Structure and Properties of Scandinavian Timber

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Common species in Sweden

Introduction

As a renewable natural resource, wood has been, and probably will be, one of the most important materials used by man. When using wood it is important to know its moisture behaviour, biological resistance to mould and decay, weather resistance, strenght properties, and other similar performance factors. All of these are linked to the cell structure and chemical composition of wood.

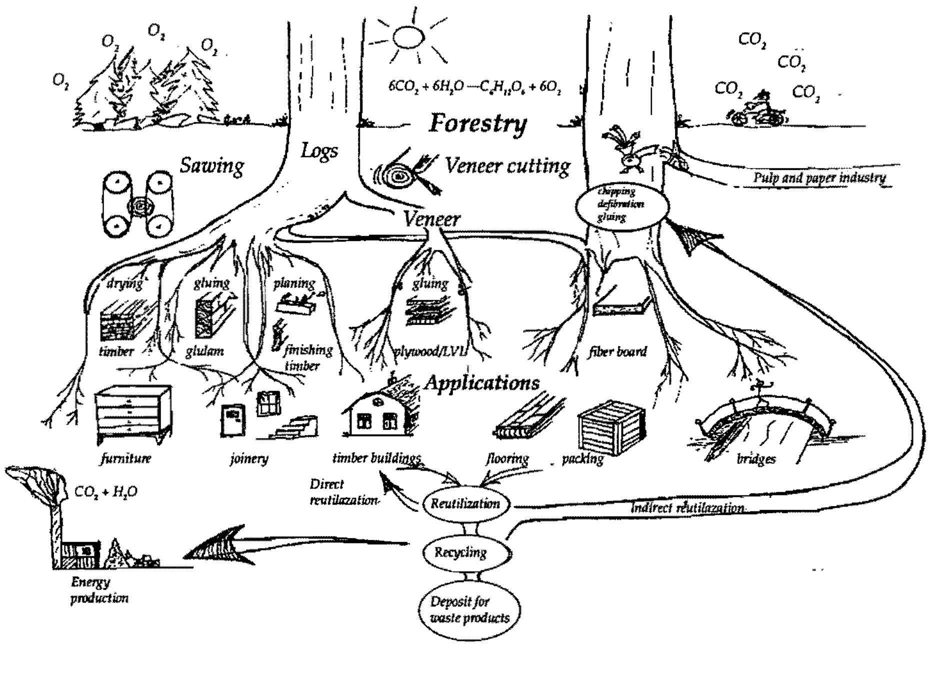
Wood is mostly composed of hollow cells with walls consisting of cellulose, hemicellulose and lignin. They are giant molecules with complex structure which are difficult to analyse. Cellulose forms the core of the cell wall, and the medium surrounding consists of hemicellulose and lignin. In addition, wood contains various organic and inorganic materials. The elemental compositions of wood are carbon (50 %), oxygen (43 %) and hydrogen (6 %).

After harvesting, wood is converted into a great number of products by sawing, slicing, gluing, chipping, pulping, modification by impregnation with chemicals, or chemical processing. Wood is also an important fuel for cooking, heating, and steam production, which can be utilized as a source of enegy. About half of the world´s production of wood is used as fuel. With the existing energy problem, wood, as a renewable product of nature, aquires an important position as fuel.

The technology required for wood processing has developed along with man´s inventiveness. Its positive effects are increasing efficiency and the promotion of human well-being. The negative effects of mechanical wood processing are few, as long as forest cultivation methods are kept in good order.

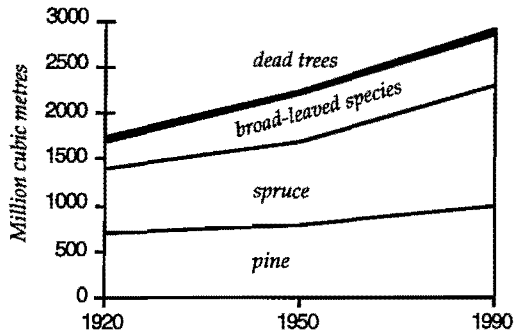
In our planning of products and structures we must now think of the spiritual dimensions of wood-processing rather than the material ones. It is quality, not quantity that matters. Quality must include not only technical skills, but also ethical, aesthetic, ecomomical and ecological features.

As with any other material, sound knowledge of its advantages and disadvantages is a prerequisite to rational utilization of wood. Such knowledge allows for improvement of the quality of wood produced in the forest, better use of the numerous available species, limitations of disadvantages, making products of the best possible quality, and reduction of waste.

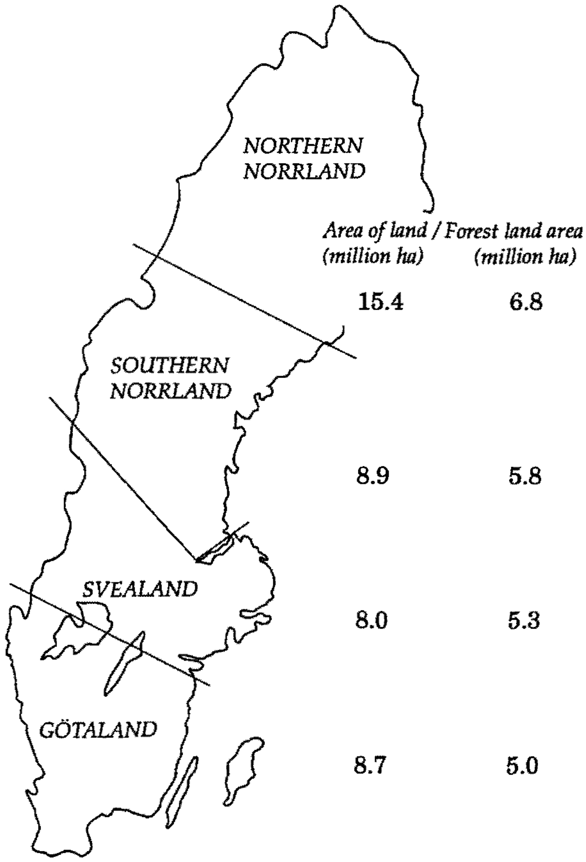


The Swedish forest

Sweden is situated in one of the world´s few areas of large coniferous forests. Sweden has an area of 45 000 000 hectares, more than half of which is covered by forests. The primary species of tree in these forests are coniferous pine (Pinus silvestris L) and spruce (Picea abies Karst), which account for about 85% of the standing volume. The growing stock amounts to 2.8 billion cubic metre of wood which makes Sweden one of the most densely forested countries in Europe.



Growing stock in Sweden, broken by species. Development since 1920.



Forestry

Careful silviculture is practiced in the Swedish forests. The planting of selected seedlings grown in nurseries is followed by clearing of undergrowth, thinning, and finally, felling. The Swedish forest resource is increasing because it is looked after carefully and the Swedish legislation demands replanting. This provides a guarantee that Swedish timber will continue to be available in the future.

Forest resources in Sweden is among the most carefully tended in the world, and have in fact increased continuosly over the last 250 years. About 600 million seedlings are planted every year.

The resource represented by the Swedish forest is the basis for a large number of different timber industries, among them more than 2000 sawmills. It also plays an important part in recreational and leisure activities.

Growing stock on forest land (standing volume)

	millon m³		percent of all species	
	pine	spruce	pine	spruce
N Norrland	259	167	50	32
S Norrland	251	346	36	50
Svealand	279	300	41	44
Götaland	229	403	29	51

Structure

Structure is any assemblage of materials intended to sustain loads. Plants such as tree are structures, designed to grow tall and stand up to strong winds.

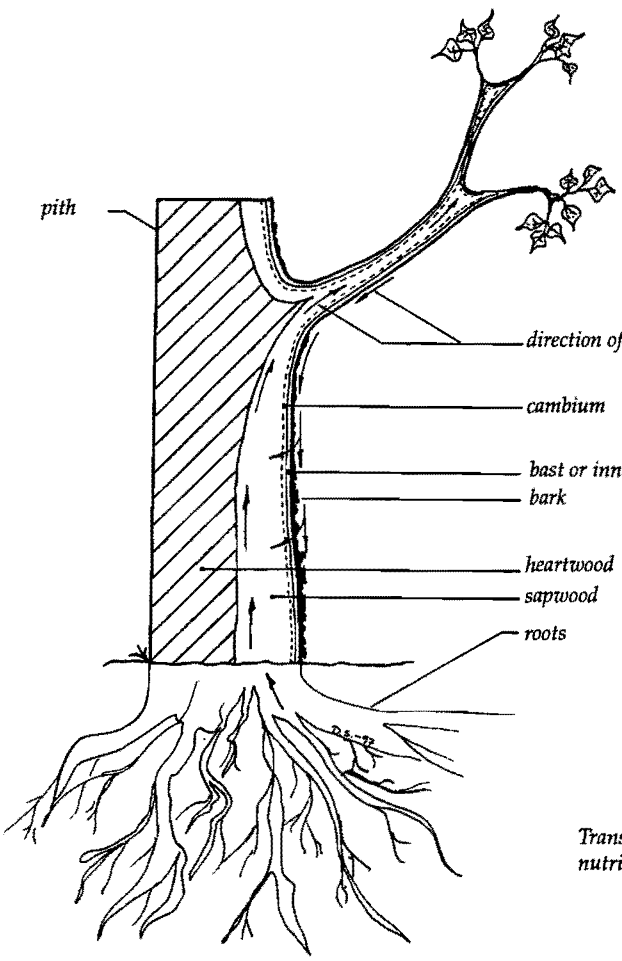
Structure of the tree

The trunk of a tree has tree physical functions to perform; firstly, it must support the crown, a region responsible for the production not only of food but also of seed; secondly, it must conduct the mineral solutions absorbed by the roots upwards to the crown; and thirdly it must store manufactured food (carbohydrates) until required.

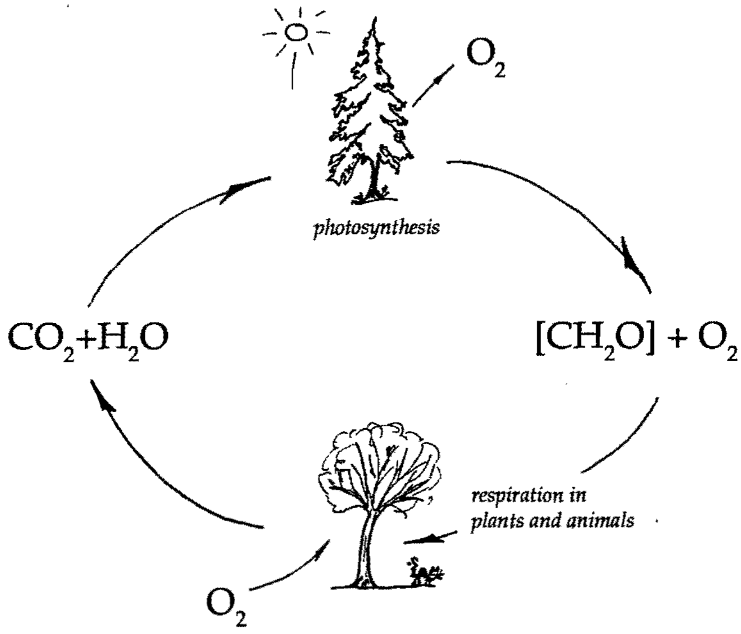
The root system of a tree acts in absorbtion of moisture and the extraction of chemical substances in solution from the soil, and as a structural anchorage in the ground. The roots often work in symbiosis with fungus in what is called mycorrhiza

Sap is transported from roots, up through the sapwood to the crown, where after photosynthesis, it flows down the inner bark and cambium, and is nutrients to all parts of the wood.

The entire cross-section fulfills the function of support, and increasing crown diameter is matched with increasing diameter of the trunk, whereas conduction and storage are restricted to the outher region of the trunk. This zone is known as sapwood, while the region where cells no longer fulfills these tasks is termed as heartwood. The width of sapwood varies with species and age of the tree, but it is seldom greater, and is ususally much less than, one third of the total radius.



Transportation of nutrients in the tree.



$$CO_2 + H_2O \xrightarrow{\text{sunlight}} \underset{\text{carbohydrate}}{[CH_2O]} + O_2$$

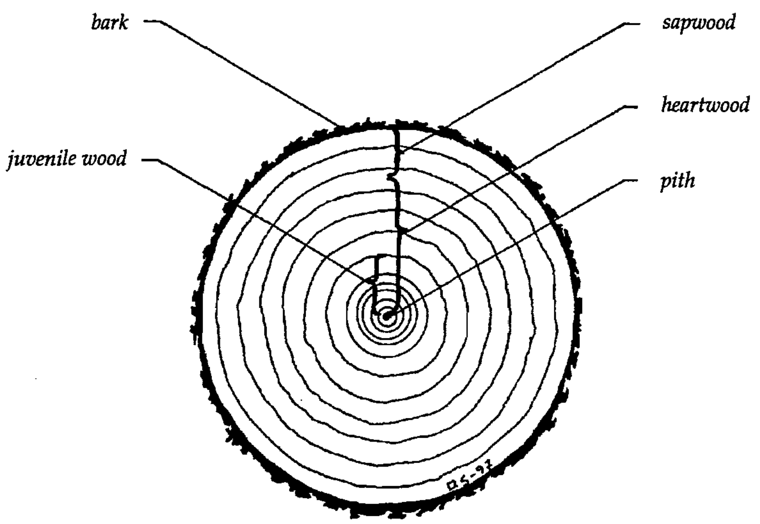
Photosynthesis

Hardly a day goes by without the importance of photosynthesis being brought to our attention. All our food and our fossil and biological fuels are derived from the process of photosynthesis. We use coal, natural gas, petroleum etc. as fuels. All these fuels are decomposition products of land and marine plants or animals.

The major chemical pathway in photosynthesis is the conversion of carbon dioxid (CO_2) and water (H_2O) to carbohydrates and oxygen (O_2). Photosynthesis can thus be regarded as a process of converting radiant energy of the sun into chemical energy of plant tissues. The carbohydrates formed posses more energy than the starting materials, namely CO_2 and H_2O.

The CO_2 content of the atmosphere remained almost constant for millenia in spite of its depletion during photosynthesis. However, there has been a 27 % increase since the Industrial Revolution in the last century, resulting in the so-called greenhouse effect.

All plants and animals carry out the process of respiration whereby oxygen is taken from the atmosphere by living tissue to convert carbohydrates and other tissue constituents eventually to carbon dioxid and water, with the simultaneous liberation of energy. The loss of organic matter and atmospheric oxygen during respiration is counterbalanced by the photosynthesis. Under ideal conditions, the rate of photosynhesis in the green parts of plants is about 30 times as much as the rate of respiration in the same tissue. Thus photosynthesis is very important in regulating the O_2 and CO_2 content of the atmosphere. All the carbon dioxid in the atmosphere is cycled through plants, via photosynthesis, every 300 years, and all the oxygen is cycled every 2000 years.



Different parts in the cross section of a stem.

Heartwood and sapwood

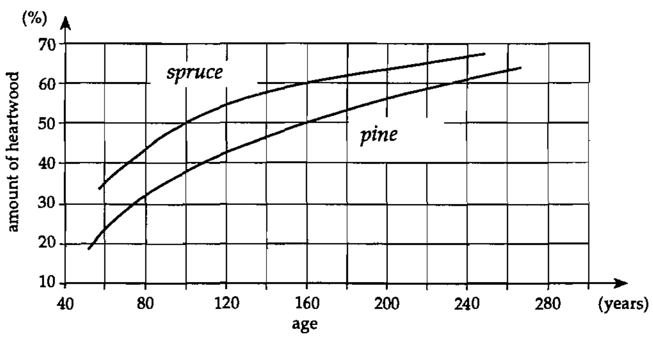
Heartwood is the inner part of the stem, while sapwood is the peripheral part.

