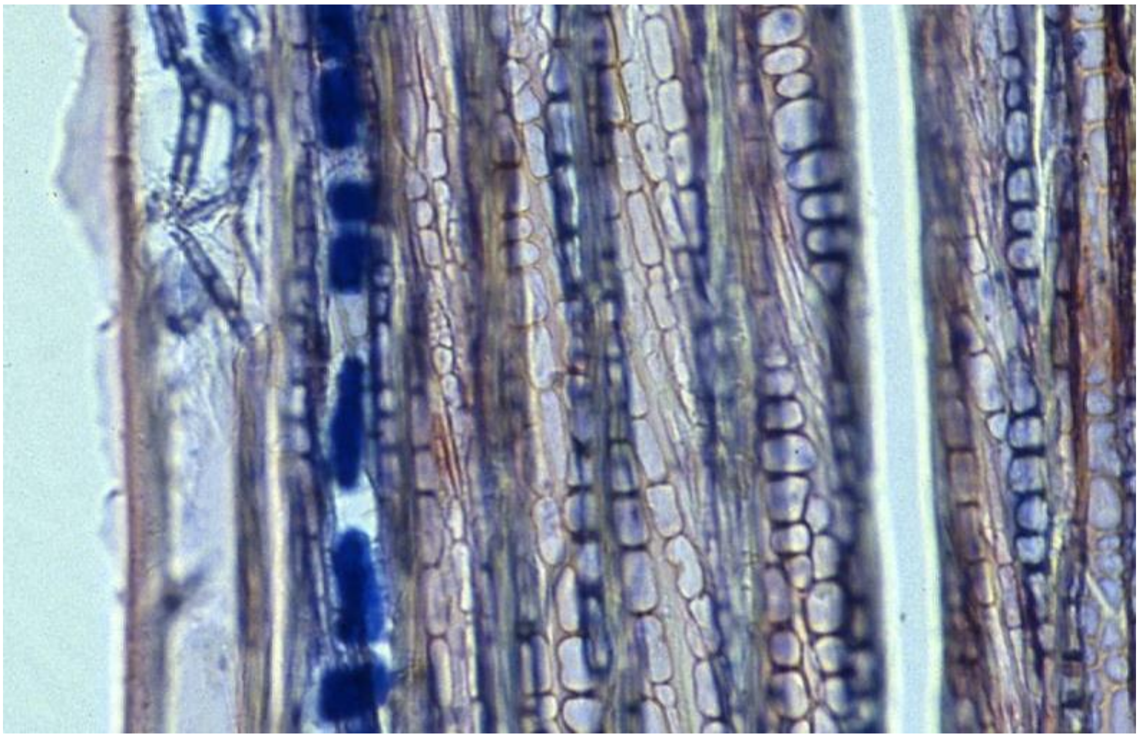


Figure 31: Soft rot decay on Scots pine. Radial section colored safranine – basic blue), Brightfield. Note: Angle of caverns and segmented hyphae (Photo: A. Rapp)

