EDITION 1:2020

Joinery Handbook

— for softwood furniture production

SWEDISH WOOD

Ordering wood

Wood is a living material. The properties of different woods are influenced by the place where the tree grows and by the forces of nature that it is exposed to. Weight and fibre density vary, affecting the strength and functionality of the resulting product. Pine has historically been one of the materials most commonly used in Sweden for furniture production. It has been employed successfully for load-bearing, supported and filler elements, as well as decoratively cut pieces.

Whether the focus is on small-scale production, creation of unique, one-off designs or industrial-scale manufacture, the choice of material is a matter of sustainability – financial, aesthetic, ethical and ecological. Sustainability considerations begin with the first production concept and continue to be present in every stage of the process from the drawing board to the finished result.

Suppliers to the joinery industry tend to be small sawmills and wholesalers. The majority of sawmill production, around 70 percent, is exported.

The sawmills seek to obtain as high a financial return as possible from the raw material. This involves getting as high a yield of sawn timber as possible out of every log, as well as sawing a high volume per unit of time and producing high quality timber at the end.

This means that it can sometimes be difficult to buy small volumes of specialist grades from large sawmills. Furniture makers often use high quality pine as their raw material, preferably free from knots and with a vertical grain.

There are small sawmills that specialise in sawing large pine logs with a large proportion of knot-free wood. It is probably easier to buy small volumes of high quality pine direct from these sawmills, or from local or national wholesalers.

3.1 Wood as a material

3.1.1 Cutting patterns and character description

Common cutting patterns

Block-sawing was once the only method used in Sweden. This involves first sawing or milling away the sides of the log. Then it is placed on one of the four flat sides and cut into planks (thickness 35 mm or more) and boards (thickness below 35 mm).

Nowadays, the profiling method mills a multi-edged block from the log and then divides it into planks and boards. The milling tool is called a reducer. The wood that is milled away becomes wood chips.

The sawing is done with either band saws or circular saws. The plank can then be split into boards for later processing.

Since different types of machinery are used to divide the log up into planks, boards, chips and sawdust, the processes are often referred to as breakdown.

The wood from the central part of the log is called the main yield. The wood from the outer parts of the log is often referred to as the side yield.

In block-sawing, the inner parts of the log are usually sawn into planks. Depending on the number of planks sawn from the log, the cutting pattern is known as 2 ex-log, 3 ex-log, 4 ex-log and so on.

To achieve a high yield of sawn timber from the log, the usual aim is for a main yield that is as rectangular as possible, for example 2 ex 50 × 100 mm.

2 ex-log

The 2 ex-log cut is commonly taken from small-diameter logs with a top diameter of 110—180 mm. It may be the butt log from a tree that has been cleared during thinning or a top log from a fully mature tree. The knots are limited in size and are usually sound, so they remain firmly in place even after drying. The pith can be seen in one flat side. It is surrounded by what is known as juvenile wood — 15—20 growth rings closest to the pith — which exhibits somewhat larger moisture-related movements.

3 ex-log

The 3 ex-log cut is commonly taken from logs with a top diameter of 190 mm or more. They could be butt logs or middle logs. With spruce the knots tend to be sound, but with pine they can be dry, known as dead knots. The knots are larger than in 2 ex-log timber. Of the three planks, the centre plank has a vertical grain, which means it doesn't bow after drying and is suitable for use in furniture. The section around the pith is juvenile wood and contains heartwood. Side boards from 2 and 3 ex-logs are entirely sapwood. The side planks may have no heartwood in them.

4 ex-log

The 4 ex-log cut is usually taken from butt logs with a top diameter greater than 230 mm. The knots may be larger than in the 3 ex-log. The inner section of the log is partially made up of heartwood with limited knot size, and this makes up part of the two middle planks. When breaking down pine butt logs, the two outer planks are likely to contain knot-free sapwood, which is suitable for use in furniture. Knot-free wood is very uncommon in spruce.

The distance between the knot whorls varies, depending on the tree's growth conditions. Spruce commonly has small pin knots between the knot whorls.

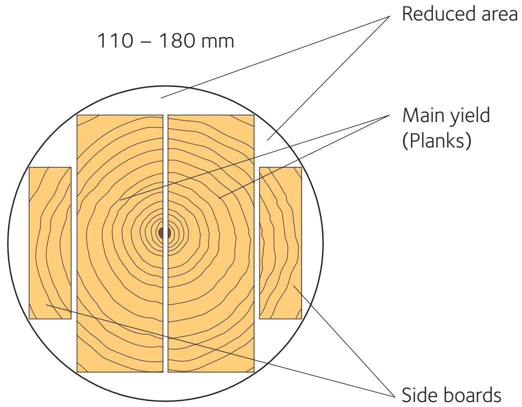


Figure 3.1 2 ex-log.

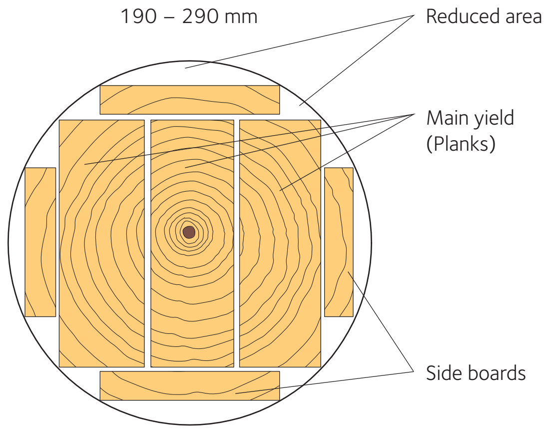


Figure 3.2 3 ex-log.

