Wood Deterioration, Protection and Maintenance
Wood Deterioration, Protection and Maintenance

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Preface

It is well known that wood has been used since ancient times as a structural material for buildings, as the main or auxiliary material in agriculture and later in industrial products, and as a material for furniture and various artistic products.

The service life of wooden products depends first of all on the natural durability of the wood species and wooden composites used, but also very significantly on their design, their methods of chemical and modifying protection, their exposure and their maintenance.

People are able to prolong the lifetime of wooden products based on practical knowledge related to wood-damaging agents (e.g. solar radiation, water, fire, aggressive chemicals, wood-decaying fungi, moulds, wood-destroying insects or marine borers), and also from theoretical studies related to the mechanisms of their action on wood at the molecular, anatomical, morphological and geometry levels.

The structural protection of wooden products is based first of all on the application of durable wood species and other high-quality materials. Simultaneously, the presence of wood-damaging agents has to be limited by using suitable designs with the aim to reduce contact of wood with rain and other sources of water, to reduce the creation of water condensate, and to reduce the impact of ultraviolet (UV) light and fire. So, for this purpose, suitable atmospheric, moisture-impermeable, UV and fire-retardant insulations are applied.

Chemical protection of wood is performed with preservatives; that is, mainly with fungicides, toxic and hormonal insecticides, fire retardants and UV-protective finishes that are applied on the wood’s surface and also into its depth. Currently, for wood preservatives not only is their efficiency important, but also their effects on human health and the environment. The optimization of wood pretreatment (e.g. debarking, drying, improving permeability) and its chemical preservation technology (e.g. time of dipping, vacuum, and/or pressure) derive from the theoretical principles of flow and diffusion of preservative substances in the capillary structure of wood. Plywood, particleboards and other wooden composites can be chemically treated during their production or subsequently.

The modifying protection of wood is a prospective mode for improving its resistance against biological agents and dimensional changes. Using active chemical modification, the —OH groups of the lignin–saccharide wood matrix react with molecules of a suitable chemical. This results in a decrease in wood hygroscopicity, and fungi, insects or marine borers then have less interest in this treated wood (e.g. acetylated wood). Thermally modified wood also leads to good resistance to atmospheric factors and biological damage, mainly where there is no contact with the ground.
Wooden products have to be regularly maintained with the aim to increase their lifetime. However, when they became damaged, a thorough inspection of their actual state is important; that is, the diagnosis of the cause, type, degree and range of their damage. Biologically damaged wood should be sterilized. Subsequently, for restoration of smaller wooden elements are used conservation methods, working with natural and synthetic substances. Load-bearing elements of wooden houses, roofs, ceilings and other constructions can be reinforced with prostheses, splicing, special bracing or other methods.

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Ladislav Reinprecht is a professor at the Faculty of Wood Sciences and Technology, Technical University in Zvolen, Slovakia. He obtained an MSc degree in organic chemistry, a postgraduate degree in mycology and a PhD degree in wood technology. For students and specialists he has written many books and monographs, both in Slovak (e.g. Wood Protection, ThermoWood, Silan-Wood, Processes of Wood Deterioration, Reconstruction of Damaged Wood Structures, Wooden Buildings – Constructions, Protection and Maintenance, Wooden Ceilings and Trusses – Types, Failures, Inspections and Reconstructions), and in English (e.g. Strength of Deteriorated Wood in Relation to its Structure, TCMTB and Organotin Fungicides for Wood Preservation). His primary research interest lies in the analysis of abiotic and biological defects in wood structure – the conditions for their creation and the methods of their detection, inhibition and prevention. He has published the results of his experimental work in many articles in scientific journals and presented results at various international and domestic conferences.
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Wooden products (furniture, flooring, doors, etc.) and constructions (log cabins, bridges, ceilings, trusses, etc.) produced from various species of wood and types of wooden composites are in practice exposed to different environments, where they can be subjected to more forms of degradation (see Chapters 2 and 3).