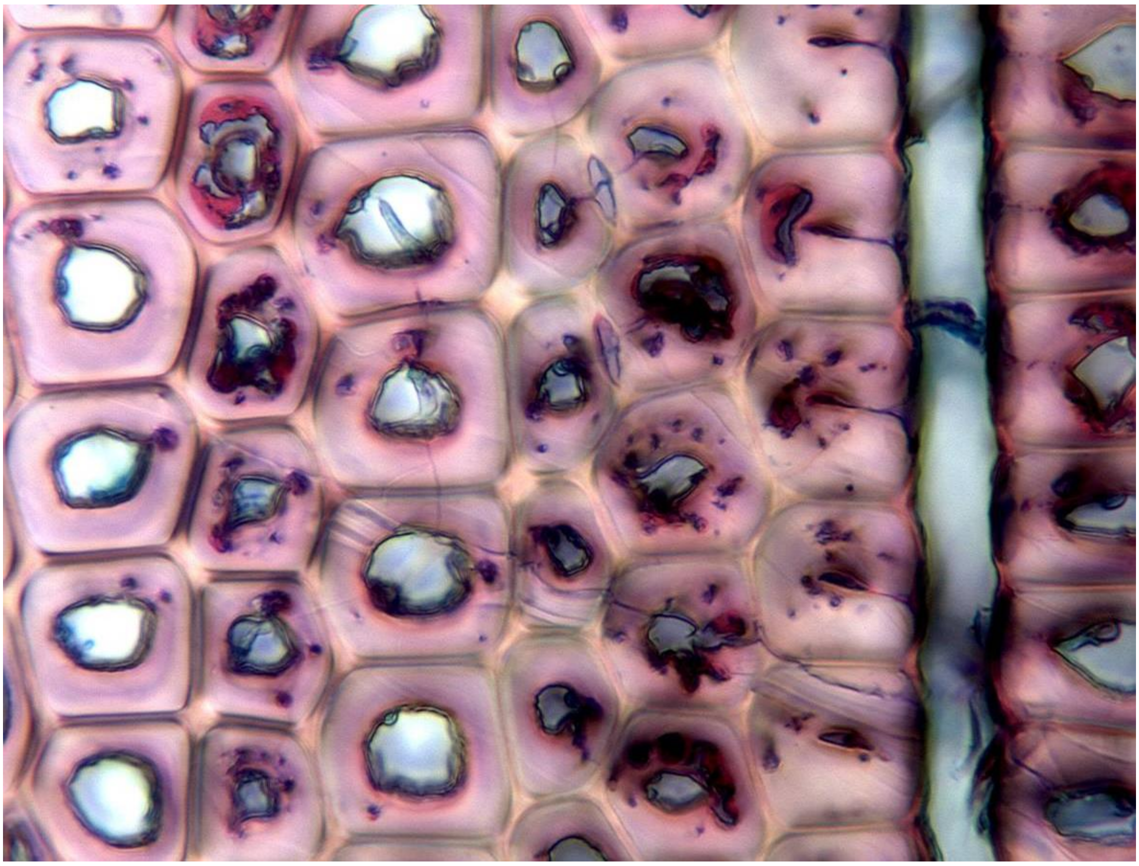


Figure 32: Soft rot decay on Scots pine. Transverse section colored with VCA, Brightfield. Note: Caverns S_2 layer (Photo: A. Rapp).

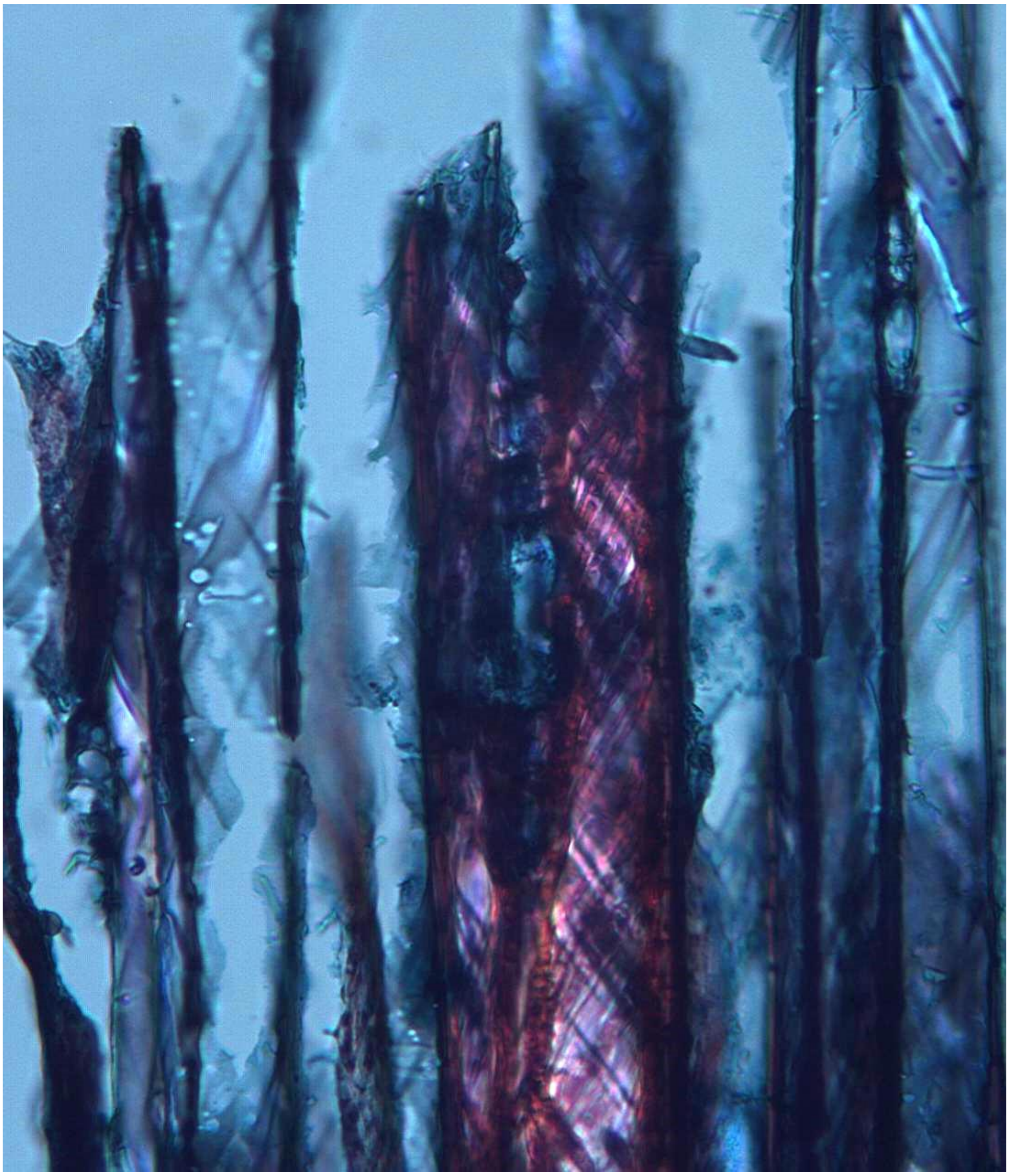


Figure 33: Soft rot and white rot decay on Scots pine. Transverse section colored with VCA, Bright-field. Note: Angle between caverns in S_2 layer and tracheid axis versus bore holes orthogonal to the axis (Photo: A. Rapp).