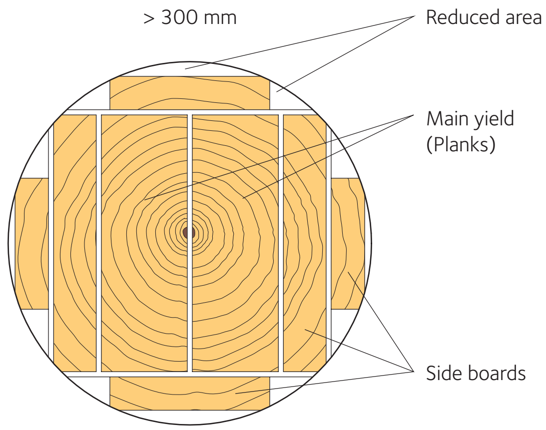


Figure 3.3 4 ex-log with centrecut.

3.1.2 Material description, pine

Knot condition and knot shape

When working with wood, account must be taken of the different types of knots in the timber. These will be sound, fixed knots of a light colour, dead knots that are not intergrown into the surrounding wood, whose colour can vary from light to dark, or unsound knots. In some cases, part of the knot's bark may also grow into the tree, creating an encased knot.

Knots are formed from the growth of the tree's branches and grow out from the pith. Knots always appear radially in a log. Small knots in the wood equate to thin branches on the tree. A young tree has thin branches that end up at the top of the growing tree.

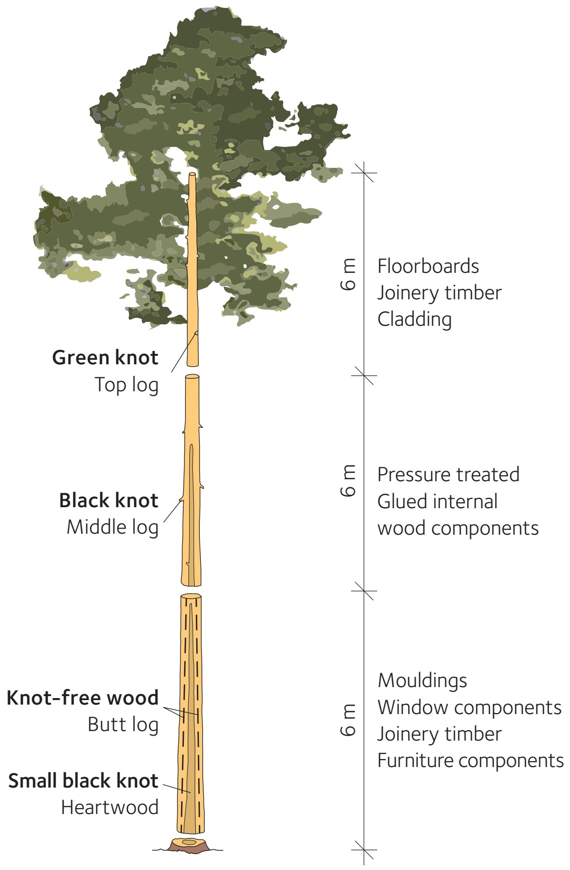


Figure 3.4 Parts of a tree

With pine, the knot pattern varies on different parts of the trunk. Generally speaking, the lower branches are the thickest and so this is where the largest knots appear on the log.

As a tree ages, the lower branches die and break off. The tree then forms new wood to seal up the wound left behind in a process known as occlusion.

In the top log most of the knots are sound. The knots are small to medium-sized, as the branches at the top of the tree are the thinnest. The yield of knot-free wood is limited. Wood from the top log is commonly used for the production of interior joinery and boards for flooring and cladding.

In the middle log, many knots will die and be grown over, but a small number of the knots may remain and they then appear as black knots. These run all the way from the core out through the sapwood. Wood from the middle log is usually used for pressure treated products such as decking, and for glued interior wood components such as edge-glued panels.

In the butt log, the inner parts always contain knots from branches on the young tree. These branches die and fall off as the tree grows. Wood then grows over the wound making this area knot-free. Wood from the butt log is used in applications such as mouldings, window components, joinery and furniture.

Knots

The way the log is sawn determines the condition and shape of the knots in the surface of the timber.

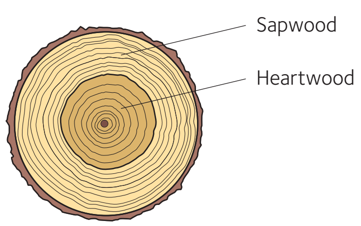


Figure 3.5 Pine

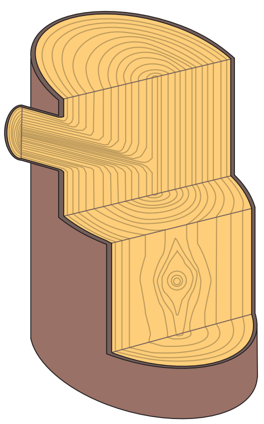


Figure 3.6 Log section.