Heartwood is often darker and consist of dead cells excluded from the water transportation and thus have much lower moisture content than the sapwood. The sapwood is mostly lighter than heartwood and contains water conducting cells. Due to high moisture content in the earlywood of the annual rings, the water content in sapwood is very high.

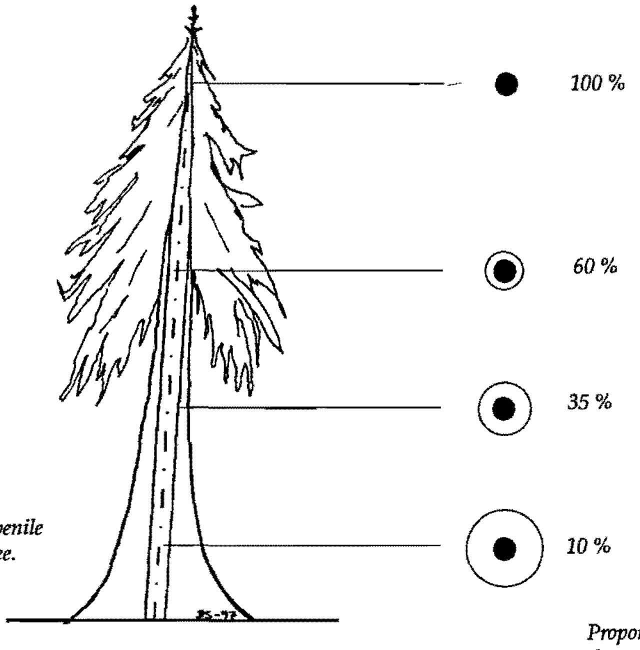
When a tree grows and increases its diameter the entire cross section is not needed for water supply. At 30-40 years of age the water transportation in the inner parts starts to decrease. Thus, the heartwood which only function is to provide strengh, is developed. The water and nutrient conduction in the heartwood stops because of aspiration (closing) of pits. Futhermore, extractives such as terpenes and natural resins, fat etc. penetrates the cell wall. This also results in slower moisture uptake in the heartwood than in the sapwood.

The extractives makes the heartwood darker than the sapwood in some species. In pine, larch, oak, elm and ash the difference in colour between heartwood and sapwood is obvious, but barely visible in spruce. In mature tree the proportion of heartwood in spruce is greater than in pine.

In heartwood of pine fungicides is produced e.g. pinosylvin. Heartwood in pine thus have relatively good resistance against fungus. The amount of pinosylvin is highest in the most recent developed heartwood, where the pinosylvin is chemically undegraded. Researchers have found that the amount of pinosylvin in pine is higher in trees from Southern Sweden than the north of Sweden. Extremly slow grown pine normally have a low pinosylvin content. The heartwood formation starts at the pith and develops annual ring by annual ring through the tree. In a mature tree the amount of heartwood is about 50 % of the cross section.



Amount of heartwood by age of pine and spruce.



Location of juvenile wood in the tree.

Proportion of juvenile wood in the cross section at different height in the tree.

Pith and juvenile (core) wood

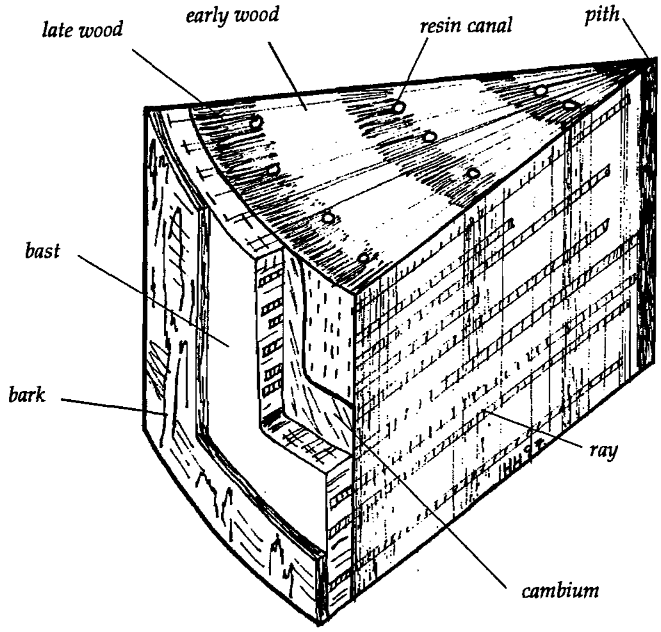
In the central part, the pith runs in the axial direction of the stem. It is surrounded by the actual wood and ends at the top in the bud. The tree growth in length and the branches are also developed from the bud.

The pith consist of thin walled cells, which contains nutrients. It is only a couple of millimetres in diameter and the form of the cross section varies.

The juvenile wood, the annual rings closest to the pith, differs considerably from the wood located in the periphery of the stem. Juvenile wood is of low quality. It tends to have lower density than the mature wood, and longitudinal shrinkage and swelling is greater, while transverse shrinkage and swelling is less.

Juvenile wood occurs in all trees, but is more prevalent in pines in which the juvenile wood normally comprises the first 10-20 annual rings.

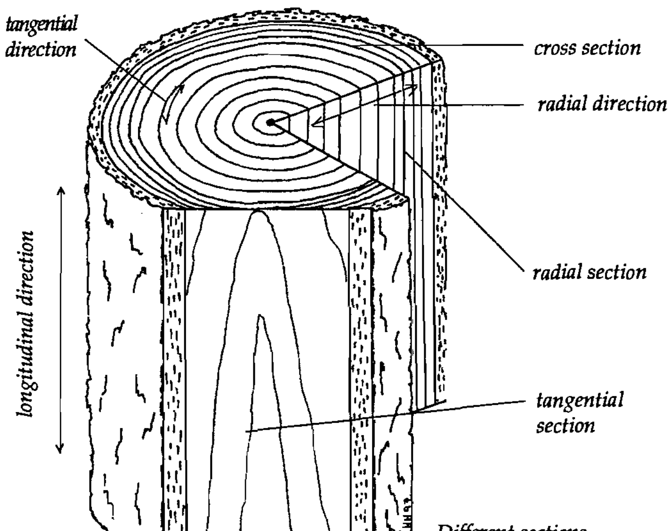
Furthermore, the juvenile wood results in drying problems, because it has different shrinkage and swelling properties. This results in cracks and deformations. Consumers aware of quality hence avoid this part of the tree. In fast grown plantation trees, juvenile wood is more prevalent than in slow grown trees.



Macroscopic structure of softwood.

Wood at macroscopic scale

Normally we can divide the way of looking at wood in a macroscopic and a microscopic point of view. With the naked eye we can recognise growth rings with earlywood and latewood. The earlywood is, as the name predicts, grown early in the year, in spring and in early summer. Subsequently there is a transformation of the wood cells to cells with thicker cell walls. When we look at a cross section of wood the light part of a annual ring is the earlywood and the dark part is the latewood. In a annual ring the density varies gradually from a lower density in the earlywood to a higher density in the latewood. It is generally recognized that the latewood density reaches its maximum value in softwood at or near the boundary with the earlywood of the succeeding year´s growth. At the boundary between two annual rings the change in density is very high, which may cause high stresses during drying of wood.



Different sections of the stem.

At the macroscopic scale we can identify three *sections* of timber: radial, tangential, and cross sections.

Furthermore, we can define three *directions* of timber:

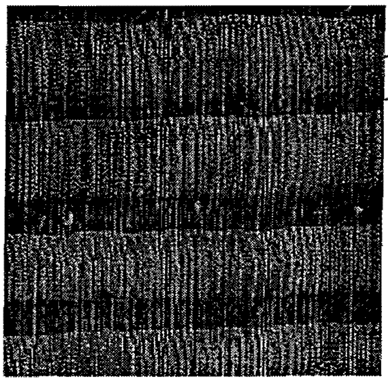
- radial direction from the centre of the stem to the peripheral bark.
- tangential direction along the annual rings.
- longitudinal direction along the stem, also called axial direction.

The cross section is showing annual rings and resin canals. The resin canal contains resin, which is pouring out and protects the tree against attacks from fungus and insects when damages on the stem occur.

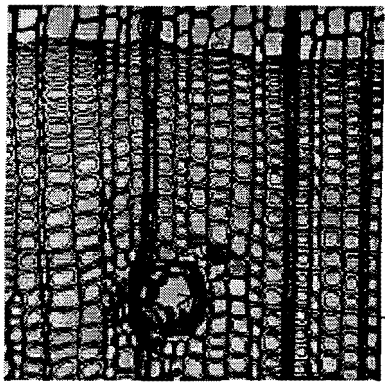
The radial section is showing annual rings and rays. The rays are always starting at the inner bark and reaching to different depth in the stem. The rays store nutrients as sugar and starch when the tree produces more than it consumes. These storages are later used when the photosynthesis is not enough to provide the growing tree with enough nutrients.

At the tangential section the cross section of rays can be seen, particularly in hardwood such as oak and beech.

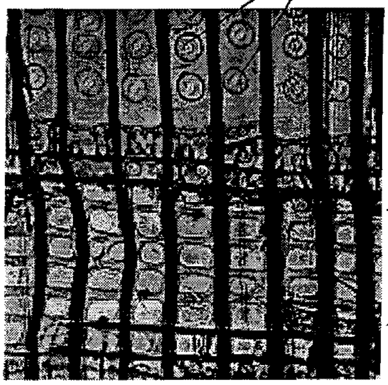
The actual wood material is surrounded by the cambium, the inner bark and on the outside of the stem the bark. Some species have very special bark as the one used for vine bottles called cork oak, *Qerqus suber.*



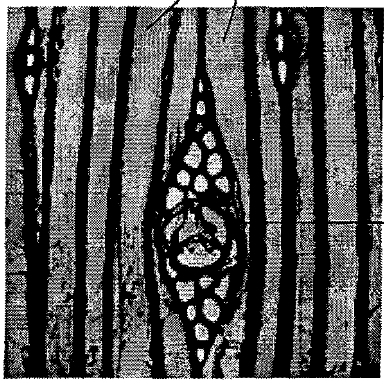
Cross section at 12 times magnification.



Cross section at 100 times magnification



Radial section at 200 times magnification.



Tangential section at 200 times magnification.

Scots pine under the microscope.

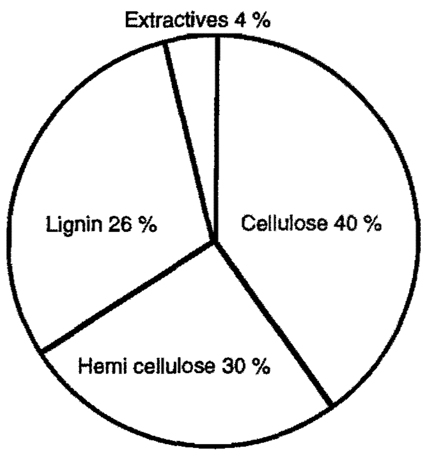
Wood at microscopic scale

Wood is composed of cells, thin walls of wood substance surrounding minute cavities, mainly oriented in the longitudinal direction of a stem. Over 90 percent of the volume of softwood timber is composed of longitudinally aligned fiberlike cells, or tracheids. These cells are typically 2 to 6 mm long, with a diameter about one-hundredth of their length, and with a central cavity or lumen occupying about three-quarters of the cell volume. The tracheids, which are arranged in regular radial rows, perform a dual function of conveying water and providing mechanical support for a tree. Free water in cell lumens moves from one tracheid to the next through bordered pits.

Also present is a system of horizontally aligned cells, or wood rays. In living trees, these cells carry nutrients radially inward from the living cambium.

Some wood, for example pine, spruce and larch, have both vertical and horizontal systems of enlarged cavities, called resin canals. Resin (pitch) will often exude from these canals during drying, and can be detected in the cross section as small droplets.

The structure of wood of broadleaved trees (hardwood) is more complex than that of softwood because more cell types are present. The most obvious difference is that in hardwood there are large vertical ducts called vessels. Vessel elements can be very large in diameter, 0.25 mm. Approximately one-half of the volume of a piece of hardwood is composed fibres. Their function in a tree is primarily of mechanical support.



Wood is mostly composed of hollow cells with walls consisting of cellulose, hemicellulose and lignin.

Chemistry of wood

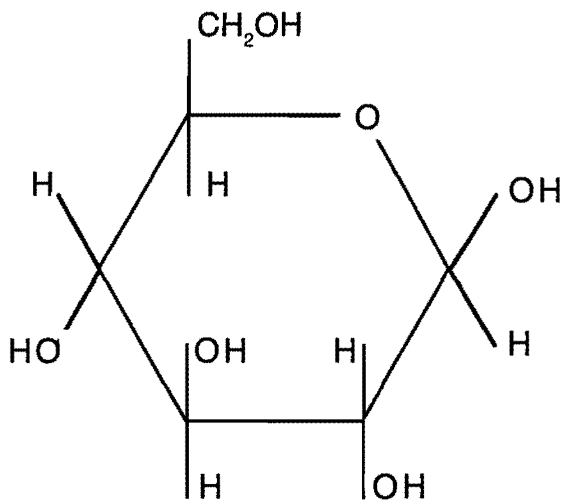
The most important structural constituents of wood is cellulose. In chemical terminology -ose denotes a sugar, so cellulose is the sugar associated with plant cells, or rather with cell walls. Cellulose is in fact a high-molecular-weight, long, linear polymer of simple common sugar, glucose.

Glucose is syntehesized in the leaves of trees and other plants by the action of photosynthesis, and with the aid of the green catalyst chlorophyll. The glucose molecule is a ring structure that is fringed with hydroxyl (-OH) groups. Because of these hydroxyl groups and because of its relatively low molecular weight, glucose is water-soluble. It is thus conveyed in solution in the sap through the various cells and vessels of the tree to the growth zones.

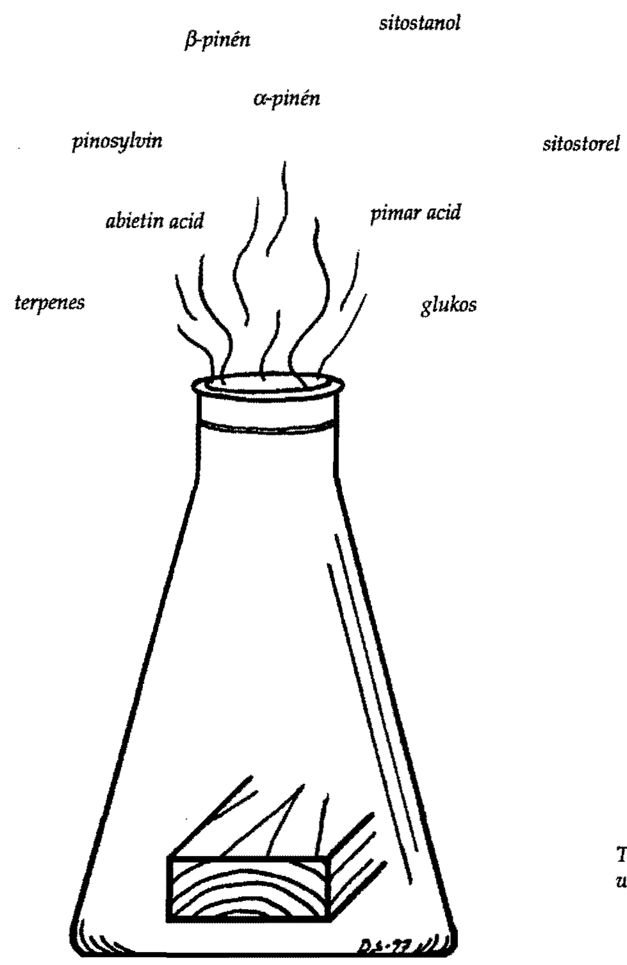
The long cellulose chains lie roughly parallel to one another in the cell wall. When they get the opportunity, the cellulose molecules crystallize into parallel bundles known as micelles or crystallites. Usually, crystals are much larger than the molecules from which they are made, but in the case of cellulose, the crystallites or micelles are usually shorter than their molecules.