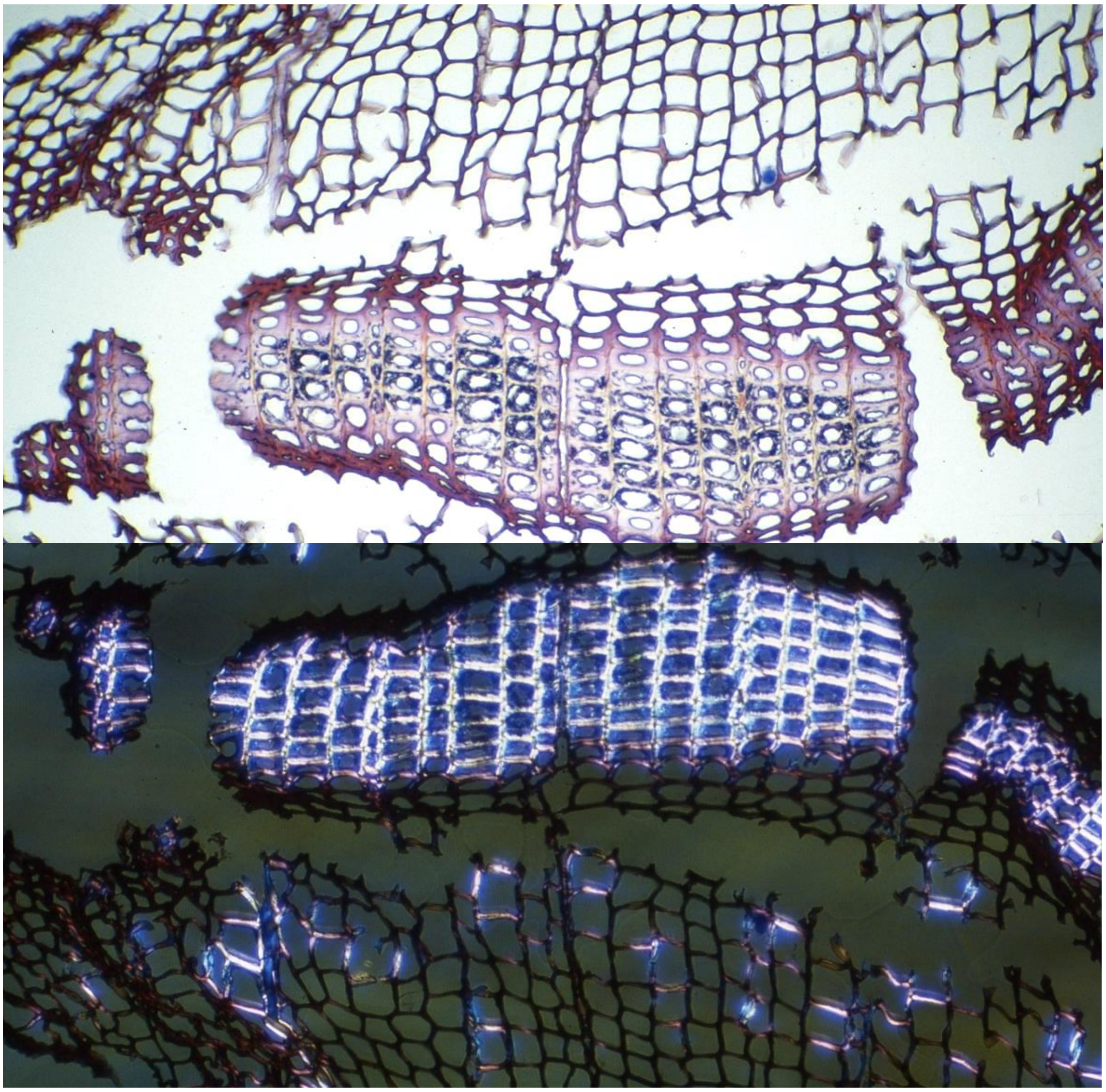


Figure 34: Soft rot and brown rot decay on Scots pine. Transverse section colored with safranine – basic blue. Top: Brightfield, bottom: polarized light with crossed polarization filters. Note: Difference in loosing birefringence and coloration of soft and brown rot in early and late wood; caverns in S2 and thinned cell walls without holes (Photo: A. Rapp).