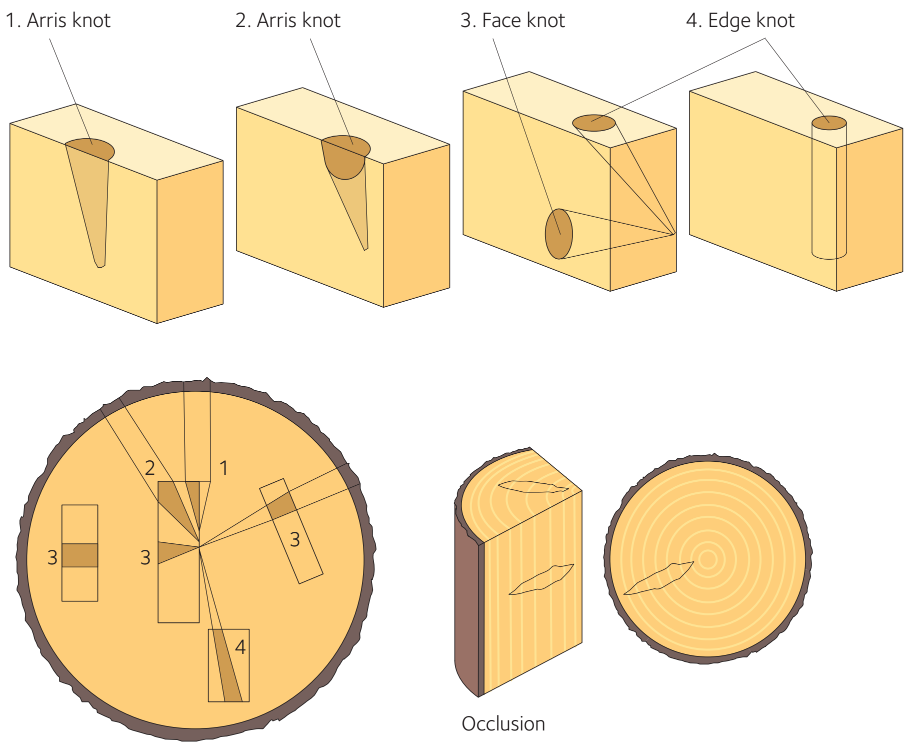


Figure 3.7 Position of timbers and knots in log cross-section

Wood with **small knots** can be obtained from a 2 ex cut of small diameter logs or the top log. Generally speaking, the smallest knots can be found in the main yield.

Large knots coupled with small ones can appear in side boards from the 3 ex or 4 ex cutting of a top log or middle log.

Almost entirely **knot-free** wood can be sourced from the side yield of a pine butt log.

Dark dead knots are most common in the middle log, where most branches have fallen off but the wood has not yet healed over.

3.1.3 Material properties of softwood

Wood is Sweden's most traditional building material. Since wood is used for a whole host of purposes — furniture, construction, exterior and interior wall cladding, fittings, floor coverings, and so on — it is important to understand how wood behaves under different conditions. Each type of wood has its typical areas of use, depending on availability and on its specific properties.

Spruce is the wood of choice for construction timber. Pine is commonly used for furniture, joinery, mouldings and internal cladding, although spruce may also be used in this context. Hardwoods such as oak and beech are used in flooring and furniture.

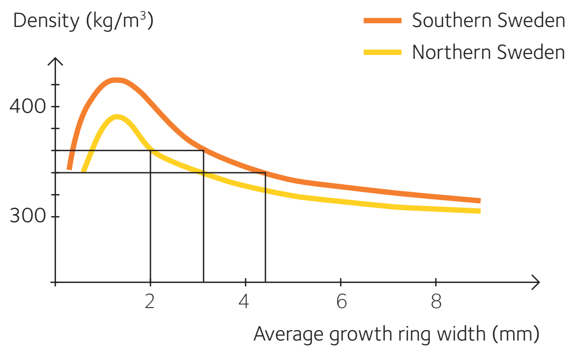
Material properties vary between the different wood species. Even within the same wood species, there are major variations between different locations, but also between different trees grown in the same location. There is, however, even greater variation within a single tree, for example between different heights in the tree, between wood that is close to the pith and to the bark, and between springwood and summerwood in the individual growth rings. Knots and other fibre distortions (peculiarities) also affect the wood's technical properties.

Normal variations for the properties of density, strength and stiffness (modulus of elasticity) within the same wood type with an undistorted fibre structure:

- Density ± 20 percent
- Strength ± 40 percent
- Modulus of elasticity ± 35 percent.

Due to the variation in the wood, the quotient is greater between, for example, the average material strength of wood and allowable working stress, in comparison with other construction materials.

Figure 3.8 **Influence of growth ring width and geographic location on basic density, in theoretical terms.**



Wood from southern Sweden is generally denser, stronger and more durable than wood from northern Sweden. This is despite the fact that southern Swedish wood generally has broader growth rings than wood from northern Sweden. The reason for this is that the summerwood band, the dark part of the growth ring, is wider in southern Sweden. The summerwood, which weighs 900 kg/m^3 torr ved, dry wood, is three times denser than springwood, which weighs 300 kg/m^3 dry wood.

Facts **Density and basic density**

Density is a piece of wood's mass divided by its volume, expressed in kg/m^3. This is usually stated as the basic density in the wood's dry state or for a particular moisture content, e.g. 12 %.

Basic density is defined as the mass of a dry wood sample divided by the volume of the fully hydrated wood sample. The density varies from wood to wood, within the same type of wood and in different parts of the same tree.

3.2 Wood and moisture

Wood is a hygroscopic material. This means that the material monitors the surrounding air humidity and temperature and constantly strives to remain in equilibrium with the local climate, i.e. the relative humidity (RH) and the temperature.

3.2.1 Moisture content

The moisture (water) content in the wood is defined as the weight of the water in damp material divided by the weight of the material in a dry state. To obtain a percentage, the result is multiplied by 100.

$$u = \frac{(\text{weight before} - \text{weight after})}{\text{weight after}} \times 100 = \text{moisture content in \%}$$

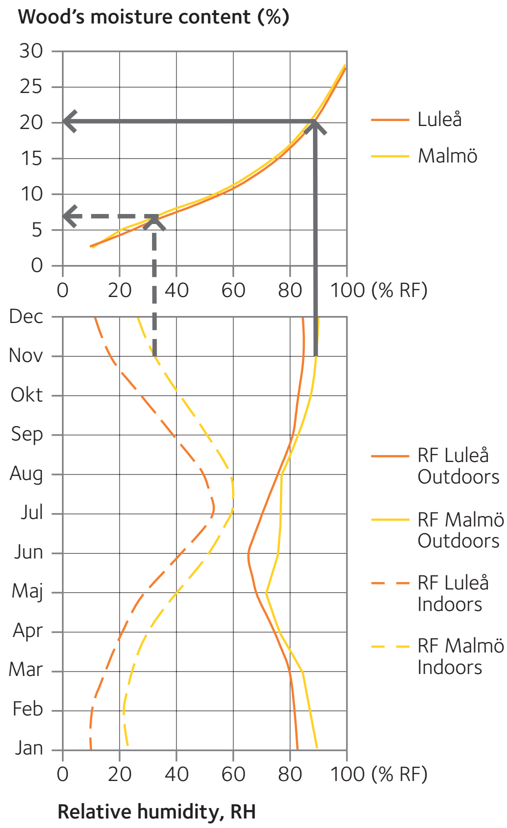


Figure 3.9 Wood's moisture content in relation to relative humidity, RH

The top section shows the correlation between ambient relative humidity (RH) and moisture content. The temperature also affects the correlation, but the effect is less than 1 % of the moisture content in the temperature range 0–20 °C.