Because of its high molecular weight, cellulose is not water-soluble in the ordinary sense, although it can and does absorb water molecules around its free hydroxyl groups. The crystallites, however, are not accessible to water. Much of the virtue of natural cellulose is due to the presence of these crystallites, it is strong, stiff, and impermeable to water. Celluloses that have been chemically dissolved and artificially reconstituted, such as cellophane are much less crystalline, much more affected by moisture, and also mechanically inferior to natural forms of cellulose such as wood, cotton and flax.

Natural cellulose in the solid state has a density of about 1500 kg/m^3 like other sugars. It is, of course, a good deal lighter than engineering metals. However, the stiffness to density ratio of cellulose and metals are nearly the same, while the tensile strength of cellulose is even higher.



The chemical structure of glucose.



The harmless monoterpenes gives wood its characteristic scent.

What makes the timber smell like wood?

The chemical constituents of wood are cellulose, hemicellulose and lignin. These polymers are non volatile macromolecules. Furthermore, wood contains a large number of substances with low molecular weight, called extractives.

The extractives work as protection against microorganism, or as nutrition-storage. The amount of extractives is normally 1-4 % in pine and spruce, but can sometimes reach 10-12 % in pine.

Extractives is commonly separated into terpenes, resin acids and phenolic substances, which acts together as the natural defence against microorganisms, and fats and carbohydrates. In all there are about fifty known substances.

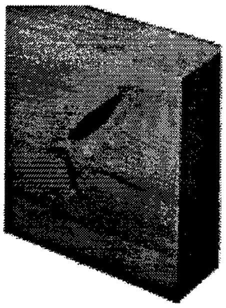
It is only the most low molecular substances, the monoterpenes, which are volatile. They are responsible for the characteristic smell from conifers. Their major function is probably to act as a solvent for other defence substances, but they themselves might also have a defence function.

A fresh cut pine section emits about 400 mg/m^2h of the most common terpene, α-pinén. That is about 80 times lower than the limit for equal organic solvents. Accordingly the scent of wood is not a health risk.

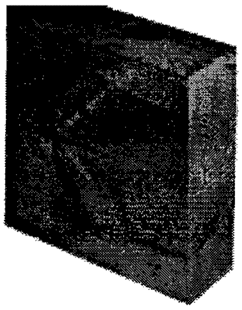
Abnormalities in wood

In wood, deviations from normal structure are not uncommon, since trees are living organisms and are subjected to various influences throught their life span. When wood is looked upon as a raw material, most abnormalities adversely affect its service value; these are commonly called *defects*. From the wood utilization point of view, defects are also certain normal characteristics of all trees - namely knots and pith.

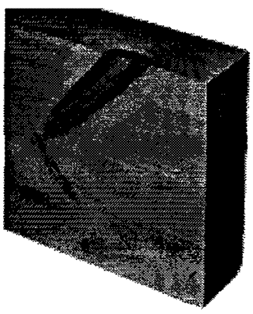
spike knot



round edge knot



splay knot



Knots

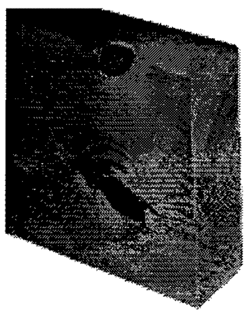
There are two kinds of knots, depending on if a branch was dead or alive at the time of inclusion. Knots from dead branches are called encased or loose. When wood dries in the form of timber or veneer, such knots may fall out. On the other hand, branches enclosed while living produce knots, which are intimately connected with the surrounding wood through continous annual rings; such branches give rise to intergrown or tight knots.

Knots may differ in shape and size. Shape depends primarily on cross-sectional shape of the enclosed branch, although it is also influenced by the direction of sectioning in relation to branch axis.

Knots affect adversely the appearance and properties of wood. Although knotty timber may have same appeal, knots in general are aesthetically and technically undesirable. Their adverse effect is due to the usually abnormal structure and higher density of their wood, and also to their association with grain deviation and checking. The strength of wood may be considerably reduced by knots. Knots also affect the machining, drying, and gluing properties of wood.

edge knot

oval knot

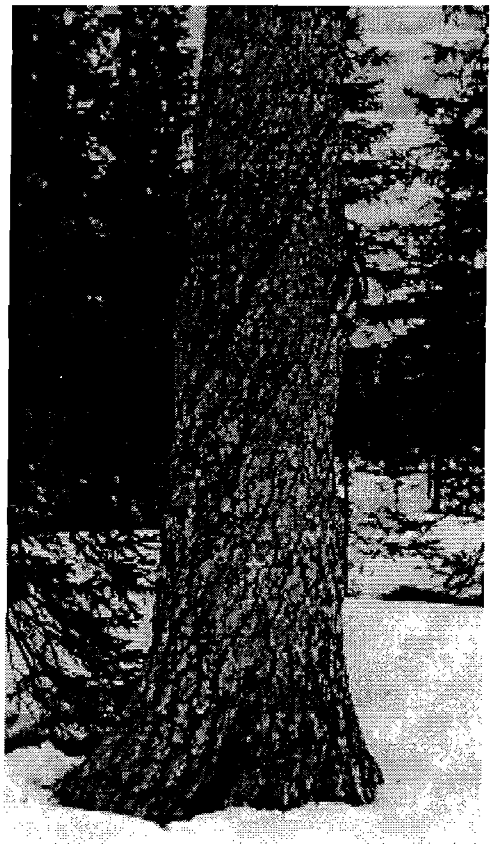


Spiral grain

The bark of some trees is twisted in apperance, which indicates that the wood is likewise twisted. Drying and shrinkage of the exposed wood forms oblique checks running in spirals over the length of the stem. This deviation is known as spiral grain.

Spiral grain is a very common defect, occuring in both softwood and hardwood. Trees with absolutely straight grain are rather scarce.

Deviated grain may be produced from entirely straight-grained trees. This occurs when sawing or otherwise machining logs at an angle (rather than parallel) to annual rings when logs come from strongly tapered trees, and from trees with irregular circumference or eccentric growth. The defect is known as diagonal grain, and affects adversely the properties of timber, particulary strength. Diagonal grain may be best observed and measured on radial surfaces.



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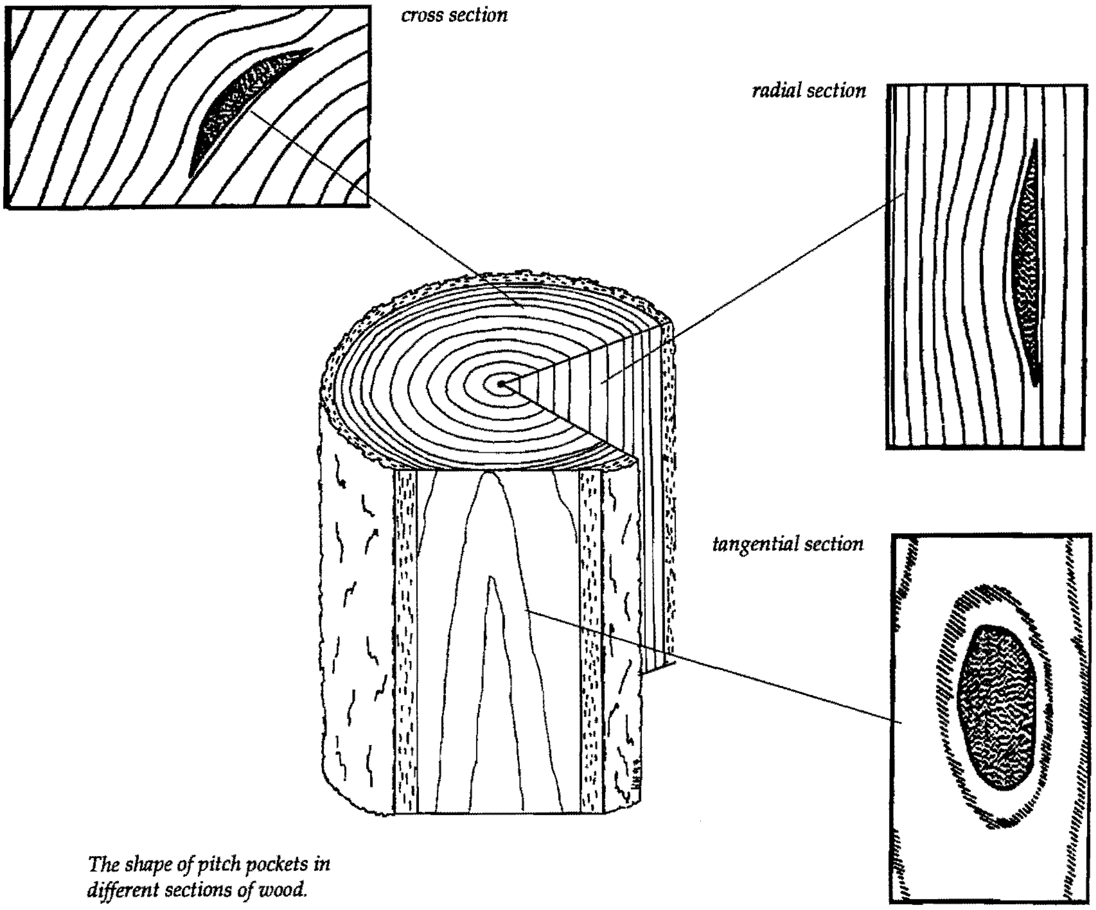


The shape of pitch pockets in different sections of wood.

Pitch pockets

Pitch pockets are small widely spread pockets in the timber that contain pitch. It is not certain why they occur but they are probably the result of storm damage of growing trees or other external factors. It is probable that in these circumstances a tree will excrete pitch as a defensive measure, either to heal or to cover the damage. Pitch pockets occur most commonly in spruce, and are one of the reasons why spruce has not been used in furniture making to any great extent.

Reaction wood

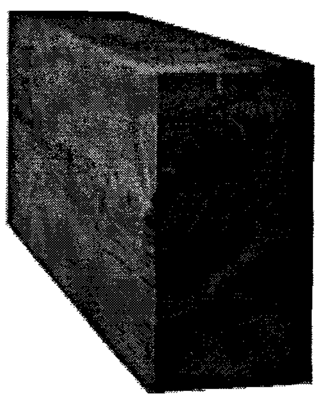
When a tree grows on a slope or is exposed to a dominant wind direction the load on the stem is single sided. The tree starts to produce cells of a different type to compensate for the "unnatural" load. Also the branches reacts in the same way, where the weigth of the branch causes a torsion at the intersection with the stem. The branch counter acts to this by ordering the cell structure in a special way. In softwood the amount of wood is increased on the lower side at such places. Compression wood is developed. Compression wood is darker, contains more resin and is harder than normal wood, it also contains more lignin.

Compression wood developes on the lower side of the stem in a tree growing in a slope.

In hardwood the amount of wood is increased on the upper side of the over tensed region and developes tension wood. Tension wood has longer fibres, more cellulose and less lignin.

Distortion in the growth of wood produces reactionwood which is a common name for both compression and tension wood.

In the cross section compression wood appears as thick walled, and round cells. The length of the cells is shorter compared to normal wood. Compression wood has large shrinkage and swelling in axial direction (in contradiction to normal wood) which may make the timber warp when drying.



Cross section of a board with compression wood.

Compression wood has good resistance to abrasion but it has low tensile strength. The transition between compression wood and normal wood results in stress concentrations when the wood is dried, and may result in cracking. Because of the abnormal structure, reaction wood is unsuitable in products and constructions.

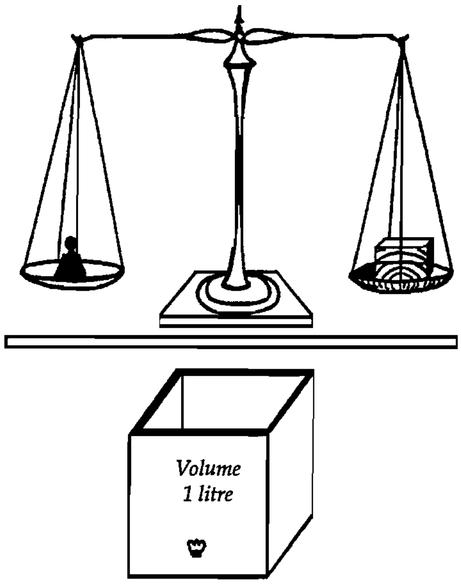
A fool sees not the same tree
that a wise man sees.

William Blake (1757-1827)

Properties of wood

Knowledge of the properties of wood, as of any other material, is a basic pre-requiste for its rational utilization in making various products. The most important properties of wood are density, hygroscopicity, shrinkage and swelling, mechanical, termal and acoustical properties.

$Density = \frac{Mass}{Volume}$



Determination of wood density.

Density and specific gravity

The density, ρ, of wood is the relation between the dry mass and the dry volyme of the wood.

$$\rho = \frac{dry\ weight}{dry\ \ volume}\ (kg / m^3)$$

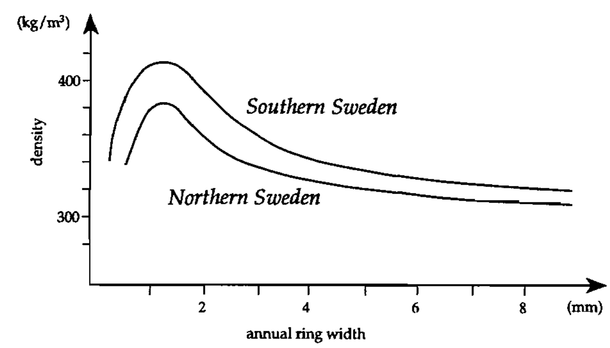
Density is the mass contained in a unit volume of material, and specific gravity is the ratio of density of the material to the density of water. For example the density of pine is about 500 kg/m³, then its specific gravity is 0.50, because the density of water is 1000 kg/m³. Specific gravity is also called relative density.

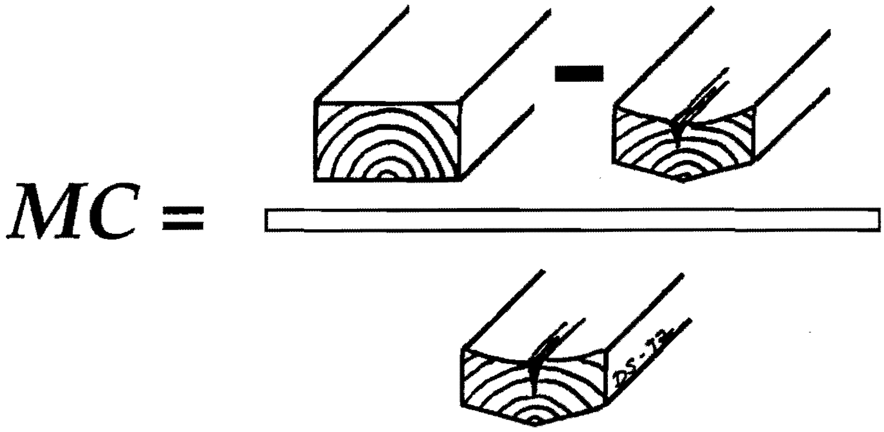
The density and specific gravity of wood are influenced by moisture, structure, extractives, and chemical compositions.

Wood is mostly made of dead cells, which are composed of cell walls and cell cavities. The density of the cell wall is practically constant, about 1500 kg/m³. The density of wood varies, depending on the amount of material (cell wall) and voids (cell cavities) present in a certain volume. The density of wood range from 100 kg/m³ (balsa) to about 1300 kg/m³ (lignum vitae).