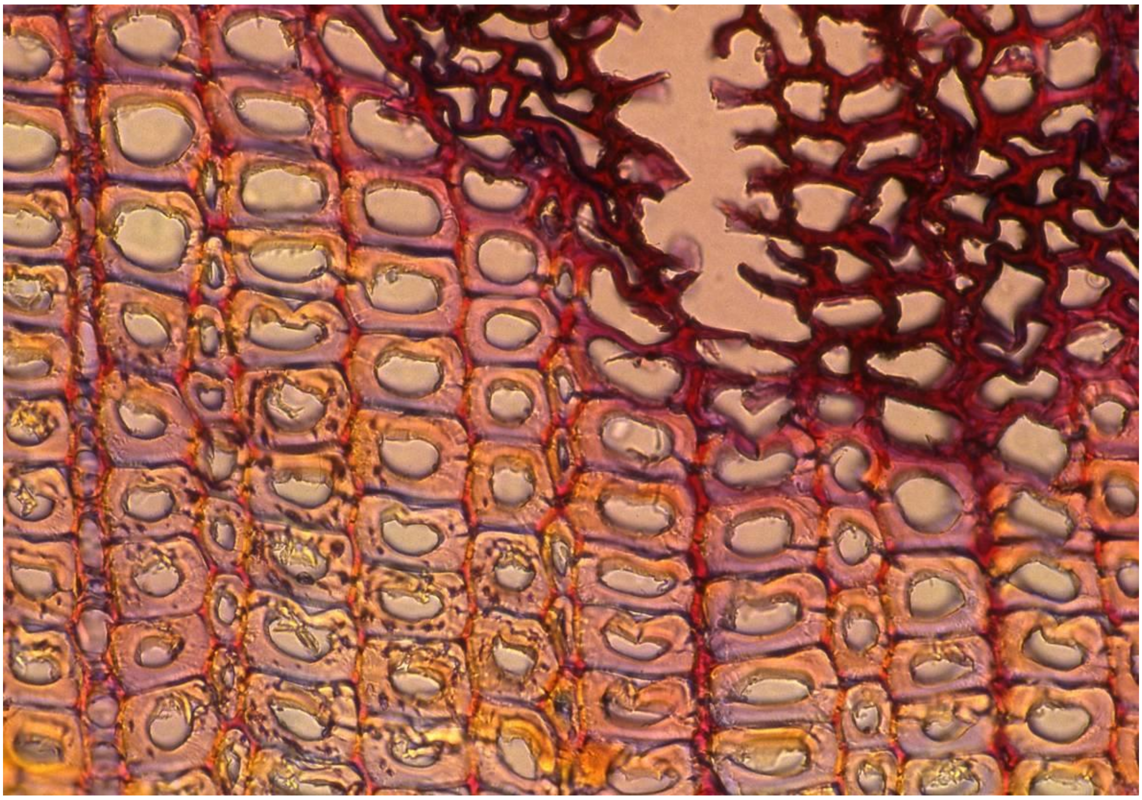


Figure 35: Soft rot and brown rot decay on Scots pine. Transverse section colored with safranine – basic blue. Brightfield, Note: Caverns in S_2 vs. thinned and deformed cell walls without holes and intense red coloration (Photo: A. Rapp).

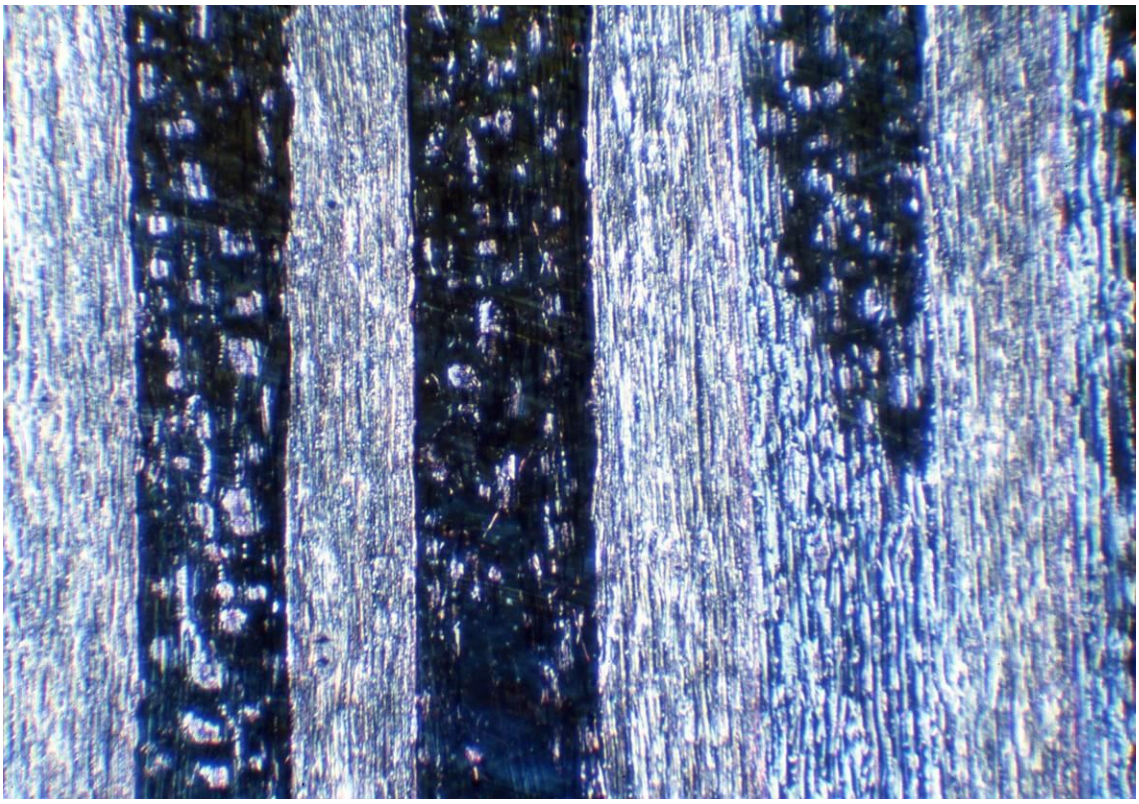


Figure 36: Brown rot decay on Scots pine. Transverse section colored with safranine – basic blue. Polarized light. Note: Loss of birefringence in early wood (Photo: A. Rapp).