The lower section shows the monthly average value for RH in the north of Sweden (Luleå) and the south (Malmö). The solid curves show RH outdoors and the dotted curves show RH indoors. The RH curves for indoors should be increased by around 18 % RH to account for the moisture added by a normal family (cooking, shower, laundry, breathing, perspiring and so on).

Example: What is the RH and average moisture content indoors in Malmö in November?
Following the black arrows, RH = 32 % and the moisture content = 7 %. (Outdoors, the corresponding figures are RH = 89 % and moisture content = 20 %). At an RH of around 32 %, the wood's moisture content is thus around 7%.

The equilibrium moisture content is the moisture content that the wood has when it is in equilibrium with the local climate.

If the wood's moisture content is higher than the equilibrium moisture content, the wood will dry out and if it is lower the wood will take on moisture. When the moisture content changes, below the fibre saturation point, the wood will therefore change its volume, depending on whether moisture is being released or absorbed – the wood swells or shrinks accordingly.

Dimensions, strength and resistance to decay are examples of key properties of wood that are affected by the moisture content.

3.2.2 Relative humidity and vapour concentration

Relative humidity (RH) may also be referred to as "relative air humidity".

The air's content of water vapour, its vapour concentration, is stated in grams water/cubic metre air and it varies over the year. Vapour concentration outdoors is at its highest in summer (9–11 g/m^3) and lowest in winter (3–5 g/m^3) – while RH and thus wood's equilibrium moisture content is lowest in summer (65–75 % and 11–15 % respectively) and highest in winter (90–95 % and 19–23 % respectively). Wood should have a surface moisture content of max 16 % if being given a surface treatment.

Physically, the RH figure lies between the water vapour's partial pressure and its saturation pressure at the temperature in question. The relative humidity of the air indoors in a heated room is therefore highest in summer (45–60 %) and lowest in winter (10–25 %). The colder it is outdoors, the drier the air indoors. The moisture content in wood, both indoors and out, adapts the RH and temperature of its surroundings. In heated homes in Mid Sweden, the moisture content in wood averages out the year at 7.5 %, with the highest figures in summer (7–12 %) and the lowest in winter (2–6 %). On average, it is drier in the north of Sweden than it is in the south, *see fig. 3.9*.

3.2.3 Target moisture content

Undried, newly sawn wood is usually dried to a particular target moisture content in the sawmills' drying chambers. Target moisture content describes the desired average moisture content for a batch of wood and the allowable moisture content of the individual pieces in the batch. It is defined in standard SS-EN 14298. Each piece of wood in a batch is unique and is affected differently by the drying, depending on its density, resins, storage time before drying, sawing pattern, green moisture content and so on. This means that the individual pieces in a batch of wood will have a certain range of moisture content figures, which are combined to form an average value – the average moisture content for the batch. When ordering wood with a target moisture content of 8 %, it would naturally be desirable for the average moisture content of the batch to be 8 % – and ideally for all the pieces in the batch to have a moisture content of 8 %. However, this is almost impossible. The average moisture content of a batch and the moisture content of the individual pieces are therefore allowed a certain range of variation for orders of a specific target moisture content in line with *table 3.1*, which is part of the standard SS-EN 14298.

3.2.4 Moisture content variation in the wood's cross-section

The moisture content doesn't just vary between individual pieces in a batch of wood — it also varies in the cross-section of a piece. When wood dries, it occurs from the outside in. If no special measures are taken, the inner part of the wood will therefore be much damper than its surface after drying at the sawmill. This difference in moisture content in the wood's cross-section is called the moisture gradient.

When wood has been dried down to 8 % in a kiln, the surface of the wood becomes very dry, often 4 – 5 % moisture content, while the moisture content in the middle of the wood may lie at around 10 – 12 %. Depending on the time between drying and packaging, the outdoor temperature and relative humidity (RH), this difference in moisture content will remain in place to a greater or lesser degree.

Note that wood dried to a moisture content of 8 % must be stored in a climate equivalent to the one we have in heated homes.

The evening out of the moisture gradient often takes a long time.

When a piece of wood has its moisture content measured, this is in fact a value for the average moisture content of the cross-section. The average moisture content of the wood can be measured in two ways. A very accurate way is to first weigh a piece of wood, then dry it in a kiln at 103 °C and weigh the fully dried wood again, in accordance with SS-EN 13183-1.

A more practical, but not as accurate, method is to use an electrical resistance moisture meter with insulated hammer electrodes, and to measure at a specific point and at a depth of 0.3 times the wood's thickness. This measurement is considered to be representative of the cross-section's average moisture content. *See section 3.2.6, page 30*.

A low moisture gradient is an important quality factor in preventing uneven shrinkage and bowing, for example.

3.2.5 Sawmill conditioned wood

Discrepancies between the average moisture content in a batch of wood and the target moisture content are difficult to reduce. Some improvement can be achieved by using good drying kilns and controlling them carefully, and by conditioning the wood after the drying process. It is easier to reduce the moisture content range via conditioning at a high temperature at the end of the drying process. The moisture gradient in the cross-section of the wood and the drying stresses in the wood can be reduced with correctly performed conditioning at the end of the drying process.

In addition, conditioning improves the wood's dimensional stability. Wood that is to be split at a later stage should therefore have the stresses and moisture content evened out in the cross-section. This also reduces the risk that a finished wood product will gradually distort after the drying process. Distortions caused by drying stresses can be measured in line with the standard SS-ENV 14464.

Driven by increasing customer demand for quality, the sawmill industry is now able to more clearly specify/state the wood's drying quality, not least with the help of the new standards. It is possible to specify the quality of a batch of wood in terms of:

- deviation from the target moisture content
- the moisture content range in the batch
- drying stresses (drying quality).

Table 3.1 Target moisture content.
Allowable variation for the average moisture content in line with SS-EN 14298.