Latewood is made of cells which have thicker walls and smaller cavities in comparsion to earlywood. This results in a higher density of latewood as compared to earlywood (triple or more), and explains why the density of wood increse with increasing proportion of latewood. It should be noted that in softwood, there are no clear relationship between annual ring width and density. The density of pine and spruce have a maximum at a annual ring width of about 2 mm.

Density is directly related to other properties and therefore, is important as an index of wood quality. Density affects hygroscopicity, shrinkage and swelling, mechanical, thermal, acoustical, electrical, and other basic wood properties, as well as properties related to the industrial processing of wood, e.g. machining and drying.





Moisture content

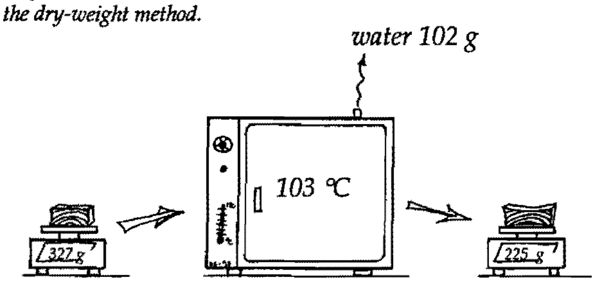
For wood and wood products, moisture content, MC, is defined as the ratio of the weight of water in wood to the weight of owendry wood. Normally, moisture content is given in per cent. It can be calculated as the difference between the wet and dry weights, divided by the dry weight.

Terms for timber with different moisture content.

air-dried	15 to 23 %
planing-dry	15 to 19 %
room-dry	10 to 15 %
furniture-dry	6 to 10 %

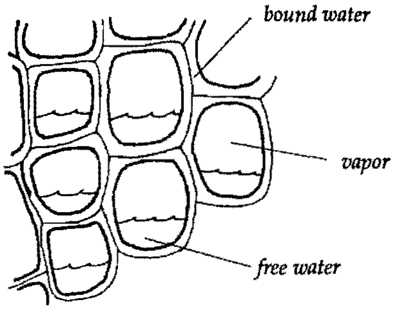
$$MC = \frac{wet \ \ weight \ - dry \ \ weight}{dry \ \ weight} \times 100 \ (\%)$$

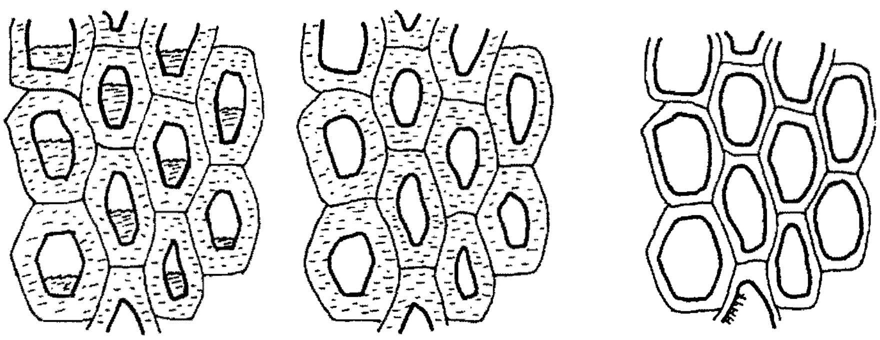
Determination of moisture content according to the dry-weight method.



$$\frac{327\text{-}225}{225} \ x \ 100 = 45 \ \%$$

Water in wood can occur in three forms.





MC above fiber saturation. *MC at fiber saturation.* *MC below fiber saturation.*

Moisture in wood

Since one of the major functions of sapwood is water conduction, it normally contains a large quantity of water, even after a tree is felled and the logs are converted to timber. In softwood, heartwood normally is characterized by its relatively low moisture content. Moisture in wood occurs in three forms:

a) as *free water* in cell cavities;

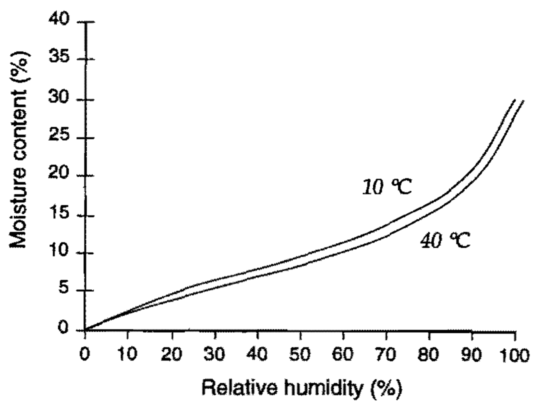
b) as *vapour* in the air in the part of cell cavities not occupied by liquid;

c) as *hygroscopic* or *bound water*, absorbed primarily on the cellulose and hemi cellulose molecules which constitute the greater part of wood substance.

Fibre saturation point is defined as the moisture content at which cell walls are saturated with bound water, but no free water exists in cell cavities. This moisture content differ in different species, due to the presence of various amounts of nonhygroscopic substances in their constitutions, but it is usually between 23 and 34 percent.

Equilibrium moisture content is the term used to define the moisture content of wood which has been reached when it is exposed to the same conditions of temperature and humidity for a sufficiently long period. A change in temperature or humidity will result in a corresponding change in the equilibrium moisture content of wood. The relationship between humidity and temperature of air and equilibrium moisture content of wood is called sorption isotherm.

Equilibrium moisture content in wood versus different relative humidity in the surrounding air at 10 °C and 40 °C.



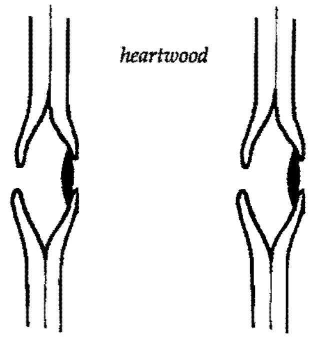
Moisture transport during drying

When drying timber, normally there will be boards consisting of both heartwood and sapwood, where the heartwood has a moisture content close to fibre saturation. This means that water is present as bound water or as vapour in these cells. In sapwood the moisture content is normally above 100 % and water is present as free water, bound water and vapour.

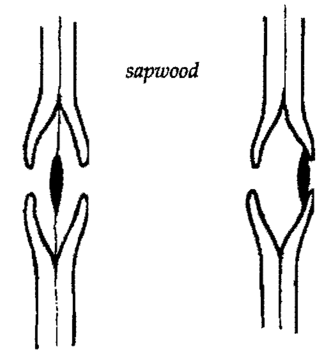
When the drying process starts the pits in heartwood are aspirated (closed) and all water transportation is done by diffusion of vapour trough cell wall by cell wall to the surface. The water transportation by diffusion is very slow.

The water in sapwood, wich is mainly free water, will in the initial state be transported by capillary forces and evaporates from the surface of the board. This transportation mechanism is relatively fast and is valid for moisture contents down to a state where the system of free water is broken. When this happens the water is transported as vapour through cells and between cells by pits, this is valid down to the fibre saturation point. At the fibre saturation point the pits in sapwood also will be aspirated, thus there will be a slower transport of water by diffusion, similar to the one in heartwood.

The difference in moisture content between heartwood and sapwood causes the heartwood to shrink immediatly as drying begins while the sapwood only looses free water. As the drying progress continues, also the sapwood will start to shrink when it reaches the fibre saturation point.

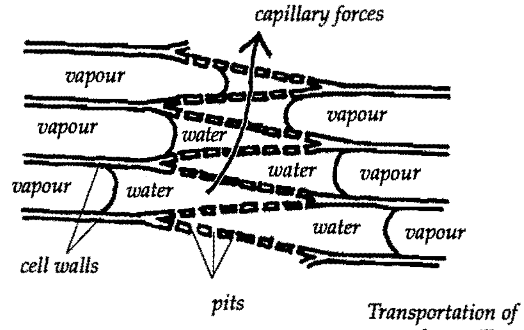


The pit is aspirated before and during drying and can not conduct water.

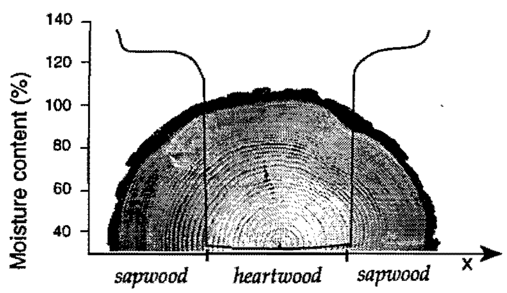


The pit before drying is open and can conduct water.

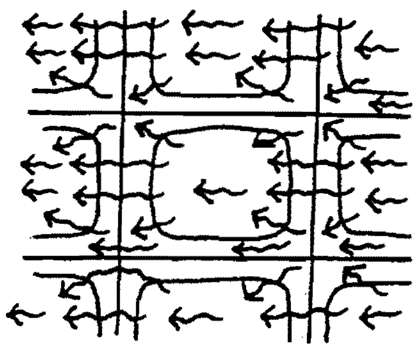
The pit aspirates during drying and can not conduct water.



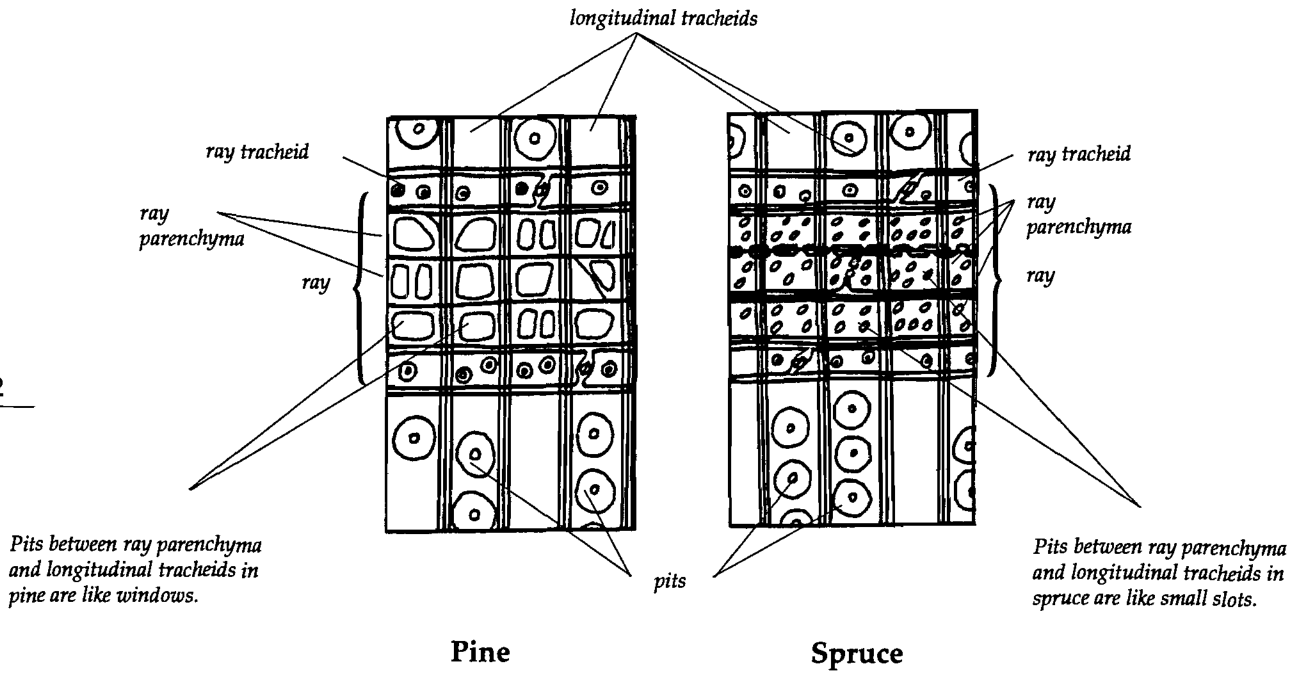
Transportation of water by capillary forces during drying.



Moisture content in sapwood and heartwood in pine before drying.



Transport of vapour in wood (diffusion) during drying.

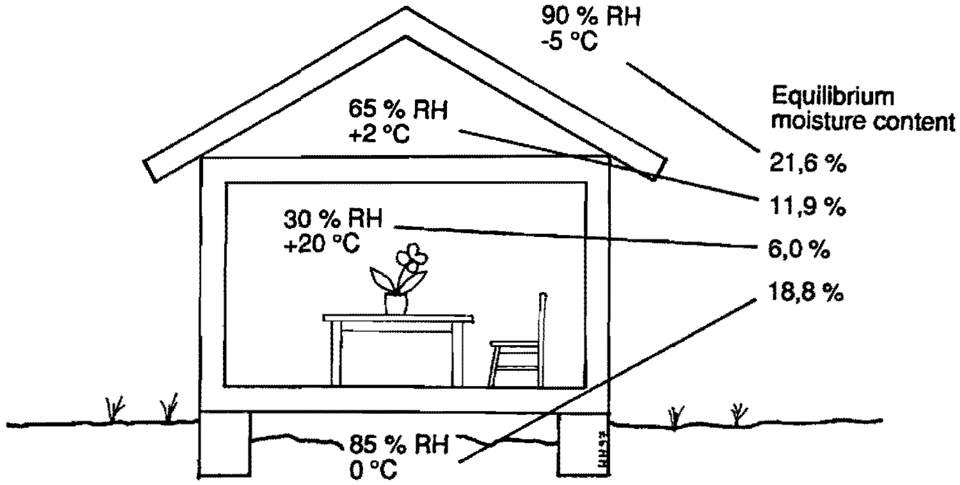


Why is pine easier to impregnate than spruce?

Aspiration, usually occurs when sapwood is transformed into heartwood or when wood dries. This phenomenon is the same in both spruce and pine. However, pine in dried state is more permeable than spruce.

The rays in pine and spruce consists of two different types of cells, ray parenchyma and ray tracheids. In a radial section the ray tracheids are located at the upper and lower side of the ray with the ray parenchyma centered. The pits between the longitudinal cells and the horizontal ray parenchyma is very different in pine and spruce. In pine these pits looks like large "windows" and in spruce the pits are like small slots.

Important for the penetration of impregnation substance, and for water uptake in the radial direction are the connections between the ray tracheids and the connections with the longitudinal tracheids. The amount of ray tracheids in pine is about five times higher than in spruce. The amount of rays in pine is only, though, twice as frequent as in spruce. The larger amount of ray tracheids in pine explains the fact that pine has better permeability.



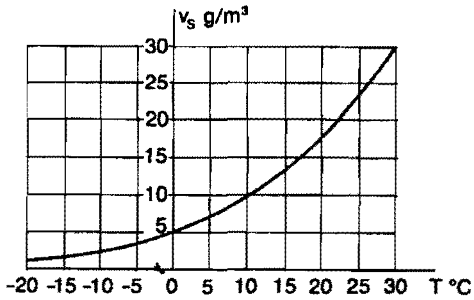
The equilibrium moisture content in wood depends on the temperature and relative humidity.

Humidity and relative humidity

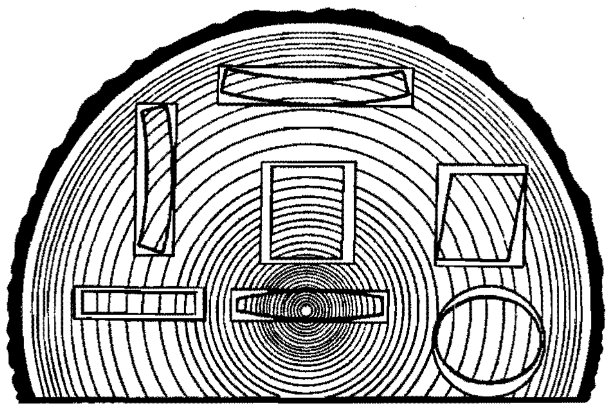
Humidity, or the moisture content of the air, may be expressed in two ways, absolut or relative. Absolute humidity is the actual quantity of water vapour contained in a given volume of air. It is measured by weight per unit volume or by vapor pressure. For example, saturated air at 30 °C has an absolute humidity of 30.31 g/m^3.