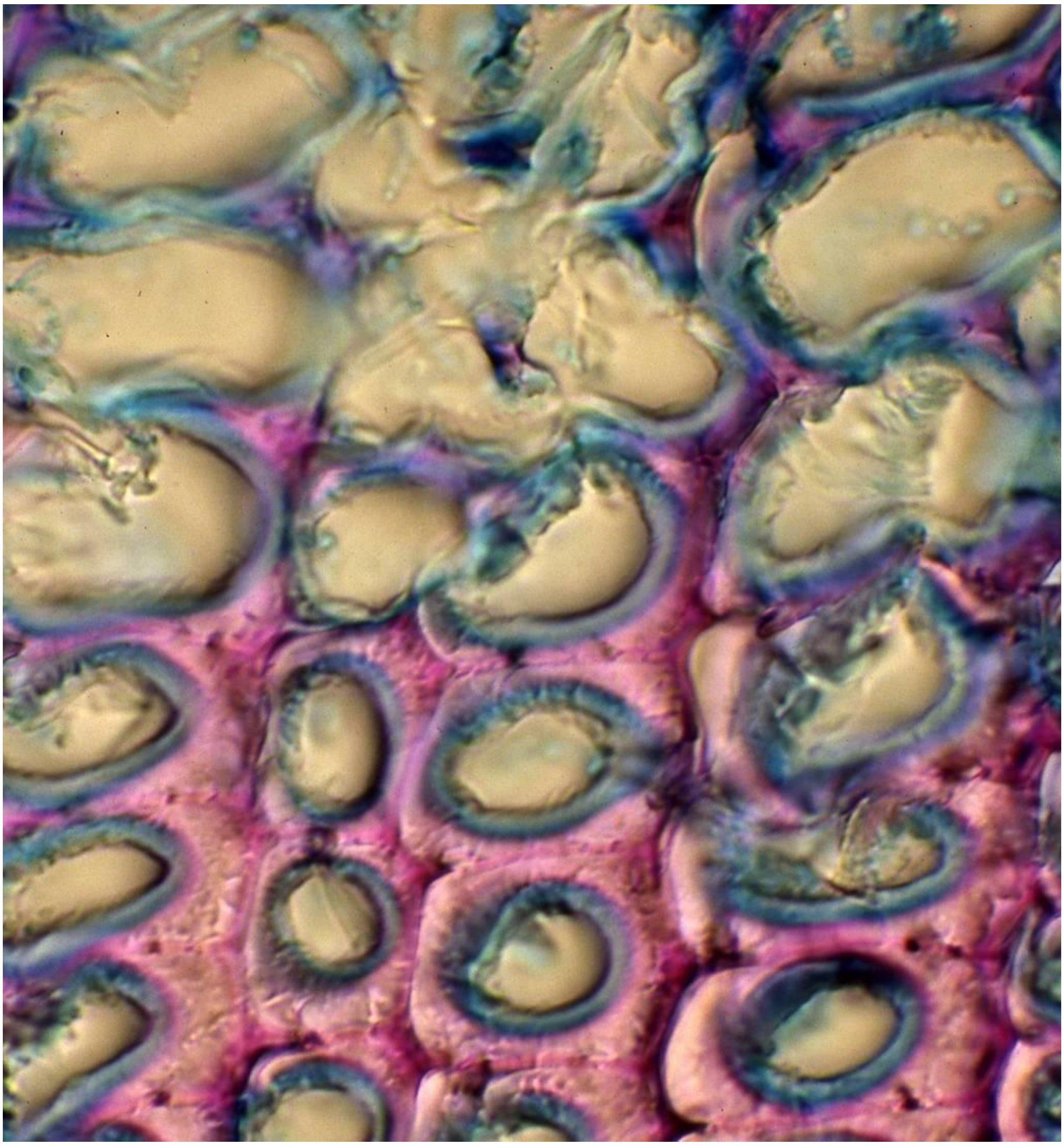


Figure 37: White rot decay on Scots pine. Transverse section colored with safranine – basic blue. Brightfield. Note: Delignification, single bore holes, complete decomposition of cell walls (Photo: A. Rapp).