Ordered moisture content (target moisture content)	Allowable variation in the timber batch's average moisture content		Allowable range for the moisture content in 93.5 % of the pieces in the timber batch	
(%)	Lower limit (%)	Upper limit (%)	Lower limit (%)	Upper limit (%)
8	7	9	5.6	10.4
12	10.5	13.5	8.4	15.6
16	13.5	18	11.2	20.8

When measuring the moisture content of all the pieces in a batch with a target moisture content of 16 %, the average value for the moisture content of the whole batch (average moisture content) is allowed to fall between 13.5 % and 18 % to be approved. As regards the individual pieces in a batch, the moisture content of 93.5 % of these must fall between 11.2 % and 20.8 %.

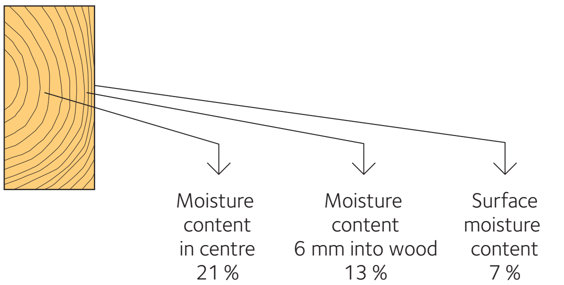


Figure 3.10 Moisture content in a length of wood after drying
The variation in the moisture content of a piece of wood at the sawmill after drying. An electrical resistance moisture meter with insulated hammer electrodes measures 16 % in line with SS-EN 13183-2. The wood may be included in a batch with a target moisture content of 16 %.

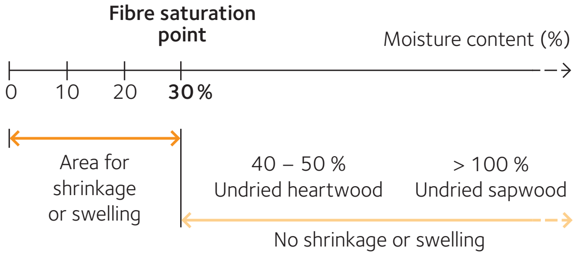


Figure 3.11 Movement in wood at different moisture contents

A rule of thumb is that if the wood has low drying stresses, the moisture content range also tends to be low.

For the joinery industry, for example, conditioned wood products are necessary in order to achieve high quality joinery products (fewer gradual deformations).

In addition to having the right target moisture content, joinery timber is also improved if the above quality parameters are used.

When buying a batch of wood, a narrow variation in the moisture content range is just as important as the batch's average moisture content being close to the target moisture content. A reduced variation in the moisture content, by conditioning the wood at high temperature at the end of the drying process, also means that the stresses in the wood will be evened out. This makes the wood more dimensionally stable and makes certain joinery products easier to manufacture.

3.2.6 Measuring average moisture content and surface moisture content

Checking the moisture content in wood involves measuring the level at different points in the structure in question. The measuring points are determined by conditions on site. Seek out the place where the risk of damp is greatest and drying conditions poorest.

Average moisture content

To measure the average moisture content in wood, random tests on a number of pieces should be conducted with an electrical resistance moisture meter with insulated hammer electrodes, to gain an indication as to whether the right moisture content has been delivered. The average moisture content of wood is measured in line with SS-EN 13183-2 as follows: measure at least 300 mm from the end. Insert the insulated hammer electrodes into the face of the wood, in the direction of the fibres, and along an imaginary line running 0.3 times the width of the wood in from the edge. The measurement depth should be 0.3 times the thickness of the wood.

It should be noted that measuring the moisture content with an electrical resistance moisture meter with insulated hammer electrodes is not an exact method, and comes with a degree of uncertainty, depending on the measuring instrument's quality and calibration. The method is, however, an effective way to get an idea of any deviations if correctly used. Regularly calibrate the moisture meter using a calibration block.

A more precise method is the aforementioned dry weight method, which can be useful for production and delivery controls, but it is not a practical method of measurement at a joinery workshop, for example.

To ensure that everyone measures moisture content and drying stresses in wood in the same way, there are now four standards:

SS-EN 13183-1 Moisture content of a piece of sawn timber. Determination by oven dry method,

SS-EN 13183-2 Moisture content of a piece of sawn timber. Estimation by electrical resistance method,

SS-EN 13183-3 Moisture content of a piece of sawn timber. Estimation by capacitance method,

and SS-ENV 14464 Sawn timber. Method for assessment of case-hardening.