With the aim to suppress the degradation processes in the wood, and also in glues, paints and other materials used for wooden products and constructions, it is desirable to use suitable forms of their structural, chemical and modifying protection so that their lifetime can be suitably increased (see Chapters 4, 5 and 6).

The service life of wooden products and constructions can be increased by their regular maintenance. However, when degradation processes in wood and/or in additional materials occur and cause damage, appropriate restoration methods should be used (see Chapter 7).

1.1 Basic information about wood structure and its properties

The structure of wood and wooden composites (Figures 1.1 and 1.2) and their exposure in conditions suitable for the action of abiotic factors and/or the activity of biological pests (Figure 1.3) are the basic prerequisites for potential damage of wooden products and constructions.

Wood is a biopolymer, created by a genetically encoded system of photosynthetic and subsequent biochemical reactions in the cambial initials of trees (Figure 1.1). Trees consist of approximately 70–93 vol.% of wood, with the rest being bast, bark and needles or leaves. Wood is the internal, lignified part of the stem, branches and roots. The characteristics of wood include: (1) anisotropy, typical in three anatomical directions – longitudinal, radial and tangential;
Figure 1.1 Structural levels of wood (modified from Eriksson et al. (1990) and Reinprecht (2008))


Figure 1.2 The basic types of wooden composites: (1) glulam (glued joints); (2) prefinished wood (coatings or foils); (3) wood–plastic (fibre reinforcement); (4) fibreboard (dispersion systems); (5) particleboard (macro-dispersion systems); (6) plywood (laminated systems); (7) impregnated wood (penetrations or diffusions). (Note: composite is a multicomponent system of materials consisting of at least two macroscopically distinguishable phases, of which at least one is solid)
Wood Durability and Lifetime of Wooden Products

Figure 1.3 Biological and abiotic wood-degrading factors

(2) inhomogeneity, influenced by the sapwood and heartwood, the early wood and late wood, and so on; (3) specificity, given by the wood species; and (4) variability, given by the growth conditions of the tree of a given wood species.

Wood is a traditional material, used for producing wooden buildings, furniture, work and sport tools, as well as art works. It is currently an irreplaceable raw material for the production of bio-based composites with the targeted combination of wood particles in various stages of disintegration and pretreatment with a complementary system of adhesives, waxes and other additives (Figure 1.2).

1.1.1 Wood structure

The structure of wood (Figure 1.1, Boxes 1.1, 1.2, 1.3 and 1.4) and wooden composites (Figure 1.2) is defined at four levels:

- primary (i.e. molecular/chemical structure);
- secondary (i.e. anatomical/submicroscopic structure);
- tertiary (i.e. morphological/microscopic structure);
- quaternary (i.e. geometric/macroscopic structure).
Box 1.1  A basic preview of the geometric structure of wood

The geometric structure of wood

Defines

The external appearance – shape, volume, colour, the ratio of tangential, radial and facial areas, the proportion of sapwood, heartwood and/or mature wood, the proportion of early and late wood in annual rings, the roughness and overall quality of the surfaces, and so on.

The macroscopic inhomogeneities – knots, compression or tension wood, juvenile wood, false heart, resin channels, and so on, together with their type, frequency and state of health (e.g. damage by rot).

Depends on

- the morphological structural level (i.e. the proportional and spatial distribution of various types of cell elements in the wood);
- the growth defects and anomalies in the wood;
- the mechanical and other loads/treatments of the wood.


Box 1.2  A basic preview of the morphological structure of wood

The morphological structure of wood

Defines

The individual cells – type, shape, dimensions, slenderness factor, orientation to the pith (longitudinal, radial), thickness of the cell wall, thinning in the cell wall (type, frequency, location), and so on.
The grouping of cells – proportion and location of parenchymatic, libriform, vessel, tracheid and other cell-types in the wood tissues.