Relative humidity is the ratio of the amount of water vapour in the air compared with the amount at saturation at the same temperature. To continue the example, saturated air at 30 °C holds 30.31 grams of water vapor per cubic metre. However, if only 24 grams are present at this temperature, the relative humidity is 24/30.31 of 100 percent or 79 %. It can also be calculated on the basis of vapor pressure, with the same result.

Increasing the temperature of the air increases its capacity of holding moisture, so that it requires more moisture per unit volume to saturate it. Increasing the temperature of the air without adding more moisture will, thereby, cause the relative humidity to decrease.



Relation between temperature and absolute humidity in saturated air.



Differences in shrinkage and deformation during drying of timber taken from various locations in the stem.

Shrinkage and swelling

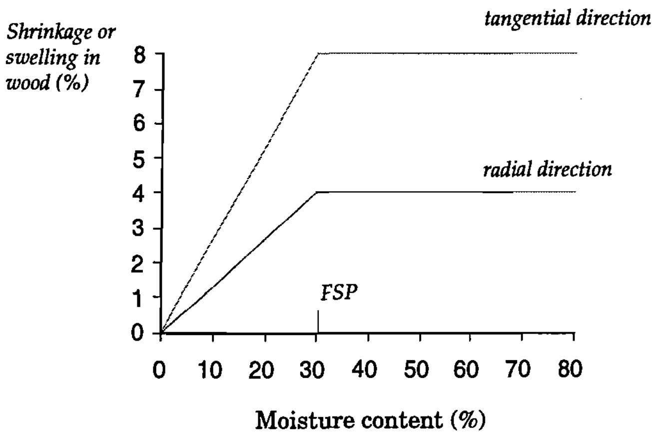
Shrinkage is decrease, and swelling is an increase of the dimensions of wood due to changes in moisture content. Such dimensional changes occur when the moisture of wood fluctuates below the fibre saturation point. Changes of moisture above this point, irrespective of the magnitude, have no effect on dimensions.

Wood is anisotropic with regard to shrinkage and swelling, i.e. the decrease or increase of its dimension, for the same change of moisture content, is different in different directions of the tree. Specially, the change of dimensions is least in the longitudinal (along the tree trunk), much greater in the radial direction (from pith to bark), and still greater in a direction tangential to the annual rings. The difference in shrinkage and swelling is attributed mainly to cell-wall structure.

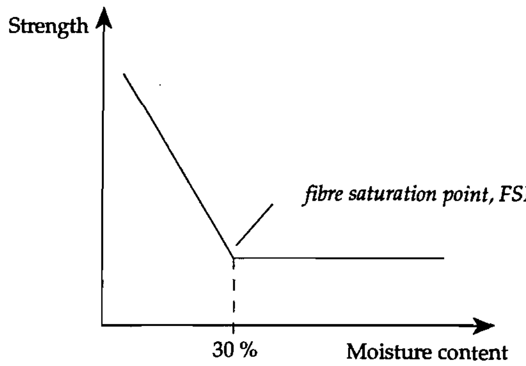
Wood is not a homogeneous material with equal shrinkage and swelling in all parts. As an example, the shrinkage and swelling ratio of knots, juvenile and compression wood are different from normal wood.

Shrinkage and swelling of wood are affected by many factors, such as moisture, density, anatomical structure, extractives, chemical composition, and mechanical stresses. It should be emphasized that the most important factor affecting shrinkage and swelling of wood is the change of moisture content below fibre saturation point. Dimensional change is found to be directly proportional to the amount of moisture, which is lost or gained by wood.

The magnitude of shrinkage and swelling is higher with larger density, i.e. wood of high density shrink and swell more than wood of low density.



Dimensional changes in wood only takes part below the fibre saturation point, FSP.



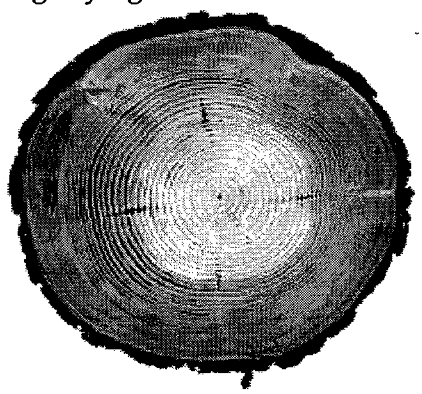
Moisture content below the fibre saturation point have a great influence on mechanical properties.

In normal wood, shrinkage and swelling of only 0.1 to 0.2 percent occurs in the longitudinal direction which for practical purposes can be ignored. In juvenile and reaction wood the longitudinal dimensional changes may be 10 times higher.

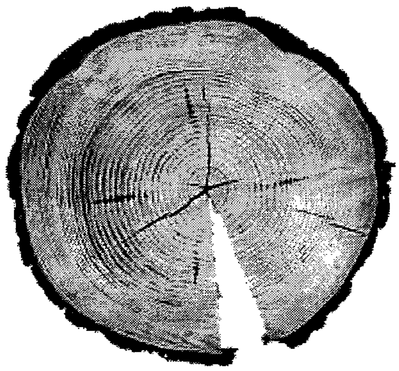
Seen in cross-section, in average, a log will shrink and swell twice as much in its circumference (tangential direction) as it will in diameter (radial direction). As tangential shrinkage is greatest, radial fissures will alwasys occur in the ends of logs during drying.

Approximate shrinkage (%) of pine and spruce, when moisture content is reduced from fibre saturation point to 0 %.

	Pine	Spruce
Radial	4.0	3.7
Tangential	7.7	7.8
Longitudinal	0.3	0.3

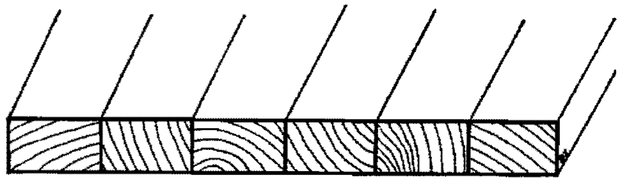


Cross section of a tree in wet condition.



Cross section of a tree in dry condition.

Gluing of many small components gives a larger and more stable product than solid wood, (solid wood panel).



Dealing with moisture related movements

The movements that occur in wood when its moisture content changes will give rise to considerable forces if they are restrained. Movements in a floor, for example, can shift walls and break up sealed joints.

There are various techniques in dealing with these movements.

Movements may be left unrestrained. Narrow floorboards gives many joints which allows the floor to move more overall freely than a floor with wide boards, which make fewer joints and less overall freedom of movement.

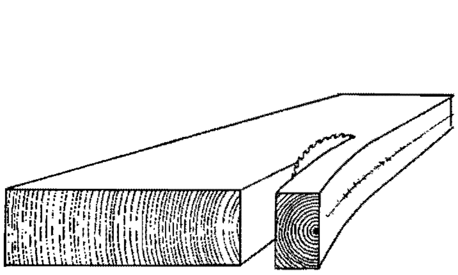
Movements may be restrained. There will be less movement if the wood is sawn thicker or if it is surface treated with an water tight coating. Movements in panelled doors can be reduced by painting them.

Extra care can be taken to ensure correct moisture content in production. During production, timber for use in furniture making should have a moisture content corresponding to the climate in which the furniture is to be used. In the case of furniture for use in heated premises the moisture content should be between 6 and 10 %.

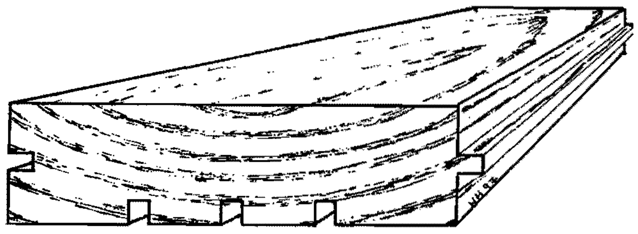
There are various methods in giving timber and other wood products shape stability.

Laminated components often involve gluing of several small pieces of solid wood to form a larger unit. Gluing of many small components yields more stable product than solid wood, specially when using radially sawn timber. Many furniture components, e. g. sofa legs and glulam boards, are made of laminated components.

Radially sawn timber, with vertical annual rings, is less suceptible to cracking during drying than ordinary sawn timber. The shrinkage and swelling due to moisture movement would be fairly uniform for such timber. Therefore the timber maintains its original shape. In addition, radially sawn board has a well controlled and precise orientation of sapwood, heartwood and juvenile wood. Thus the possibility of eliminating the undesireable juvenile wood from the mature wood is very simple.

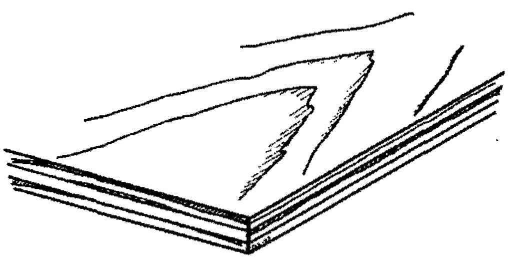


Pith and juvenile wood is easily removed in radially sawn boards.

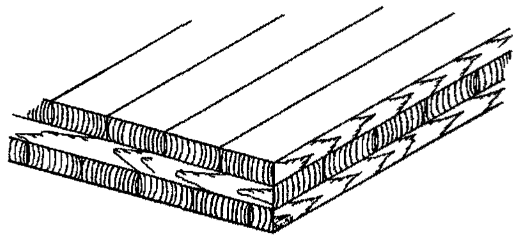


Grooving reduces cupping in boards.

Plywood is a board material made up of an uneven number of veneer lamellas that are glued together crossvise at right angles to each other. In this way it is possible to take advantage of the fact that there is little movement along the fibres (longitudinal direction) to restrain the greater movement across them (radial and tangential directions). Grooving the boards will reduce their tendency to cup, and also reduce the forces that would have resulted from cupping. Movement across the the width of boards will not be noticeably affected.

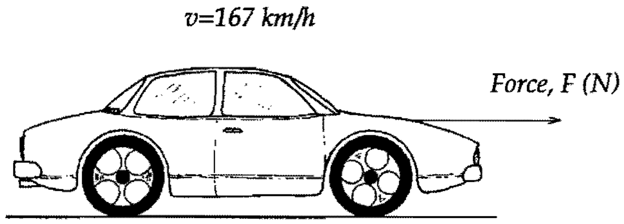


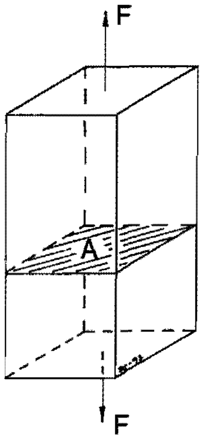
plywood



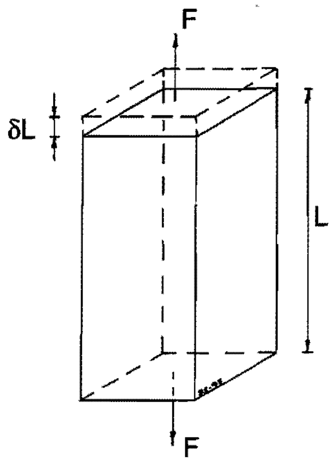
three-layer glulam board

Plywood and three-layer glulam board uses the small longitudinal shrinkage to restrain the movements in radial and tangential directions.



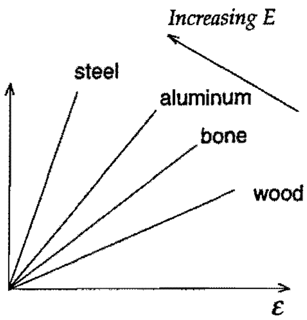


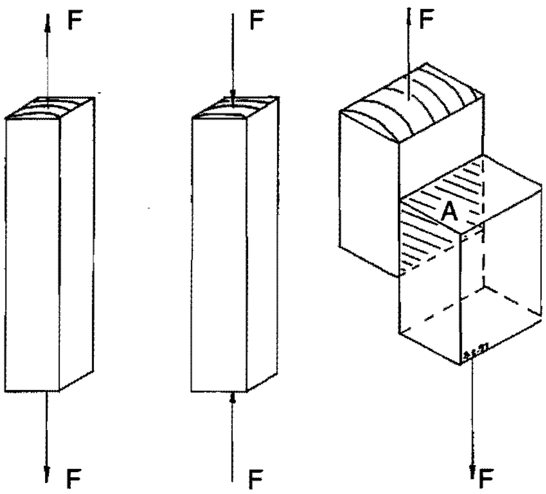
Stress: $\sigma = \frac{F}{A}$ (N/m²)



Strain: $\varepsilon = \frac{\delta L}{L}$

Modulus of elasticity: $E = \frac{\sigma}{\varepsilon}$ (N/m²)





tension *compression* *shear*

Mechanical properties

The mechanical properties of wood are measures of its resitance to exterior forces which tend to deform its mass. In contrast to metals and other materials of homogenous structure, wood exhibits different mechanical properties in different growth directions, (axial, radial and tangential), and therefore it is mechanically anisotropic.

Before discussing the mechanical properties of wood, it is useful to explain certain basic concepts regarding the mechanics of materials in general.

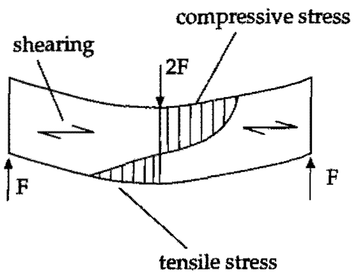
Force, F, (load) is any action that tends to move a body at rest, or change its shape or size, or if the body is moving, to change the speed or direction of its movement. A force is expressed in Newton (N).

Stress, σ, is defined as the load (F) per unit area (A) of a cross section of material. In general stress is expressed in N/m^2 which is the same as Pascal (Pa).

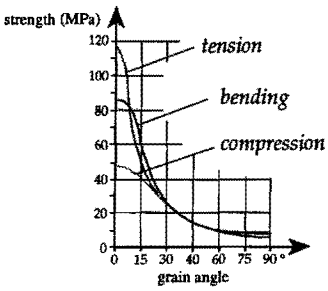
Strain, ε, specifies the effect of applying a stress to a material. Strain is defined as the ratio of the stress-induced change in length of a material to its original length. Because strain is a ratio, it has no unit.

Modulus of elasticity, *E*. The relationship between stress and strain defines the modulus of elasticity (Youngs modulus). A high modulus of elasticy indicates a stiff (difficult to bend) body.

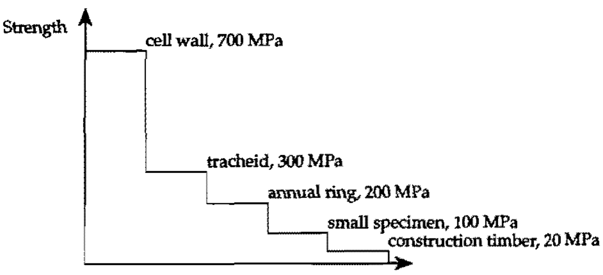
There are three basic stresses: tensile, compressive, and shearing. A body is under tensile stress when the force acting tend to increase its length. If the force is acting in the opposite direction, the body is under compressive stress and tends to become shorter. Shearing stresses develop when the forces tend to cause a part of the stressed body to slide onto adjacent part at the same body. As an example, in a beam bent under external forces, which are perpendicular to its length, all the three stresses are developed.