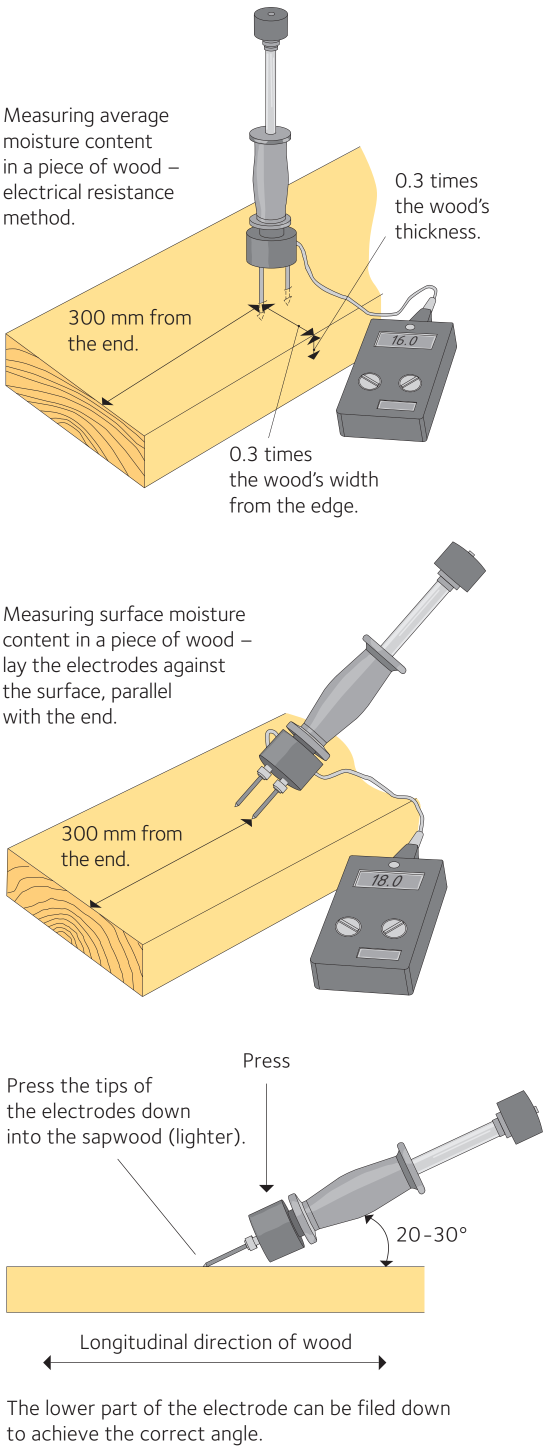


Figure 3.12 **Measuring moisture content.**

Surface moisture content

Measure the surface moisture content with an electrical resistance moisture meter by pressing the conical jacket of the insulated hammer electrode tips down into the springwood of the surface by hand, so that half the jacket of the electrode tips makes an impression in the wood, going across the grain. Always take three measurements close to each other at the measuring point and then work out an average. The average can then be checked against the relevant requirement.

It is important to check the surface moisture content before coating the wood, since it is crucial in determining the risk of microbial growth. It also has an impact on the adhesion of paint.

The wood may have become damp due to rain, incorrect storage or the wood being placed in contact with damp concrete, giving it an elevated surface moisture content. The moisture content in the inner part of the wood will not normally be affected by short-term exposure to damp. Wood that has become damp must be dried – naturally, with a dehumidifier or with a construction fan.

Note

There is no standard for measuring the surface moisture content of wood.

Acceptance check of drying quality

Acceptance checks have also been standardised. Two standards are used for this purpose:

SIS-CEN TS 12169 Criteria for the assessment of conformity of a lot of sawn timber.

SS-EN 14298 Sawn timber. Assessment of drying quality.

SIS-CEN TS 12169 describes how samples from a batch of wood are to be selected to check whether the ordered drying quality (average moisture content in a batch, moisture content range and drying stresses) has been delivered as per the contract or building specification. The method is based around the use of the most common control method for all industries, Acceptable Quality Level (AQL). An acceptance check involves randomly selecting a set number of sample boards or planks, depending on how many boards or planks are contained in the batch. The standard sets out what deviations are allowable, depending on the chosen quality level.

Note

The whole package must be made available for inspection in the event of a complaint.

3.2.7 Moisture-related wood movement

For floorboards and internal cladding, the target moisture content should be 8 % and 12 % respectively to minimise swelling or shrinkage, *see fig. 3.9, page 28* and the relevant product standard.

The moisture content of undried softwood is up to 160 % in the sapwood and up to 50 % in the heartwood. During drying, the first water to disperse is the unbound water in the gaps in the fibres' cells. When the moisture content then reaches fibre saturation, at around 30 % moisture content, the moisture in the cell walls begins to leave the wood, and this contributes to the wood beginning to shrink. The wood begins to shrink in its outer parts, before later shrinking further in. This creates seasoning checks (cracks) if the drying

Facts Moisture content, dry basis and wet basis

Moisture content (dry basis) is defined as the mass of the water in damp material divided by the mass of the material in a dry state. It is usually expressed as a percentage (%).

Moisture content (wet basis) is used in certain wood technology contexts, such as wood fuels, and is defined as the mass of the water in damp material divided by the mass of the damp material.

Around 95 % of sawn wood products are now dried in kilns. Only 2 % is dried in stacks at the sawmill during the summer, known as timberyard seasoning, while 3 % is delivered from the sawmills undried, primarily to the furniture and joinery industry, which dries the wood itself.

The drying of newly sawn wood is the most energy-intensive step in the sawmill process. The kilns are heated primarily by burning bark and possibly shavings, while the fans run on electricity.

Table 3.2 Examples of suitable moisture contents.

Application	Moisture content
Furniture and fittings for regular heated rooms	8 %
Dowels	6 %
Windows, external doors, furniture and fittings for rooms that are rarely heated	12 %
Objects that stand outdoors under a roof	15 %

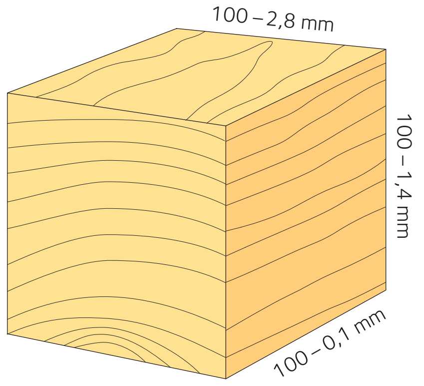


Figure 3.13 Shrinkage or swelling.
Shrinkage in a cube of softwood with 100 mm sides during drying from 20 % to 10 % moisture content. The greatest movement is tangential to the fibres, and the least occurs parallel with the fibres..

temperature is too low or the drying happens too quickly. The shrinkage in the outer parts of the wood also causes high drying stresses, which can be reduced by introducing a conditioning phase at the end of the drying process. *See section 3.2.5, page 29*.

In a board or plank the growth rings are usually curved, which is why there is rarely purely tangential or radial shrinkage. A rule of thumb is therefore that the average movement (shrinkage or swelling) for pine and spruce in both a radial and tangential direction is around 0.26 % per percentage point of change in the moisture content. *See table 3.3, page 33* for the percentage of shrinkage per 1 percentage point moisture content change for other woods.

Example: A 95 mm wide floorboard with a moisture content of 12 % is laid in a room with a climate equating to the wood's equilibrium moisture content of 8 %. The change in moisture content 12 – 8 = 4 percentage points. The board shrinks 4 × 0.0026 × 95 mm = approx. 1 mm in width.