**Depends on**

The wood species (Fengel & Wegener, 2003; Wagenführer, 2007; Wiedenhoeft, 2010; Wiemann, 2010):

- **Wood of coniferous species** has a simple and fairly regular morphological structure. Approximately 90–95% of wood volume is formed of early and late tracheids. Tracheids have a conductive and strengthening function. They are 2–5 mm long (late are approximately 10% longer) and 0.015–0.045 mm wide. Their cell walls, with a thickness of 0.002–0.008 mm, contain a fairly high number of pit pairs, usually 60–100 in early tracheids and 5–25 in late tracheids. Pit-pairs with a diameter of 0.008–0.03 mm are mainly at the end of tracheids on their radial walls. Opened pit-pairs provide interconnection between tracheids, which is used in the transport of liquids into the wood at its chemical protection and modification. Parenchymatic, thin-walled cells form stock tissue with living protoplasm. They are located in radially oriented pith beams and in longitudinally oriented parenchymatic fibres and resin channels. Resin channels are lacking in some coniferous species (i.e. they are not present in fir or yew wood).

- **Wood of broadleaved species** has a more complicated morphological structure compared with coniferous wood. Libriform fibres, present in a volume of 36–76%, have a strengthening function. They are relatively short, from 0.3 to 2.2 mm, with a width from 0.005 to 0.03 mm. They have a weak connection with other types of cells due to the small number of simple pit or half-pit thinned areas. Vessels, present in a volume of 20–40%, have a conductive function. Their conductive function is important for the transport of nutrients during a tree’s growth, as well as for transport of preservatives and modifying substances into wood.
In ring-porous species (ash, elm, hickory, oak), large vessels in early wood have a diameter from 0.2 to 0.5 mm, whilst small vessels in late wood are from 0.016 to 0.1 mm. The length of vascular systems are usually up to 0.1 m, but in some wood species this can even be several metres (e.g. as long as 7 m in oak). They are created from a long, vertical line of vessels connected via openings – simple, reticular or ranking perforations. Cell walls of vessels have circular and spiral thickenings. The conductive function of vessels decreases under the influence of tyloses (i.e. when blocked by outgrowth from the surrounding paratracheal parenchyma). Parenchymatic cells, present in a volume of 2–15%, mainly have a storage function. Longitudinal, paratracheal parenchymata (single-sided, group, vasicentric, etc.) group around the vessels and vessel tracheids and connect to them via single-sided pit pairs. Longitudinal, apotracheal parenchymata do not come into contact with the vessels. In radially oriented pith beams, several parenchymatic cells are combined with a rectangular shape, horizontal or vertical, either in morphological unity (homogeneous beam) or in morphological diversity (heterogenic beam).

Box 1.3  A basic preview of the anatomical structure of wood

The anatomical structure of wood

**Defines**

*The structure of the cell walls of wood’s cells:*

- layering (i.e. the individual layers ML, P, S₁, S₂, S₃ – see Figure 1.1);
- proportion and localization of the structural polymers (cellulose, hemicelluloses and lignin) and extractives in the individual layers of the cell wall.

![Diagram showing the anatomical structure of wood](image)

- Lignin 0.5%
  - Cellulose 1-2%
  - Hemicelluloses 3-5%

- Lignin 9-11%
  - Cellulose 6-8%
  - Hemicelluloses 4-6%

- Lignin 8-10%
  - Cellulose 34-38%
  - Hemicelluloses 12-18%

- P & ML
  - Lignin 7-9%
  - Cellulose ca 1%
  - Hemicelluloses ca 1%

**Depends on**

The wood species and the type of cell (Fengel & Wegener, 2003; Wiedenhoeft, 2010):