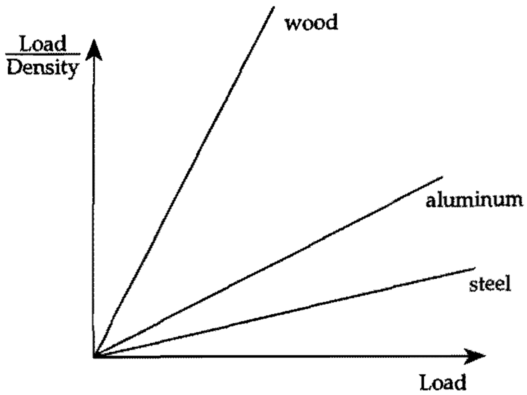


In a beam bent under external forces, which are perpendicular to its length, tensile, compression and shear stresses are developed.



Grain deviation strongly influence the strength of wood.





Strength properties of wood

In relation to its density, strength properties of the wood is very good. Wood is strongest in the grain direction, (the longitudinal direction). This continues to apply even when loads to which it is subjected give rise to tensile, compressive or bending forces.

Clear wood have a high tensile strength in the grain direction. In pine and spruce the tensile strength is nearly twice the compression strength. Perpendicular to the grain direction however, the tensile strength is 25-30 times lower.

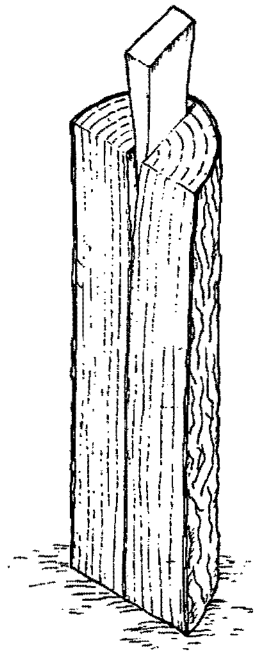
Grain deviations obvious influence the tensile, compressive and bending strength of wood. Tensile strength is affected more than compressive strength, while the reduction in bending is intermediate. The main reasons for grain deviations are fibre distubances around knots and spiral grain.

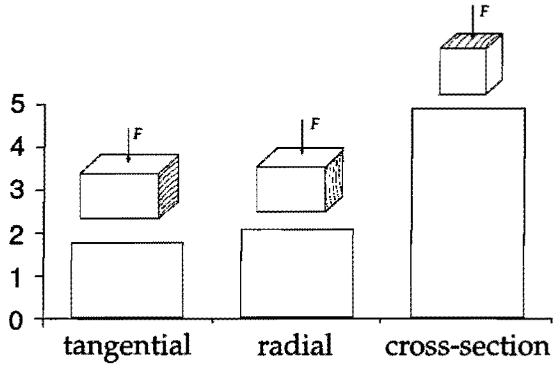
There is a great difference in strength between construction timber, and the fibre wall material of which the construction timber consist. As an example, the tensile strength of the fibre wall in latewood is about 15 times higher than for a board without defects.

Moisture affect the mechanical properties when it reaches below the fibre saturation point. When moisture is reduced, strength increases, and vice versa.

Density is the best and simplest index of the strength of wood without defects. With increasing density, strength also increases. This is because density is a measure of wood substance contained in a given volume.

In general, the strength of wood is reduced with increasing temperature.





Brinell hardness on different sections of pine.

Cleavage

The resistance of wood to cleavage refer to exterior forces acting in the form of a wedge. Due to its structure, wood has a low axial resistance to cleavage. This is an advantage for certain uses, e.g. splitting fuelwood, and a disadvantage for others, e.g. wooden member splitting when nailed or screwed. Different wood species posses different resistance to cleavage. Softwoods and light hardwood have low resistance in contrast to heavier hardwood.

Hardness

By hardness is meant the susceptibility of a wood surface to damage by impression, e.g. heel marks on floors and impact marks on table tops.

The resistance is much higher in the axial direction (on the cross section) than sidewise, and radial surfaces have normally higher hardness than tangential surfaces. Apart from the direction of grain, hardness depends first and foremost on the wood density.

Load direction	Surface
radial	tangential section
tangential	radial section
longitudinal	cross section

Construction timber

Many parts of a building are loadbearing, for example, floor beams, roof trusses, and certain parts of timber framed walls. It is often necessary to calculate the loads involved and then choose material which can carry these loads. In relation to its weight wood is a strong material and it is therefore frequently used in loadbearing constructions. Timber used for this purpose is called construction timber, and it is stressed graded, either by machine or visually, on the basis of various stress grading rules. Although, yet there are no uniform international rules of this type, the difference between different countries rules are seldom particulary great. General rules for European sorting of structural timber are now ready for implementation. Timber sorted in accordance with these regulations will be accepted in all member states of the EU without the need for resorting.

In Sweden pine and spruce are regarded as having the same strength. The most common type of stress graded and marked timber in Sweden is called T-timber. Swedish T-timber is divided into three grades, T30, T24 and T18. The Swedish design code details strength classes given the prefix K. For structural calculations, T30 matches strength class K30, T24 matches strength class K24 and so on.

The annual production of stress graded and marked timber in Sweden is estimated to be about 370 000 m^3. Two thirds of this is exported, and many sawmills grade and mark their timber in accordance with the rules in British standard.

Finger jointed construction timber is accepted in Sweden provided that it is manufactured in accordance with the Swedish authorities rules for approval. Correctly finger jointed timber has a strength equal to any of the stress grades.

Graded timber of different strength classes.

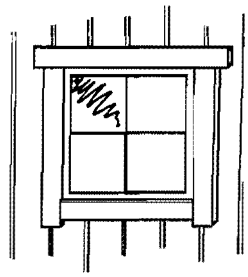
Grading	K30	K24	K18	K12
visually graded	T30	T24	T18	V
machine-graded	T30M	T24M	T18M	–
ECE-graded	S10	S8	S6	–

Some characteristic strength values (MPa) of structural timber of different strength classes.

	Structural timber			
Strength values	K30	K24	K18	K12
bending parallel to grain	30	24	18	12
tension parallel to grain	20	16	11	8
tension perpendicular to grain	0.5	0.5	0.5	0.5
compression parallel to grain	29	23	17	14
compression perpendicular to grain	7	7	7	7

Timber for joinery and furniture industry

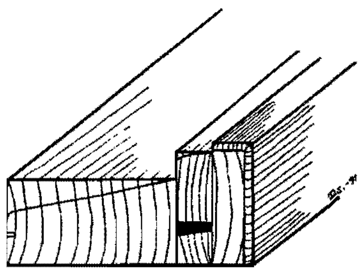
There is no clear borderline between joinery and furniture making industries. Both use similar raw materials and employ roughly the same techniques in refining and adding value to finished products.



Timber is used for various purposes in the joinery industry. Typical applications are windows, doors, stairs, and floorings.

Sawn timber for use in the joinery industry undergoes a number of process stages. There are considerable variations in the processes, and therefore no generally applicable concept. It depends on tradition, the machinery available etc, and in many cases the actual process may well be unique.

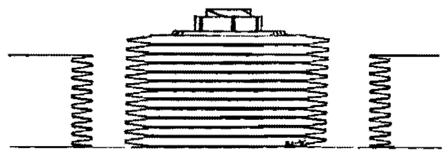
Timber for joinery industry is usually sawn in thickness of 50, 63 or 75 mm, and in widths from 100 to 200 mm. In some applications a high proportion of heartwood is desired, as well as timber without pith and juvenile wood.



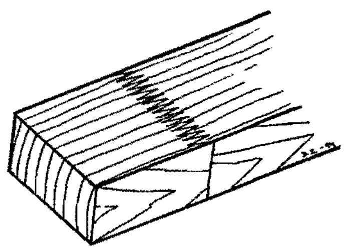
Laminated component for windows.

The original dimensions of the timber can be reduced by cutting and resawing, or increased by gluing smaller pieces together. Laminating is also used to eliminate cracks, and to limit changes in shape such as warp.

The original length of timber is cut into shorter pieces for use as finished components or for futher processing. This may take the form of finger jointing in long lengths followed by cutting into components. Due to the necessity of joining, it is desirable to avoid knots near ends. This makes special demands when the timber is cut into exact lengths.

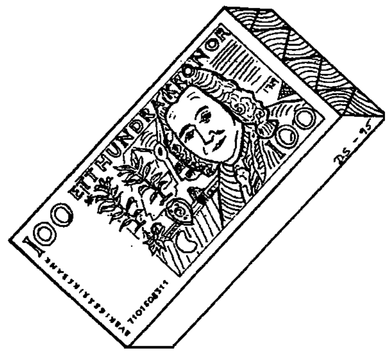


Finger jointing provides longer boards without defects.



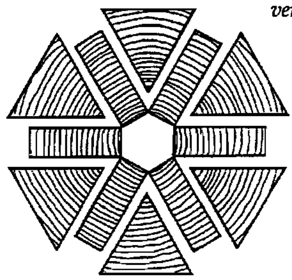
Timber containing only sound knots is to be preferred, but black pearl or round knots may be acceptable. Knots are unacceptable in the finished product and can be cut away during processing.

The furniture industry has a certain requirement on solid timber and wood-based board products. When solid wood is included in a visible surface of piece of furniture, special demands on the quality of the timber are used. The wood shall be free from fissures and the knots should be sound and firmly secured to the surrounding wood. Solid wood can also form the core in a veneer laminated board, and then the quality can be lower.



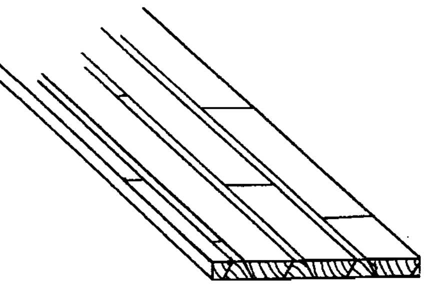
When free from knots material are required, timber for use in furniture making is taken from side boards in butt logs. Timber with sound knots firmly attached to the surrounding wood is usually taken from the main yield in top logs, known as "green fifth".

Star-sawing, a new sawing pattern to produce timber with vertical annual rings.

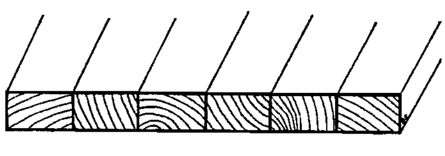


In many cases the original quality of the timber is of a minor importance, since elements are limited in length. A single defect that results in a full-length board being down-graded may be cut away so that the quality of the rest of the timber can be put to good use. Making optimum use of raw materials is an important economic aspect of furniture making.

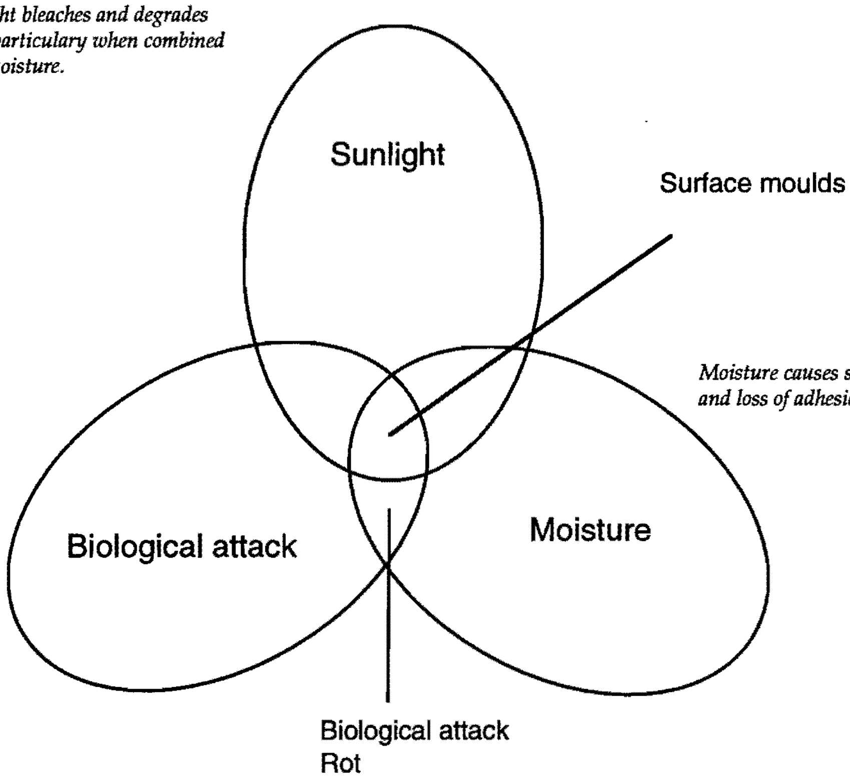
Components are obtained from the original timber in a number of ways, including resawing and laminating. Laminating also makes it possible to limit changes in shape. Good stability in form can also be attained by using timber with vertical annual rings, by means of special sawing pattern.



The most common wood-based product for use in furniture making is laminated board (solid wood panels), consisting of rectangular (in some cases with triangular) cross-sectioned staves that have been glued together. As the staves have small dimensions, e.g. between 25x25 and 25x50 mm, they can be cut as almost free of knots or with knots that gives an attractive apperance. Larger knots can be cut away, and the staves can be joined, normally by finger joint. The adhesive used are normally of types that produce invisible glue lines.



Sunlight bleaches and degrades wood particulary when combined with moisture.



Moisture causes splitting and loss of adhesion.

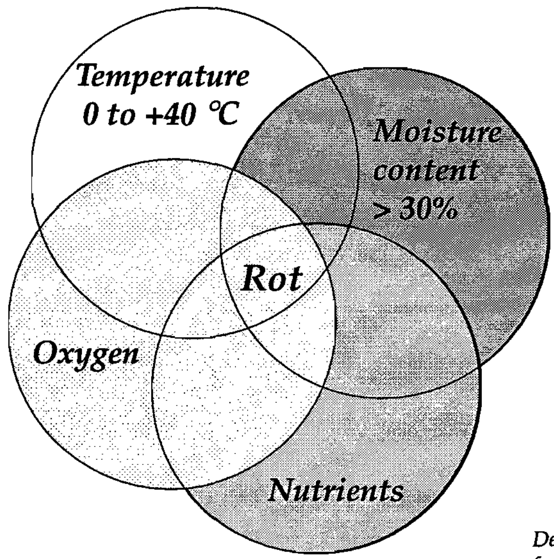
Biological attack can remain dormant for long periods.

Wood's natural enemies constantly attack timber in service.

Degradation of wood

Degradation of wood is part of the natural life cycle. This yields problems to achive products that can resist natural decay when wood is used as construction material. Wood is used in such diverse functions as painted out door panels, which should protect a house and at the same time be aestetical preferrable, to fence poles, which only function is to hold the fencing. After cutting the life functions of a tree, cease and decay starts. By different ways of wood manufacturing, this process can be detained. At the same time when wood is excluded from the life cycle it decreases the emissions of carbondioxide to the atmosphere.

Degradation of wood is a very complex process and can for solid wood excluded from extreme chemical or thermal exposure be separated into three different mechanisms; biological, mechanical and photochemical degradation. All of these mechanisms are active individually or at the same time.



Development of rot requires four factors at the same time.

Biological degradation

Biological degradation is assigned to fungal, insect and bacterial attacks. To this group also a number of marine borers can be counted, and to some extent birds. The constituents of wood; cellulose, hemicellulose, lignin, and extractives are decomposed into simpler components and become food to fungus and insects. The decay is done by enzyma which is produced by these organisms. The content of nitrogen is of importance for insect larvae.

Blue stain is caused by fungus that spreads inside timber, making it more permeable to fluids such as water, oils and primers. There are two ways in which timber may be attacked in this case:

• In the forest during spring, when the spores of the fungus are spread by insects. This is known as log stain, and is characterized by deep blue streaks.

• In sawn timber before drying, in cases where the moisture content is over 18 %. This is known as piling stain. It results in blue stains on the surface of the timber. It is sometimes known as surface stain.

Blue stain fungus does not attack timber with a moisture content lower than 18%, the level normal in timber delivered from the sawmill. Attacks is first and foremost on sapwood.