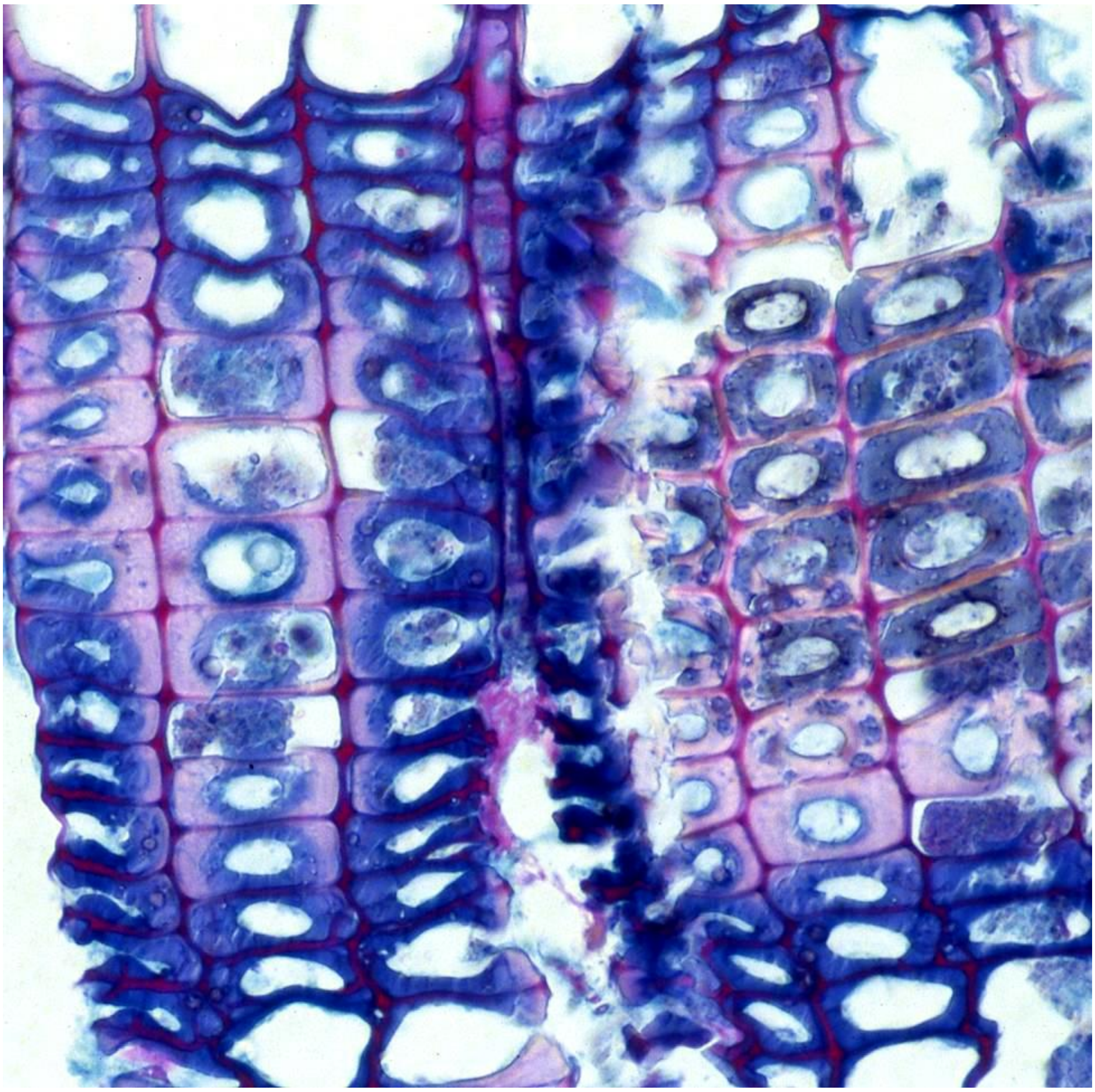


Figure 38: White rot decay on Scots pine. Transverse section colored. Brightfield. Note: Delignification, single bore holes, complete decomposition of cell walls (Photo: A. Rapp).

Figure 39: Filamentous white rot decay on Scots pine. Radial section colored. Polarized light. Note: fine partly net-like caverns, NOT following the fibril angles (Photo: A. Rapp).

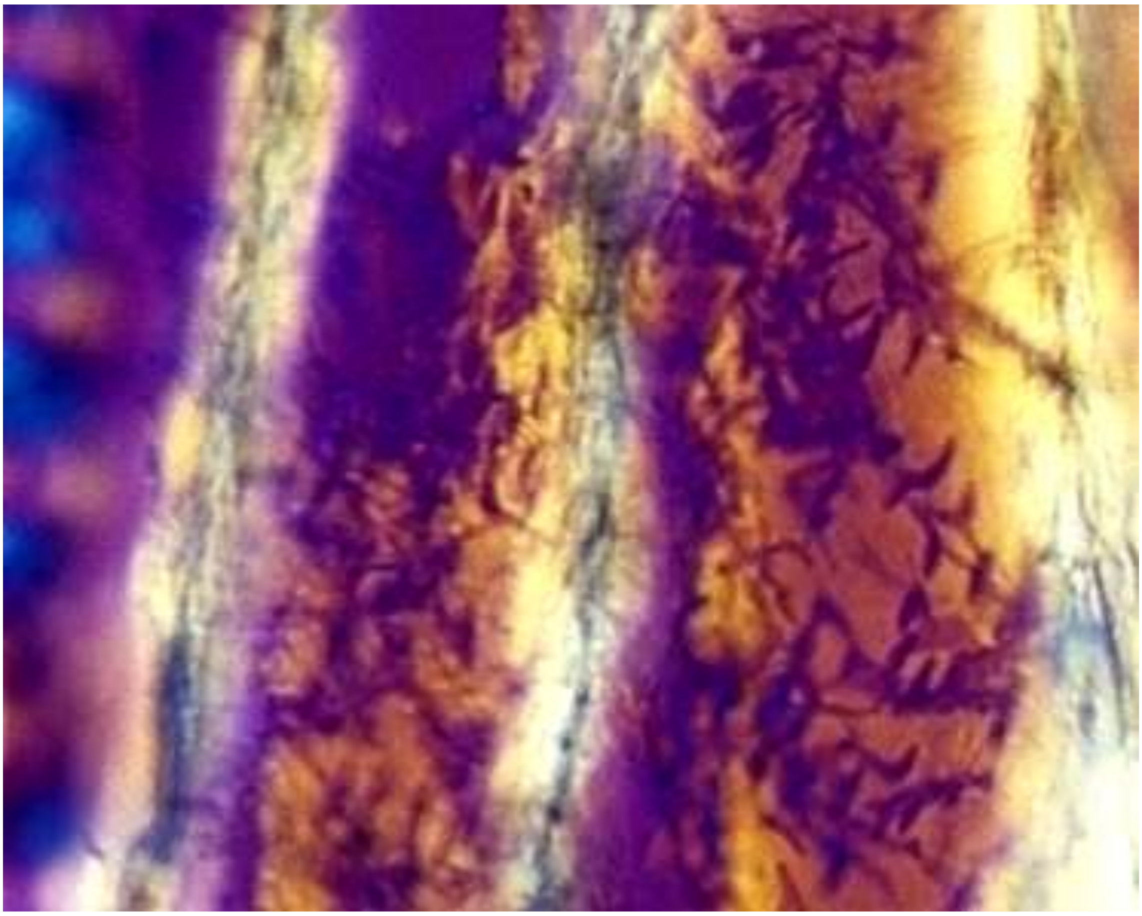


Figure 40: Tunneling bacteria on Scots pine (Photo: A. Rapp).