- Elementary fibrils, formed usually of 40 macromolecules of cellulose, are the basic elements of the cells’ walls with a cross-section of ca 3.4 nm × 3.8 nm. Microfibrils consist of 20–60 elementary fibrils. Macrofibrils consist of cellulose microfibrils as well as of hemicellulose fillings and lignin microlayers.
- Microfibrils and macrofibrils form substantial lamellae that are the structural base for individual layers of a cell wall (i.e. the ML, P, S₁, S₂ and S₃):
  - ML → middle lamella, mainly formed of lignin granules;
  - P → primary wall, with a thickness of 0.06–0.09 μm, formed of a high proportion of lignin and cellulose fibrils orientated randomly into a multilayered network;
S → secondary wall, with a thickness of 1–6 μm, formed of three separate layers, S₁, S₂ and S₃; these layers differ in thickness, orientation of fibrils and the proportion and structure of lignin and polysaccharides; for example, in the tracheids of conifers the ratio of layers S₁/S₂/S₃ is around 12/78/10.

**Affects**

*The permeability of the wood:*

- Cell walls of wood are able to transmit gases and polar liquids. This is due to their microporous structure with vacant pores of size 1–80 nm, as well as due to hydroxyl (−OH), carbonyl (C=O) and other polar groups of lignin and polysaccharides. Macromolecules of polysaccharides in the cell walls repel each other in the presence of polar liquid molecules (e.g. water), which also continuously increase the porosity of the cell wall to a maximum size of ~80 nm. Therefore, its permeability for diffusion and capillary transports continually increases.

- Micropores in the cell walls of wood – gaps in elementary fibrils (~1 nm), capillaries in microfibrils (~10 nm), capillaries in macrofibrils (<80 nm), pores in a pit membrane (<150 nm).

*The mechanical properties of the wood:*

- For example, cell walls with a greater proportion of the S₂ layer, and also therefore cellulose, provide wood with a greater tensile strength along the fibres.


---

**Box 1.4 A basic preview of the molecular structure of wood**

**The molecular structure of wood**

**Defines**

*The types and chemical structure of wood components* – cellulose, hemicelluloses and lignin located in the cell walls, and extractives (accompanying substances) located in the cell walls or also in the lumens.

*The physical–chemical status of wood components* – the degree of polymerization, conformation and configuration structures (spatial grouping into globules, rods, helixes), the supramolecular status (crystalline, amorphous), the physical status (glassy, plastic, viscoelastic), the ability to form intramolecular bonds (hydrogen bonds, van der Waals interactions).
Depends on

The wood species, the type of cell, and the specifics of its composition (Eriksson et al., 1990; Fengel & Wegener 2003):

- Cellulose is a linear polymer consisting of 1,4-\(\beta\)-D-glucopyranose units. These are either arranged into crystalline units (elementary fibrils) or are in an amorphous state.
- Hemicelluloses form branched macromolecular systems of mannanes (in coniferous wood), xylanes (in broadleaved wood) and other polysaccharides.
- Lignin in coniferous woods is a guaiacyl-type based on coniferyl phenyl-propane units (i.e. 15% \(\text{OCH}_3\) groups/C\(_9\)). Lignin in broadleaved woods is a mixture of guaiacyl-type and syringyl-type, at which lignin of syringyl-type is based on synapyl phenyl-propane units (i.e. 20–21% \(\text{OCH}_3\) groups/C\(_9\)).
- Terpenes are accompanying biologically effective substances in the wood of more durable coniferous species. Tannins, flavonoids and some other substances play this role in the wood of more durable broadleaved species.

Affects

The durability of the wood:

- hemicelluloses are the overall most unstable component of the wood, mainly against high temperatures and hydrolysis in the presence of acids in the environment or enzymes produced by wood-decaying fungi;
• lignin is not stable when facing oxidation induced by ultraviolet (UV) radiation in exterior, or by peroxidases and other enzymes of white-rot fungi;

• accompanying substances affect the resistance of wood to biological damage; various woods contain different amounts of (1) easily biodegradable substances (e.g. starch, pectin, glycosides and lipids) and (2) substances biologically effective against wood-decaying fungi, moulds or wood-boring insects (e.g. tannins, flavonoids, stilbenes, terpenes and resin acids).