Blue stain does not affect timber strength or hardness. However, timber that has been attacked should not be glazed as the stained areas will absorb more fluid and pigments than the rest, resulting in a blotchy finish. Timber that has been attacked by blue stain is also unsuitable for use in external finishes.

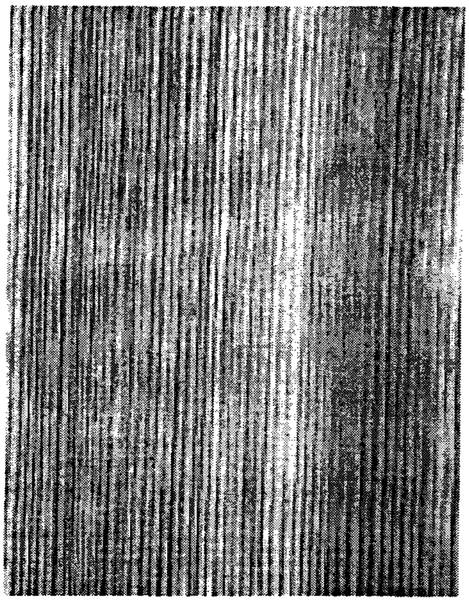
Rot

Rot is the result of a fungoid attack that breaks down the wood and reduces its strength and hardness. Heartwood of pine exhibits better resistance against rot than spruce or pine sapwood.

Timber showing signs of an attack of rot will be sorted into the lowest class after drying at the sawmill.

Rot does not attack timber with a moisture content lower than 30 % and will be halted if the moisture content is reduced below this level. Some fungus can transport water long distances and hence cause decay on timber with lower moisture content than 30%. In all applications of wood, attempts are made to find technical solutions that will keep the moisture level below 30 %. Where this cannot be achieved the wood can be chemically treated to prevent attacks. This process is known as wood preservation.

Tangential surface exposed outdoors during 3 years.



Radial surface exposed outdoors during 3 years.

Photochemical degradation

Wood undergoes a number of chemical changes, including alterations in colour, when exposed to solar radiation (visible light, ultra violet and infra red radiation). Many of these reactions also require the presence of water and oxygen.

In dry conditions unfinished wood tends to become brown but becomes progressively grey on normal weathering. The colour changes are believed to reflect radiation catalysed reactions which involve the oxidation depolymerisation and general breakdown of both the lignin and cellulose constituents of wood. Tests have shown, that the presence of highly active chemical species, known as free radicals, in irradiated wood also take part in this process. Because the breakdown products are soluble they are leached out by water leaving a grey, denatured surface consisting mainly of cellulose .

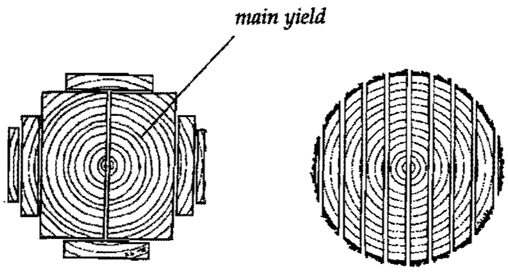
Chemical degradation

Wood is relatively resistant to chemicals, acids with pH over 2 and to alkalii with pH lower than 10. Wood is hence used in agressive environments, where other materials are degraded. Wooden frames are common for e.g. storage of beer and salt.

Wood can be used in pipes above or in ground or in water. Pipes of wood are especially common in process industry where other types of pipes would not resist the stress from different chemicals.

Sawing and timber defects

The primary step in the chain of wood utilazation is the conversion of the log to boards. The choise of sawing pattern has great importance on the quality of the sawn product and economy of the sawing process, e.g. volume yield. Sawing patterns are influenced by several factors, such as machinery, intended use of the timber, kind of wood, log diameter, yield, and cost. A great variation of sawing patterns exists.



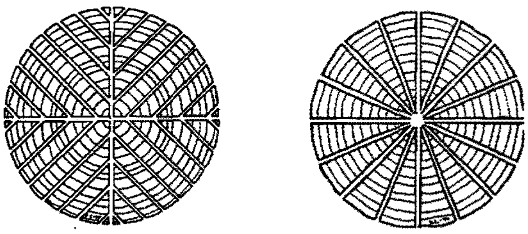
Square sawing *Through-and-through sawing*

The most common sawing pattern in the Scandinavian countries is square sawing (block sawing) followed by resawing. The timber, in form of planks and boards, is given a rectangular cross-section except on the periphery of the log which have a certain amount of wane, i.e. the edges will be uneven.

The most usual method of sawing hardwoods is through-and-through sawing. With this sawing method all timber will have a certain amount of wane. Thereafter each piece will be individually edged.

As a consequence of the anisotropic behaviour of wood, e.g. the tangential shrinkage is twice as large compared to the radial shrinkage, boards from square sawing will show cup.

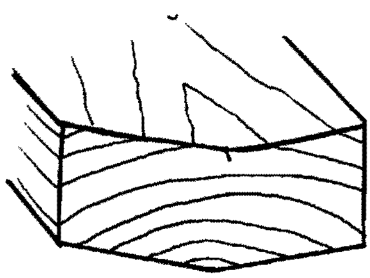
The traditional way to avoid cupping is sawing the boards radially from the log. It has been known for a long time that if boards is sawn radially from a log, no or very small changes in shape occur. The



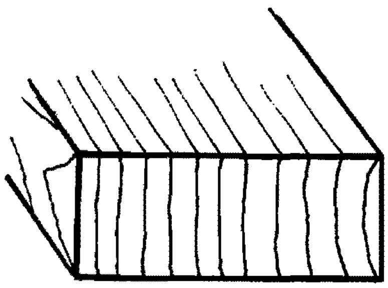
Quarter sawing *Sector sawing*

Example of two sawing patterns which gives timber with vertical annual rings.

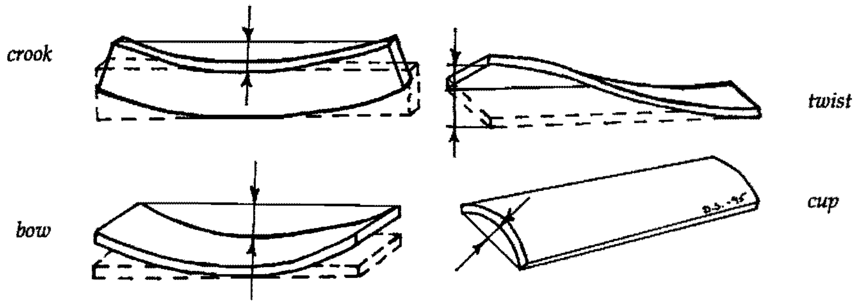
boards then have vertical annual rings. There are several methods of producing timber with vertical annual rings. The methods which give boards with a rectangular cross-section adopt in most cases the traditional quarter sawing pattern. With other methods which give timber with vertical annual rings, sectors are sawn with more or less triangular shape. A combination of these two methods is star-sawing.



Cupping in a board after drying. Annual rings with a great curvature tends to "straighten out" during drying. This is a consequence of different shrinkage between the radial and tangential direction of wood.



Boards with vertical annual rings do not show cup.



Definitions of measuring warp.

Warping, e.g. crook, twist, bow, and cup, may occur because of different shrinkage in drying caused by annual ring orientation, or presence of cross grain, spiral grain, reaction wood or juvenile wood.

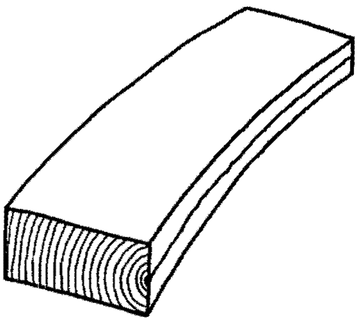
Bow is a lengthwise curvature of the wide surface of the board; crook is a lengthwise curvature of the narrow edge of a board; twist is the curving of the edges of a board, so that one of four corners is no longer in the plane of the other three; and cup, as earlier mentioned, is a curving across the face of a board.

It is well known that juvenile wood, the annual rings closest to the pith, differs considerably from the wood located in the periphery of the log. Juvenile wood shrinks more in the longitudinal direction than the mature wood, which means that timber that contains both mature and juvenile wood will show great deformation during drying.

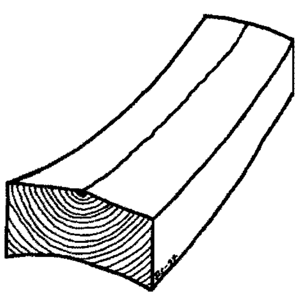
The main yield from square sawing have juvenile on its flatside closest to the pith, and mature wood on the opposit side. Drying these boards cause bow.

In the same way, a radially sawn board that contains juvenile wood on one of the edges will show crook after drying.

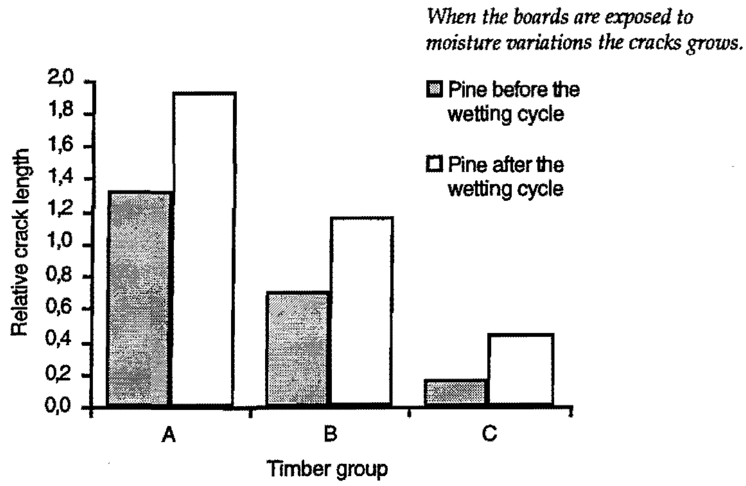
Juvenile wood makes the boards warping, as a consequence of different shrinkage during drying.



Juvenile on the edge cause crook.



Juvenile wood on the flat side cause bow.



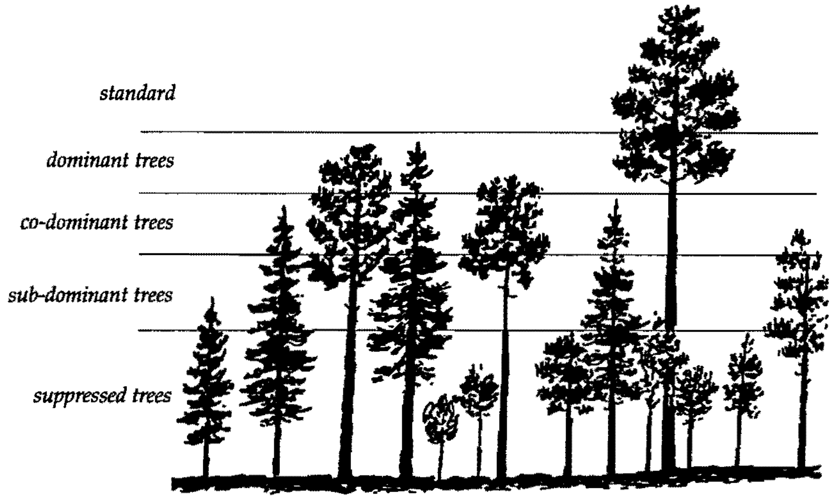
Crack length in pine boards sawn with different distances from pith.
A - boards with the pith enclosed.
B - Boards containing juvenile wood.
C - Boards without juvenile wood.

How to prevent warp and cracks?

In some extent warp can be reduced by timber processing. The first operation in which warp can be controlled is in sawing. By avoiding extreme grain deviations, and seperate the pith and the surrounding juvenile wood from the other wood, the degree of warp and cracking will be reduced.

A very effective way to reduce warp is to stack timber so that it will be held flat during drying. On the other hand, improper piling can cause warp in lumber having no outstanding tendency to warp. Poor practices include not placing stickers in vertical alignment, or placing them to far apart, or building loads with overhanging board ends. The choice of a proper kiln is important.

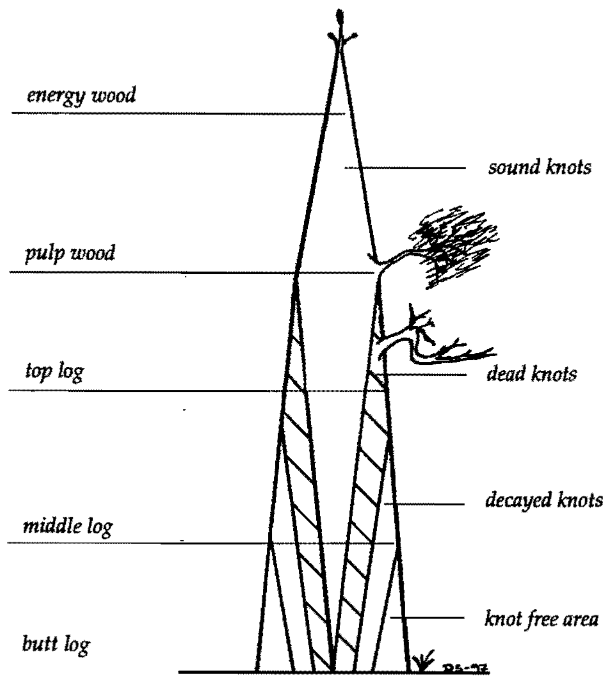
It is of great importance to remember that timber that are restrained during drying to prevent warp, probably will warp later on when the timber are exposed to moisture variations. This phenomena usually is called mechano-sorption.



Quality variations in the tree

A forest or a stand can be divided into different layers according to the height of the trees. The tallest trees are the standard trees. These are usually very old, for example seed trees which have been ingrown in the stand.

Dominant trees are taller than co-dominant trees, which are taller than sub-dominant trees. The supressed trees have no traditional industrial application, but can be used as fuel.



Since dominant trees are tall they also have the broader annual rings, and hence great branches and low density. In contradiction, sub-dominant trees have thinner annual rings and hence small branches and normally a higher density than dominant trees. Density, as earlier mentioned, clearly affect the strength properties of wood.

The quality of sawn timber is strongly related to different parts of a tree. The top log from dominant and co-dominant trees contains only sound knots. These logs are normally of small dimensions and with a higher proportion of juvenile wood. When timber with dimension stability are required, top logs are inappropriate as sawtimber.

The middle log has a great proportion of dead and decayed knots. As a consequence, timber from this part of the tree are normally used as construction timber.

The most valuable part of a tree is the butt log. Butt log shows the greatest variation in quality. This means it is important to process the logs in a correct way to get high value. The peripheri of the but log is free from knots, and timber from this parts are used in furniture industry. Other parts of the log contains dead, decayed or sound knots.

Common species in Sweden

Some useful definitions:

Family	*taxon of order over genus*
Genus	*taxon of order beteen family and species*
Species	*taxon of order between genus and subspecies*
Subspecies	*taxon of order under species*

Pine

English:	Scots pine, redwood, Norwegian pine
German:	Kiefer, Föhre
French:	pin silvestre
Swedish:	tall, furu
Latin:	*Pinus silvestris L.*

The genus pine (Pinus) is among the greatest of the conifers and comprises about 90 species, widely spread on the northern hemisphere from the arctic to the subtropic zone. Scots pine is widely spread including most of Europes forest areas except Southern Spain, Portugal, southern and middle parts of Italy and Balkan. The most northern growth place is Kistrand, Norway where pine grows as far north as 70°29′ N. In Sweden two different subspecies is to be found, the wide crowned South Swedish pine (septentrionalis Schott) and the North Swedish pine (lapponica Fr. Hn.) which has slight straighter stem and thinner bark.