The shrinkage will be half that size if the board is sawn in a radial direction rather than in a tangential direction, i.e. with vertical growth rings. Floorboard gaps will be half the size.

The delivery moisture content for the wood from the sawmill was previously around 20 % for planks and around 16% for boards. This was called "shipping dry". Now the wood's moisture content is adapted more to the product or application. Since wood strives to achieve equilibrium with the air's temperature and relative humidity, the moisture content will move towards the equilibrium moisture content. This takes quite a long time.

The capacity to absorb water is different for spruce and pine. Spruce absorbs water slowly in both the heartwood and the sapwood. The absorption capacity of pine varies greatly between the heartwood and the sapwood. The heartwood of pine has around the same capacity to absorb water as spruce, while pine sapwood absorbs water many times faster. A window should therefore be made from pine heartwood. This keeps the risk of rot very low.

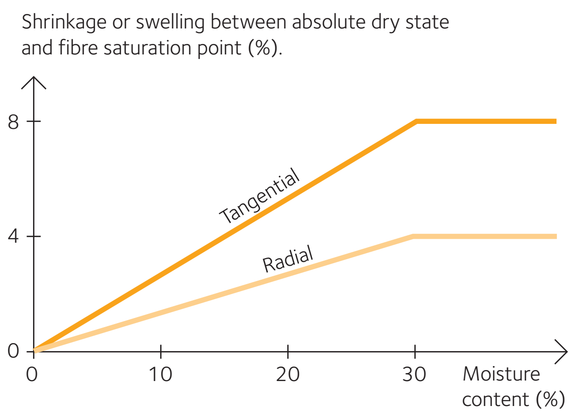


Figure 3.14 Wood movement between zero and the fibre saturation point. The movement is similar in pine and spruce when the wood swells from an absolute dry state to the fibre saturation point, approx. 30 % moisture content.

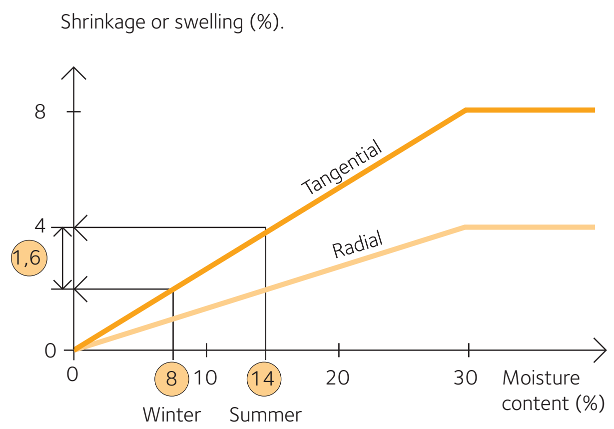


Figure 3.15 Shrinkage or swelling between winter and summer indoors.
Example: The wood's movement indoors over the year, from summer to winter, is 1.6 % on average. The moisture content in the wood changes by around 6 % from summer to winter, which can give a maximum movement of 16 mm/metre in a tangential direction..

These pine logs were recently felled. The left image shows the root end and the extent of the pine heartwood. The right image shows the top end and how the transport of nutrients, in the fluid which runs through the sapwood in the log, has not yet stopped.

Table 3.3 **Average values for shrinkage in various wood types during drying, from fibre saturation to absolutely dry wood.**

Wood type	Shrinkage				Shrinkage in percent per 1 percentage point change in the moisture content
	Fibre direction, along length of stem, axial βa (%)	Radial direction, across the growth rings, radial βr (%)	Tangential direction, along the growth rings, βt (%)	Volume change βv (%)	
Alder	0,5	4,4	9,3	14,2	0,31
Ash	0,2	5	8	13,2	0,27
Aspen	0,2	3,8	8,7	12,7	0,29
Birch	0,3	6,7	10,4	17,4	0,35
Beech	0,3	5,8	11,8	17,9	0,39
Oak	0,4	4	7,8	12,2	0,26
Pine	0,4	4	7,7	12,1	0,26
Spruce	0,3	3,6	7,8	11,7	0,26

For practical calculations, 7 % can be used as the average figure for movement in sawn pine and spruce timber, which corresponds to 0.24 % per 1 percentage point change in the moisture content.

Figure 3.16 **Shrinkage or swelling in a softwood log**
Shrinkage or swelling in a piece of timber varies depending on how the growth rings are positioned in the wood. The smallest dimensional changes occur in wood where the growth rings are perpendicular with the face, known as vertical grain.

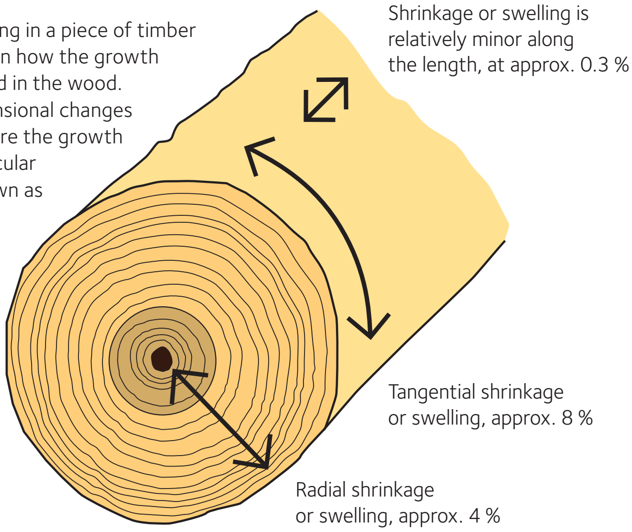
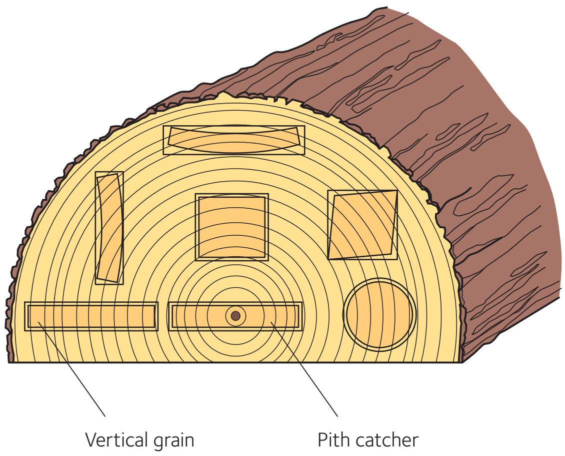


Figure 3.17 **Growth ring orientation in a piece of wood**



Pine edge-glued panels.