The preservation and modification of the wood:

• diffusion and fixation processes of preservatives and modifying substances in wood depend not only upon their physical and chemical properties but also upon the molecular structure of the cell walls in the wood;

• modification of the molecular structure of wood (acetylation, etherification, etc.) can increase resistance to biological pests, and the dimensional stability and strength properties can be improved.


The structure of wood significantly determines its natural durability, defined as its resistance to abiotic and biological damages (see Chapters 2 and 3). In this view, the structure of wood also affects the conditions for storing of cut logs and produced timber, the methods and technologies for the structural, chemical and modifying protection of wooden products (see Chapters 4, 5 and 6), as well as the methods and technologies for their maintenance and restoration (see Chapter 7).

1.1.2 Wood properties

The properties of wood (Box 1.5) usually worsen due to its damage (see Chapters 2 and 3). The restoration of damaged wood returns its original properties – strength, dimensional stability, aesthetics, and so on (see Chapter 7).

Box 1.5 A basic preview of the properties of wood

See also Sections 2.4 and 3.6.

Density

The wood of broadleaved species commonly used in Europe for products and constructions (Table 1.3: beech, birch, black locust, elm, hornbeam,
linden, maple, oak, poplar, etc., 440–800 kg/m³) is usually more dense than the wood of commonly used coniferous species (Table 1.3: cedar, Douglas fir, fir, larch, pine, spruce, 370–530 kg/m³). The density of wood is decreased after being damaged by fire, fungal rot or insect galleries. However, the opposite trend (i.e. an increase of density) is not uncommon in subfossil wood or wood attacked by alkalis.

**Strength properties**

Wood has a relatively high strength in relation to its density when compared with other materials used in construction. The strength properties of wood (compression, tension, bending, hardness, etc.) depend upon its density and structure, which assist us in selecting a suitable type of wood for a particular use. Depolymerization of polysaccharides in decayed or otherwise damaged wood decreases its strength, mainly in its wet state, where the support strengthening effect of hydrogen bonds and van der Waals interactions already do not apply.

![Strength properties graph](image)

**Moisture properties**

The humidity of wood adapts to climatic conditions of its exposure. During long-term exposure to air with a relative humidity of 95–99%, wood greatly humidifies and its equilibrium moisture content settles around 28–30%; that is, the fibre saturation point (FSP). The wood also easily receives liquid water via capillary forces, and its maximum moisture depends upon its porosity/density; for example, beech with a density of 600 kg/m³ has a maximum moisture of ~120%, whereas for spruce with density of 400 kg/m³ it is as much as ~200%.
The swelling and shrinkage of wood are processes connected with receiving of bound water until it reaches the FSP (wood swells) and vice versa with its drying when water is released (wood shrinkages). The dimensions of wood change as well as when its moisture changes from FSP to 0%; for example, for common wood species the maximum shrinkages are in a longitudinal direction \( \alpha_L = 0.15–0.65\% \), a radial direction \( \alpha_R = 2.5–6.7\% \) and in a tangential direction \( \alpha_T = 8.3–14.7\% \).

The moisture properties of wood also affect its strength, durability and use; that is, (1) strength of wood usually decreases with increased moisture within the range from 0% to the FSP; (2) resistance of wood to biological damage is usually lower at higher moistures; and (3) frequent and marked changes in the moisture content of wood lead to shape deformation and the creation of cracks.

**Thermal properties**

Wood has relatively good thermal insulation properties. However, it does not resist temperatures over 150 °C for a long time and may ignite. Despite the fact that it is flammable, during fires it is often more stable in terms of shape and strength than metals or plastics are.


### 1.2 Types and principles of wood degradation

Wood is more or less susceptible to various forms of degradation (Figure 1.3, Table 1.1; and see Chapters 2 and 3). In wood degradation, the dominant role is played by its molecular structure (Box 1.4). However, its higher structural levels – anatomical (Box 1.3), morphological (Box 1.2), and geometric (Box 1.1) – also have significant roles. Wood can already be damaged during its growth in trees, subsequently at harvesting, during storage and transport of logs and timbers, and also after processing on products and constructions.