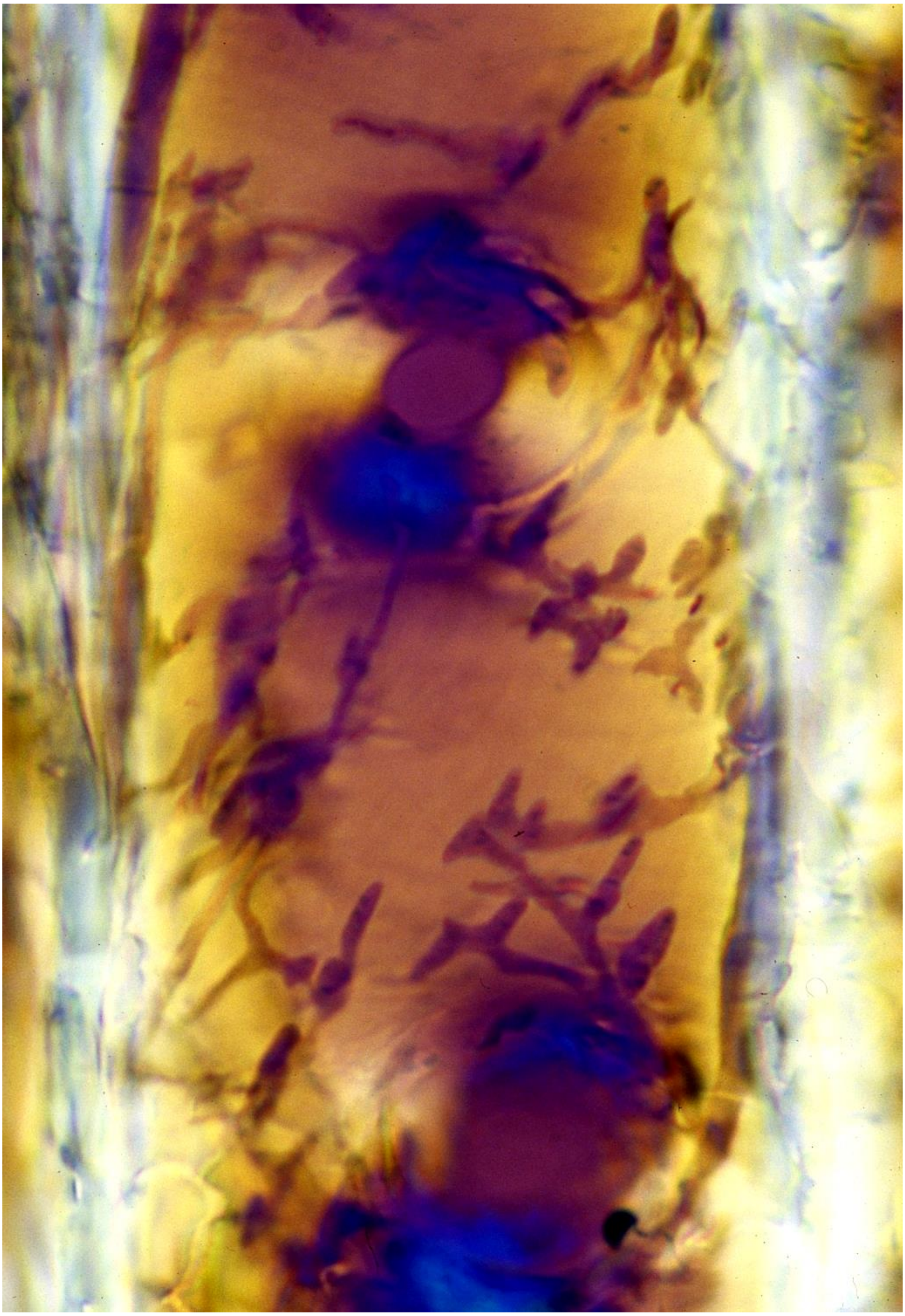


Figure 41: Tunneling bacteria on Scots pine, radial section (Photo: A. Rapp).