The timber is rather soft and easy to split. The relationship between strength and volume weight is good. It is easy to machine, rather easy to dry and the sapwood is easy to impregnate. The unimpregnated heartwood is resistant to weathering, which is not the case for the sapwood

Property	Value	Unit
Density, dry	450-500	kg/m³
Shrinkage		
radial	4.0	%
tangential	7.7	%
longitudinal	0.3	%
volume	12.0	%
Strength at 12 % MC		
Tensile strength		
fibre direction	102	MPa
cross fibres	3	MPa
Compresssion strength		
fibre direction	45-47	MPa
cross fibres	7.5	MPa
Youngs modulus		
fibre direction	10 000-12 000	MPa
cross fibres	460	MPa
Hardness, Brinell		
cross section	4.9	kp/mm²
radial section	2.1	kp/mm²
tangential section	1.8	kp/mm²

Spruce

English:	whitewood, Norway spruce
German:	Fichte, Rottanne
French:	épicéa, sapin épicéa, sapin de Norvége
Swedish:	gran
Latin:	*Picea abies Karst.*

The genus spruce comprises about 40 species, which belongs in the colder regions of the northern hemisphere. Of these, 18 grows in China and 7 in North America. Our common spruce is naturally widely spread in an area consisting of North Europe, the mountains of Middle Europe and Northern Asia.

In Sweden spruce is naturally spread all over the country excluding the south and south west coasts.

The wood is softer than pine. Also the strength is slight lower compared to pine. It is easy to split, machine, dry and surface treat. The wood shrinks and swells moderate.

Spruce, especially fast grown, have less duration and is hard to impregnate with the usual impregnation methods.

Spruce is commonly used to produce chemical and mechanical pulp. Furthermore, it is very common in construction and building. It is also used in simpler furniture, boxes, mouldings, fibre boards and plywood. Especially good qualities are used in instruments as violins and guitars.

Property	Value	Unit
Density, dry	370-400	kg/m³
Shrinkage		
radial	3.6-4.2	%
tangential	7.8-8.8	%
longitudinal	0.2-0.3	%
volume	12.0	%
Strength at 12 % MC		
Tensile strength		
fibre direction	88	MPa
cross fibres	3.3	MPa
Compresssion strength		
fibre direction	35-44	MPa
cross fibres	6.5	
Youngs modulus		
fibre direction	8 300-13 000	MPa
cross fibres	440	MPa
Hardness, Brinell		
cross section	3.2	kp/mm²
transverse section	1.2	kp/mm²

Lodgepole pine (contorta)

English:	lodgepole pine, contorta pine, shore pine
German:	Lodgepole Kiefer, Drehkiefer
French:	pin lodgepole
Swedish:	contortatall
Latin:	*Pinus contorta Dougl.*

Lodgepole pine is not a native specie in Sweden. It is naturally grown in North America at the Pacific coast and Rocky mountains up to Alaska.

It was introduced in Sweden in the beginning of this century to compensate for over-cutting. Its major feature is high increment, about 40 % greater than Scots pine, and its good resistance against barren conditions.

The advantages of contorta is most pronounced in Northern Sweden with meagre land and high habitats. Hence, the contorta can only be planted in the northern regions of Sweden.

The properties of contorta is comparable with Scots pine but its stability against wind is slightly lower, while its hardiness is very good.

The timber has low amounts of checks in normal wood after drying but has frequent amounts of checks in knots. Furthermore warping is less in contorta compared to Scots pine.

The timber is relatively resistant against decay and is less hygroscopic than Scots pine.

Property	Value	Unit
Density, dry	400-450	kg/m^3
Shrinkage		
radial	4.3	%
tangential	6.7	%
longitudinal	0.3	%
volume	11.3	%
Strength at 12 % MC		
Tensile strength		
fibre direction		MPa
cross fibres	2.0	MPa
Compresssion strength		
fibre direction	37.0	MPa
cross fibres	4.2	
Youngs modulus		
fibre direction	9 200	MPa
cross fibres	-	MPa
Bending strength	-	MPa
Hardness, Brinell		
cross section	-	kp/mm^2
transverse section	-	kp/mm^2

Larch

English:	common larch
German:	gemeine Lärche, Europäische Lärche
French:	mélèze d'Europe
Swedish:	lärk
Latin:	*Larix decidua Mill.*

European larch botanically belongs to the family Pinaceae. Larches comprises about 10 species, growing in East Asia, North America and Europe. Larch is not native in Sweden, but the European larch has been cultivated since the end of the 18th century. The European larch is native in the Alps and Eastern Europe, from where it has been spread over the Continent, Brittain and Scandinavia.

The sapwood is light yellow or light red and is very thin, only 10 to 15 annual rings. The heartwood is red-brown and becomes darker in contact with air.

Contrary to Scots pine, branch whorls do not exsist in larch. Larch is the hardest among the commercial softwood in Sweden. The strength properties are fairly good. It is easy to split, and machine. Its shrinkage and swelling is moderate. Staining is hard to perform if the extractives on the surface are not first dissolved.

The heartwood is very sustainable and have good resistance against acids and alkalis.

Property	Value	Unit
Density, dry	520-600	kg/m^3
Shrinkage		
radial	3.3-4.3	%
tangential	7.8-10.4	%
longitudinal	0.3	%
volume	11.9	%
Strength at 12 % MC		
Tensile strength		
fibre direction	105	MPa
cross fibres	2.3	MPa
Compresssion strength		
fibre direction	47-54	MPa
cross fibres	-	MPa
Youngs modulus		
fibre direction	9 900-13 500	MPa
cross fibres	-	MPa
Bending strength	92-94	MPa
Hardness, Brinell		
cross section	5.2	kp/mm^2
transverse section	1.9-2.5	kp/mm^2

Birch

English:	birch
German:	Birke
French:	bouleau
Swedish:	björk
Latin:	*Betula verrucosa Ehrh.*

The birch belongs to the family Betulaceae and contains about 40 species, which are widely spread in the northern hemisphere. Mainly two different species are to be found in Sweden; *vårtbjörk* and *glasbjörk*.

Birch timber is relatively soft but hard to split, especially timber with irregular structure and curly-grained wood. It is elastic and has good strength. It is easy to machine and bend, and it is easy to surface treat. Birch is not durable in places with high moisture.

Birch is widely used as solid wood, veneer and plywood in the furniture industry. It is also used in panels, skis, and milling. In pulp industry large volumes of birch is used.

Property	Value	Unit
Density, dry	580-620	kg/m^3
Shrinkage		
radial	5.3	%
tangential	7.8	%
longitudinal	0.6	%
volume	13.7	%
Strength at 12 % MC		
Tensile strength		
fibre direction	137	MPa
cross fibres	7	MPa
Compresssion strength		
fibre direction	54-60	MPa
cross fibres	-	MPa
Youngs modulus		
fibre direction	13 000-15 000	MPa
cross fibres	-	MPa
Bending strength	107-123	MPa
Hardness, Brinell		
cross section	-	kp/mm^2
transverse section	2.2-2.7	kp/mm^2

Ash

English:	European ash
German:	Esche, gemeine Esche
French:	frêne élevé
Swedish:	ask
Latin:	*Fraxinus ecxelsior L.*

European ash is the only native tree in Sweden that belongs to the family Oleaceae. The genus ashes comprises about 65 different species in the temperated areas of the northern hemisphere.

European ash is widely spread over Europe, though it is not found in Northern Scandinavia, Scotland, Ireland and parts of the Iberian Peninsula. In Sweden the northern border passes through Southern Värmland, South-east of Dalarna and the coastal areas of Gästrikland and Hälsingland.

The sapwood is yellow-white and wide, normally comprising 60-70 annual rings. The heartwood is grey-brown.

Ash is one of the most valuable timbers in Sweden. It is relatively heavy and hard. The timber is also elastic and has high strength. Timber from ash is hard to split but it is easy to machine and polish. The shrinkage and swelling is relatively moderate. Ash is durable in dry places but perishable in moisture and outdoors.

Property	Value	Unit
Density, dry	530-780	kg/m^3
Shrinkage		
radial	3.8-5.0	%
tangential	5.4-8.4	%
longitudinal	0.2	%
volume	9.4-12.6	%
Strength at 12 % MC		
Tensile strength		
fibre direction	165	MPa
cross fibres	7	MPa
Compresssion strength		
fibre direction	35-58	MPa
cross fibres	11	MPa
Youngs modulus		
fibre direction	8 300-13 400	MPa
cross fibres	-	MPa
Bending strength	80-120	MPa
Hardness, Brinell		
cross section	6.5	kp/mm^2
transverse section	3.0-4.1	kp/mm^2

Oak

English:	common oak, penduculate oak, english oak
German:	Stieleiche, Sommereiche
French:	chéne, pédonculé
Swedish:	skogsek, sommarek
Latin:	*Quercus robur L.*

Oak belongs botanically to the family Fagaceae. The genus oak contains most species of all hardwoods. Between 200 and 300 species are identified. In Europe 12 species are to be found and about 80 in North America, and the rest in Asia. In Sweden the norther border of oak is the southern part of Värmland, along Dalälven to the east coast of Gävle.

The sapwood is yellow-white and relatively narrow. The heartwood is grey-brown. Timber of oak is heavy, hard and elastic with high strength. It is easy to split, machine and finish. Timber from oak is pretty hard to dry, but shrinks and swells relatively moderate. Oak is resistant against abrasion. Heartwood of oak is among the most durable native species in Sweden.

Property	Value	Unit
Density, dry	650-720	kg/m^3
Shrinkage		
radial	4.0-5.0	%
tangential	7.8-10	%
longitudinal	0.4	%
volume	12.2-15.4	%
Strength at 12 % MC		
Tensile strength		
fibre direction	90	MPa
cross fibres	4	MPa
Compresssion strength		
fibre direction	53-65	MPa
cross fibres	11	MPa
Youngs modulus		
fibre direction	10 000-13 000	MPa
cross fibres	-	MPa
Bending strength	90-100	MPa
Hardness, Brinell		
cross section	6.4-6.6	kp/mm^2
transverse section	3.4-4.1	kp/mm^2

Beech

English:	common beech
German:	Rotbuche, gemine Buche
French:	hétre commun, fayard
Swedish:	bok, rödbok
Latin:	*Fagus silvatica L.*

Beech botanically belongs to the family Fagaceae. The genus of beech comprises 10 species, growing in the northern hemisphere, two species in Europe, one species in North America and the rest in Asia.

The common beech has a distribution area including Western and Middle Europe, and Southern Scandinavia, England and Northern Spain. In Sweden beech is not naturally found above Northern Småland and Västergötland, though it is cultivated up to Mälardalen and South Uppland. About 95 % of the Swedish beech is found in the southern regions.

The wood has a light redish or light brownish colour. Darker heartwood is normally missing but older trees can contain so called "red heartwood" or "frost heartwood". Red heartwood often have irregular shape and a grey-brown or a grey-black colour.

Beech timber is heavy and hard with high strength properties. It is easy to machine, split and finish. Beech timber has good resistance against abrasion. The timber shrinks and swells considerably. It is resistant indoors and under water but not resistant outdoors.

Property	Value	Unit
Density, dry	640-680	kg/m^3
Shrinkage		
radial	4.4-4.9	%
tangential	10.0-11.8	%
longitudinal	0.3	%
volume	17.5	%
Strength at 12 % MC		
Tensile strength		
fibre direction	135	MPa
cross fibres	7	MPa
Compresssion strength		
fibre direction	53	MPa
cross fibres	9	MPa
Youngs modulus		
fibre direction	10 000-16 000	MPa
cross fibres	-	MPa
Bending strength	110	MPa
Hardness, Brinell		
cross section	7.2	kp/mm^2
transverse section	2.7-4.0	kp/mm^2

Alder

English:	black alder
German:	Schwartzerle, Roterle, gemine Erle
French:	aune glutineux, aune commun, vergne
Swedish:	al, klibbal
Latin:	*Alnus glutinosa (L.) Gaertn.*

The alders belongs to the family Betulacae. The genus alder comprises about 30 species, which is found in the temperated regions of the northern hemisphere and in mountain areas of South America. Four species grows in Europe and nine in North America.

In Sweden two of the European species are to be found; black alder (Alnus glutinosa (L.) Gaertn) and grey alder (Alnus incana (L.) Moench). The alder can be found almost all over Europe, except Northern Scandinavia, Greece and southern parts of the Iberian Peninsula. In Sweden it is common in Götaland, Svealand and at the coastal areas of Norrland.

Before drying, the colour of the wood is light yellow but changes, through oxidation, to a light brown colour. The timber is soft, very easy to split and easy to stain and polish. The shrinkage and swelling is moderate. The timber is resistant under water but not at changing climate and weathering outdoors.

Property	Value	Unit
Density, dry	470-510	kg/m^3
Shrinkage		
radial	4.3	%
tangential	9.3	%
longitudinal	0.4	%
volume	14.0	%
Strength at 12 % MC		
Tensile strength		
fibre direction	92	MPa
cross fibres	2	MPa
Compresssion strength		
fibre direction	54	MPa
cross fibres	-	MPa
Youngs modulus		
fibre direction	11 500	MPa
cross fibres	-	MPa
Bending strength	95	MPa
Hardness, Brinell		
cross section	3.7	kp/mm^2
transversal section	1.4	kp/mm^2

Aspen

English:	trembling poplar
German:	Zitterpappel, Aspe, Espe
French:	peuplier tremble
Swedish:	asp
Latin:	*Populus tremula L.*

Aspen belongs botanically to the family Saliaceae. The genus populus comprises about 35 species, widely spread on the northern hemisphere, from the subtropic to the arctic regions.

Aspen is found all over Europe with exception of Southern France and the Iberian Peninsula. It is also found in Northern Asia, Northern Africa and the Middle East.

The wood has a light yellow colour and a dark heartwood is missing. Timber from aspen is light, soft and generally has a very straight grain. The strength properties is reasonably good compared to its weigth. The timber is very easy to split and machine, and has relatively small shrinkage and swelling. The timber is resistant only in dry conditions.

Property	Value	Unit
Density, dry	440-490	kg/m^3
Shrinkage		
radial	3.1-4.5	%
tangential	8.5-9.6	%
longitudinal	0.4	%
volume	12.0-14.5	%
Strength at 12 % MC		
Tensile strength		
fibre direction	110	MPa
cross fibres	4.2	MPa
Compresssion strength		
fibre direction	45	MPa
cross fibres	-	
Youngs modulus		
fibre direction	11 000-13 500	MPa
cross fibres	-	MPa
Bending strength	75-82	MPa
Hardness, Brinell		
cross section	3.7	kp/mm^2
transverse section	1.7	kp/mm^2

Linden

English:	linden, small-leaved linden, lime
German:	kleinblättrige Linde, Winterlinde
French:	tilleul, tilleul sauvage
Swedish:	lind, skogslind
Latin:	*Tilia cordata Mill.*

Linden belongs botanically to the family Tiliaceae. The genus linden comprises about 30 species, which are spread in North America, Europe, China and Japan.

Small-leaved linden is widely spread over Europe, especially in the eastern parts. In Sweden linden can be found in all regions up to Ångermanland.

The wood is light yellow and a dark heartwood is missing. The inner parts of the wood is often darker and has a more red tone.

Timber from linden is of medium weight, hard and elastic. It is hard to split but easy to machine and finish. Its shrinkage and swelling is moderate. The timber is resistant only in dry conditions.

Property	Value	Unit
Density, dry	490-520	kg/m³
Shrinkage		
radial	5.0-5.5	%
tangential	6.1-9.1	%
longitudinal	0.3	%
volume	14.9	%
Strength at 12 % MC		
Tensile strength		
fibre direction	85	MPa
cross fibres	4	MPa
Compresssion strength		
fibre direction	34-52	MPa
cross fibres	6.9	MPa
Youngs modulus		
fibre direction	6 750-7 400	MPa
cross fibres	-	MPa
Bending strength	92-106	MPa
Hardness, Brinell		
cross section	-	kp/mm²
transverse section	1.6	kp/mm²