Changes in structural levels of wood are caused by abiotic agents or energies and biological pests. Subsequently, its strength, hygroscopic, thermal, aesthetic and other properties are also changed, and usually impaired. The intensity and scope of the structural and property changes of wood depend upon the type and mechanism of the degradation process. In the case of some degradation types (e.g. due to weathering or moulds), just surface damage of wood occurs. In contrast, in the case of fire, fungal decay or feeding by wood-damaging insects, wood is degraded to a greater depth, often in full.

Damage that begins at the molecular structure of wood is the most important for changes in its properties (Table 1.1). All degradation effects in the
### Table 1.1 Types of wood degradation related to the deterioration of its polymers (polysaccharides and lignin) or without their deterioration

<table>
<thead>
<tr>
<th>Type of wood degradation</th>
<th>Wood-degrading factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>With destruction of wood polymers</strong></td>
<td></td>
</tr>
<tr>
<td>Photo-oxidations (mainly in lignin, 0.05–2.5 mm from surface)</td>
<td>UV radiation</td>
</tr>
</tbody>
</table>
| Thermo-oxidations, dehydrations (mainly in hemicelluloses) | Thermal effects  
- temperature of air above \(-150\ \degree\ C\)  
- fire (flame) |
| Hydrolytic reactions, lignin plasticizing | Hydrothermal effects  
- temperature of water/steam above \(-70\ \degree\ C\) |
| Various reactions – hydrolytic, dehydrogenation, oxidation, etc., cellulose de-crystallization | Aggressive chemicals  
- emissions (e.g. \(\text{SO}_2\), \(\text{NO}_x\))  
- acids and alkalis  
- inorganic fungicides  
- fire retardants |
| Biochemical reactions catalysed by enzymes and low molecular weight agents of fungi and bacteria | Wood-decaying fungi  
- white rot  
- brown rot  
- soft rot  
Bacteria |
| Mechanical decompositions and then biochemical reactions in digestive tract | Wood-damaging insects  
Marine organisms |
| **Without destruction of wood polymers** |                      |
| Mechanical cracks | Humidity and thermal gradients |
| Mechanical holes, nibbling marks | Some insects, birds and mammals |
| Colour changes | Wood-staining fungi and moulds |
| Degradation of bordered pits in tracheids | Bacteria and moulds |


Molecular structure of wood – in its polymers, caused by atmospheric factors, high temperatures, aggressive chemicals and fungal decay – are reflected also at its anatomical and morphological structural levels (e.g. with regard to damage of cell walls and entire tissues), and usually also at its geometric level (e.g. more intensive degradation of sapwood or early wood), and of course in its properties as well.

Damage that begins only at the upper structural levels of wood is usually less important for changes in its properties. For example, small changes in the density and strength of wood can occur as a result of microscopic and macroscopic cracks created by moisture stresses due to badly regulated drying, although without great changes in its hygroscopicity and colour.
1.3 Natural durability of wood

Wood has several implicit advantages in comparison with other materials (e.g. stone, clay, brick, concrete, metals, plastics):

- it is a permanently renewable material source (e.g. it has low impact on the environment and low energetic demands for processing in total);
- it is easily workable;
- it has high strength in relation to density;
- it has low thermal conductivity;
- aesthetically pleasing qualities in products.

In contrast, wood also has negative properties, reflected by its lower natural durability:

- weathering
- flammability
- biodegradability.