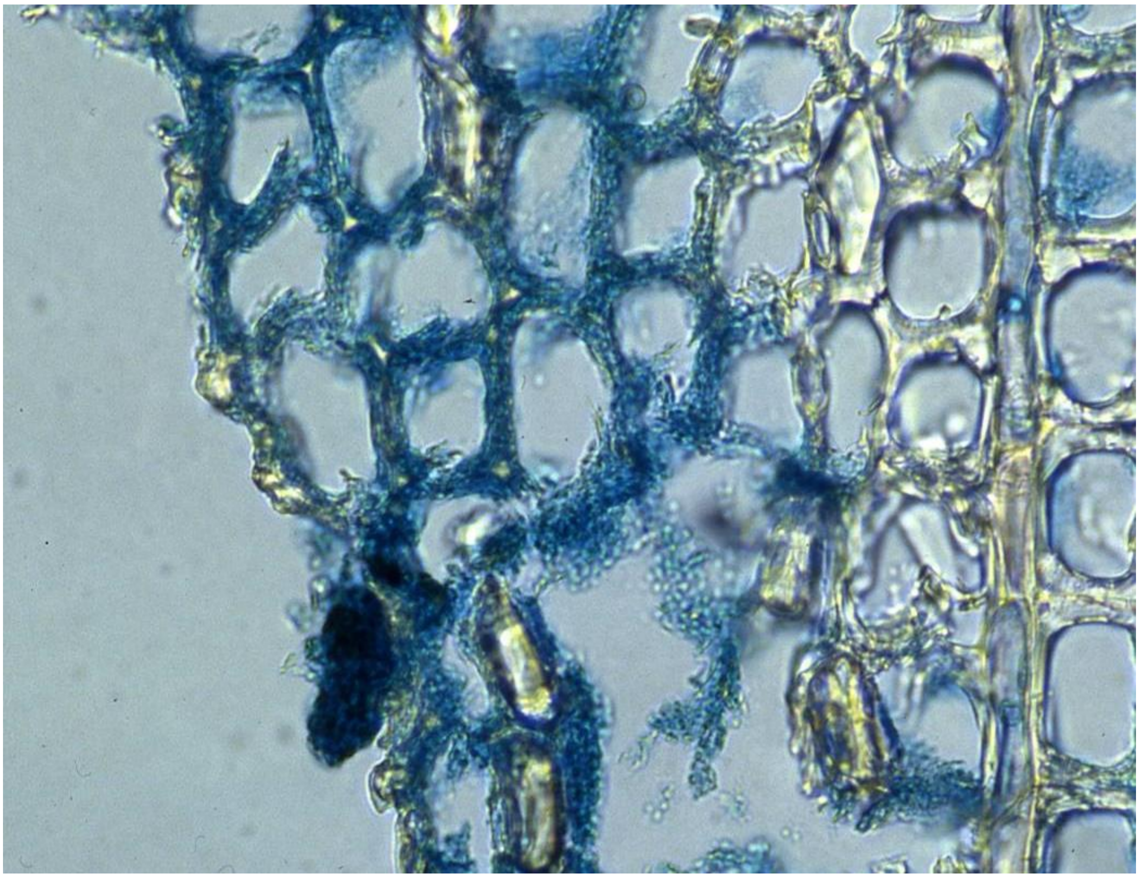


Figure 42: Melamine resin treated pine: Tunneling bacteria, transverse section colored with basic blue, Brightfield (Photo: A. Rapp).

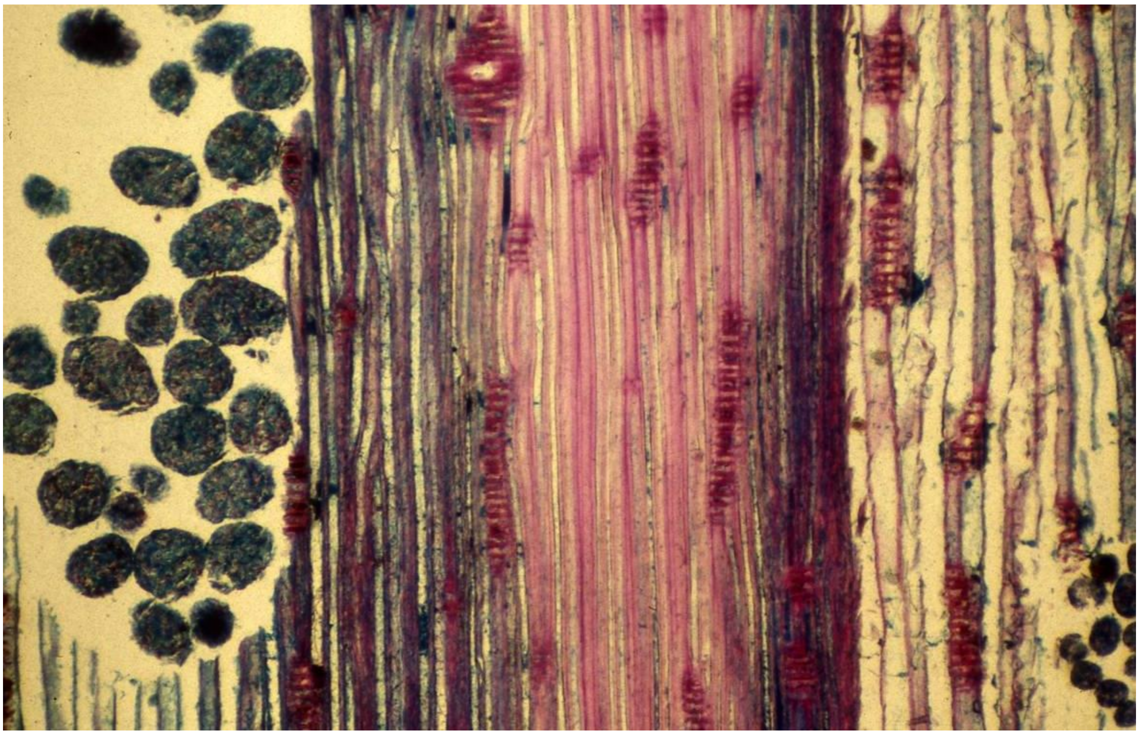


Figure 43: Scots pine, transverse section colored with safranine – basic blue, nutritional traces from wood lice and fecal pellets (Photo: A. Rapp).

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