The natural durability of wood is its inherent resistance to various abiotic factors and biological pests (see Chapters 2 and 3). The natural durability of a defined wood species (and also of a defined type of wooden composite) may be only supposed – it may not be exactly defined. The cause is the complementary effects of many variables. The most significant of these are:

- Differences in the structure of the individual wood species; that is, there is a specific dependence on the age of the wood and the presence of juvenile wood, and also on the climatic, soil and other conditions of tree growth (Table 1.2).
- The environment around the wooden product. That is, there is usually a difference between interior and exterior environments, as well as in various exterior climatic zones; there is also an influence of the structural protection of wood used (prEN 16818). For example, weather factors acting on the exterior are more aggressive in a direct contact with the ground or above ground without shelter (Brischke & Rapp, 2008); a northerly orientation is usually more suitable for the activity of wood-damaging fungi, while abiotic degradation of wood surfaces due to UV radiation and temperature changes is stronger in a southerly orientation.

The natural durability of individual wood species is known from practice; however, it is permanently studied also on the basis of both laboratory and field tests. Several studies on the natural durability of various wood species were elaborated by, for example, Rapp et al. (2000), Van Acker et al. (2003) and Van Acker and Stevens (2003). The natural durability of woods is now based on practical knowledge and experiments assembled in the form of (1) the percentage ratio
Table 1.2 Natural durability of wood predetermined by its structure

<table>
<thead>
<tr>
<th>Structural level of wood</th>
<th>Wood durability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molecular</strong></td>
<td></td>
</tr>
<tr>
<td>• Accompanying substances:</td>
<td>higher resistance to fungi and insects</td>
</tr>
<tr>
<td>Tannins (e.g. black locust, chestnut, oak)</td>
<td>higher resistance to fungi and insects</td>
</tr>
<tr>
<td>Resins (e.g. Douglas fir, larch, pine)</td>
<td>lower resistance against ignition</td>
</tr>
<tr>
<td>Inorganic substances (e.g. containing Na, K, Ca, Mg, P, S) comprised mainly in the wood of fast-growing species (e.g. poplar, alder)</td>
<td>lower resistance against fungi</td>
</tr>
<tr>
<td>• Crystalline cellulose</td>
<td>higher resistance against fungi</td>
</tr>
<tr>
<td>• Lignin</td>
<td>higher resistance against combustion</td>
</tr>
<tr>
<td></td>
<td>lower resistance against UV radiation</td>
</tr>
<tr>
<td><strong>Anatomical</strong></td>
<td>impeded transfer of enzymes of fungi and bacteria in cell walls</td>
</tr>
<tr>
<td>• Both polysaccharides and lignin in cell walls</td>
<td></td>
</tr>
<tr>
<td><strong>Morphological</strong></td>
<td>easily attacked by bacteria and fungi (since they comprise nutrients)</td>
</tr>
<tr>
<td>• Parenchyma cells</td>
<td>easily permeable for fungi hyphae (also for liquids and gases)</td>
</tr>
<tr>
<td>• Vessels</td>
<td>easily attacked by some decay-causing fungi (compared with vessels)</td>
</tr>
<tr>
<td>• Libriform fibres</td>
<td>easier transfer of enzymes in wood</td>
</tr>
<tr>
<td>• Opened pits in cell walls</td>
<td>easier changes of wood moisture</td>
</tr>
<tr>
<td><strong>Geometric</strong></td>
<td>worse durability</td>
</tr>
<tr>
<td>• More frontal surfaces</td>
<td>worse durability</td>
</tr>
<tr>
<td>• More sap-wood</td>
<td>usually worse durability</td>
</tr>
<tr>
<td>• More early wood</td>
<td>usually worse durability</td>
</tr>
<tr>
<td>• Rougher surface</td>
<td></td>
</tr>
</tbody>
</table>


durability, with regard to a well-known wood species (e.g. to oak heartwood), or (2) durability classes (e.g. by EN 350-2), which rank woods on the basis of their resistance to activity of selected biological pests (Table 1.3).

The natural durability of individual wood species is influenced also by the pest’s interest about the wood, or by the ability of a specific chemical compound to be attacked in the wood. For example, some species of wood-damaging insects attack only wood of conifers and only in interiors – typically, the house longhorn beetle (*Hylotrupes bajulus*). Woods having tannins or similar extractives (e.g. oak) become black in colour near to a contact with iron nails or screws, but others woods (e.g. beech) are resistant to such colour changes.
Table 1.3 Classes of natural durability of selected wood species in their contact with ground – against rot (modified from EN 350-2)

<table>
<thead>
<tr>
<th>Durability class</th>
<th>Commercial name</th>
<th>Scientific name</th>
<th>B or C&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Density (kg/m&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very durable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greenheart</td>
<td>Ocotea rodiaei</td>
<td>B</td>
<td>1030</td>
<td>South America</td>
</tr>
<tr>
<td></td>
<td>Jarrah</td>
<td>Eucalyptus</td>
<td>B</td>
<td>830</td>
<td>Australia</td>
</tr>
<tr>
<td></td>
<td>Mansonia</td>
<td>Mansonia altissima</td>
<td></td>
<td>620</td>
<td>West Africa</td>
</tr>
<tr>
<td></td>
<td>Okan</td>
<td>Cylicodiscus</td>
<td>B</td>
<td>920</td>
<td>West Africa</td>
</tr>
<tr>
<td></td>
<td>Padouk</td>
<td>Pterocarpus</td>
<td>B</td>
<td>740</td>
<td>West Africa</td>
</tr>
<tr>
<td></td>
<td>Teak</td>
<td>Tectona grandid</td>
<td>B</td>
<td>680</td>
<td>Asia</td>
</tr>
<tr>
<td></td>
<td>Walaba</td>
<td>Eperua falcata</td>
<td>B</td>
<td>900</td>
<td>South America</td>
</tr>
<tr>
<td>1–2</td>
<td>Black locust</td>
<td>Robinia pseudoacacia</td>
<td>B</td>
<td>740</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Kapur</td>
<td>Dryobalanops</td>
<td>B</td>
<td>700</td>
<td>South-East Asia</td>
</tr>
<tr>
<td>2</td>
<td>Durable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bubinga</td>
<td>Guibourtia</td>
<td>B</td>
<td>830</td>
<td>West Africa</td>
</tr>
<tr>
<td></td>
<td>Chestnut</td>
<td>Castanea sativa</td>
<td>B</td>
<td>590</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Oak</td>
<td>Quercus robur</td>
<td>B</td>
<td>710</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>White cedar</td>
<td>Thuja plicata</td>
<td>C</td>
<td>370</td>
<td>North America</td>
</tr>
<tr>
<td>3</td>
<td>Medium durable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Douglas fir</td>
<td>Pseudotsuga</td>
<td>C</td>
<td>530</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>Turkey oak</td>
<td>Quercus cerris</td>
<td>B</td>
<td>770</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Walnut</td>
<td>Juglans regia</td>
<td>B</td>
<td>670</td>
<td>Europe</td>
</tr>
<tr>
<td>3–4</td>
<td>Larch</td>
<td>Larix decidua</td>
<td>C</td>
<td>600</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Pine</td>
<td>Pinus sylvestris</td>
<td>C</td>
<td>520</td>
<td>Europe</td>
</tr>
<tr>
<td>4</td>
<td>Less durable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elm</td>
<td>Ulmus sp.</td>
<td>B</td>
<td>650</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Fir</td>
<td>Abies alba</td>
<td>C</td>
<td>460</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Spruce</td>
<td>Picea abies</td>
<td>C</td>
<td>460</td>
<td>Europe</td>
</tr>
<tr>
<td>5</td>
<td>Non-durable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>Fraxinus excelsior</td>
<td>B</td>
<td>700</td>
<td>Europe</td>
</tr>
<tr>
<td></td>
<td>Beech</td>
<td>Fagus sylvatica</td>
<td>B</td>
<td>710</td>
<td>Europe</td>
</tr>
</tbody>
</table>