3.3 Quality and range

Some woodworkers and artisans gather their wood from the forest and work on the material in its fresh state. However, most producers and designers of products in wood choose from the range of wood offered by their supplier.

3.3.1 Wood grades, appearance grading

The grade of wood can be specified using a number of parameters, including:

Knots
Checks
Wane
Pitch pockets
Bark-encased scar
Open scars
Cross grain
Top rupture
Compression wood
Wavy grain
Pitchwood
Fungal attack
Deformation
Insect damage
Discolouration
Handling damage
Dimension deviations.

The parameters are assessed in visual sorting, known as appearance grading. In Sweden this is usually done at the sawmill, following the guidelines in the document *Grading of sawn timber, 2019 version 1*. Builders' merchants use the grading standard SS-EN 1611-1.

The sawmill will commonly stamp each piece of wood on the end with a shipping mark. This allows the graded quality to be checked along the chain from the sawmill to the joinery workshop. After processing, e.g. planing or splitting, these marks may be cut away or hard to identify. The grade is then marked on the packaging.

The grading of wood is a general process based on appearance. It is thus not designed to take account of the wood's use, for example in joinery, construction or packaging.

Examples of knot types

Sound knot

Dead knot

Unsound knot

Leaf knot

Horn knot

Pin knot

Encased knot

Arris knot

Knot cluster

Appearance grades – Quality classes

The wood is shown in the dimensions: 25 × 100, 50 × 150 and 75 × 200 mm

Class I – Pine

Class II – Pine

Grade G4-0 – Pine
Class III – Pine

Grade G4-1 – Pine
Class IV – Pine

Grade G4-2 – Pine
Class V – Pine

Grade G4-3 – Pine
Class VI – Pine

3.3.2 Regulations for appearance grading

Grading of sawn timber

Under the rules in the document “Grading of sawn timber”, wood is sorted into seven classes, with Class I representing the highest quality. Classes I—IV are usually grouped under the designation U/S, unsorted. Class V is generally referred to as fifths and Class VI is named sixths.

Standard SS-EN 1611-1

According to the standard for appearance grading of softwoods, SS-EN 1611-1, the grading may be performed on the faces and the edges or only on the faces. In these cases, the grades are called G4 and G2 respectively. The grading designations are followed by a number from 0—4 stating the quality of the wood, with 0 as the highest quality. A grade can thus have the designation G4-2, which means a 4-sided visual sorting of typical construction timber, corresponding to the fifth grade, V. An approximate comparison between the two sorting systems is given in *table 3.5*. G2 is a grade that is rarely used in Sweden.

Facts Specialist grades

Swedish sawmills may in some cases also supply specialist grades for specific purposes. Specialist grades may include custom dimensions, moisture content and sorting parameters.

Table 3.4 Wood grades. Common wood products with appropriate appearance grades and wood types.

Type of wood product	Grade, class	Wood type
Interior cladding	G4-1, Class IV or better	Pine and spruce
Planed wood for interior joinery	G4-1, Class IV or better	Pine
Floorboards	G4-2, Class V or better	Pine and spruce
Mouldings	A – B	Pine as per SS 232811

See also table 3.5.

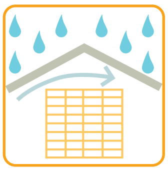
Table 3.5 Wood grades. Approximate relationship between the different appearance grades – quality classes.

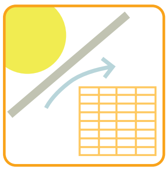
Grading rules	Grades – quality classes						
Grading of sawn timber	U/S				Fifths	Sixths	
	I	II	III	IV	V [2]	VI	VII
SS-EN 1611-1							
4-sided grading			G4-0	G4-1	G4-2 [2]	G4-3	G4-4
2-sided grading [1]			G2-0	G2-1	G2-2	G2-3	G2-4

[1] 2-sided grading, G2, seldom used in Sweden.
[2] Most common for construction timber.

3.4 Handling and storage

Wood offers good durability – as long as it is handled correctly. To preserve the high quality of the wood until it is processed, it should be protected from precipitation, condensation, sun, dirt and ground moisture.


Protect from precipitation


Protect from sun


Protect from dirt

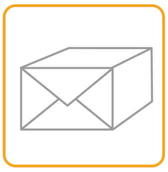
3.4.1 Planning and preparation

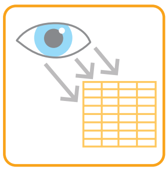
Plan deliveries to match the pace of production, order materials in batches and prepare for their delivery and storage. If the wood is stored, transported and handled so that it is not exposed to precipitation, dirt or strong sunlight, it can be supplied without packaging. If this is not the case, ensure that the wood is delivered in packaging which is not transparent.

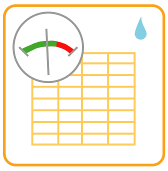
Wood to be used in interior applications where it will be seen, such as mouldings, cladding and floorboards, must be stored in a well ventilated space with a typical indoor climate.

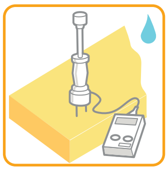
Choose a storage place where water will not pool under the wood. Asphalt or coarse macadam is a good underlay, as there is minimal risk of soil and dirt splashing up.

The ground should be cleared of snow. Do not place the wood where there is a risk of soiling and splashing from guttering or traffic, for example.


Check that the packaging is intact


Check the quality


Check the moisture content


Moisture meter

3.4.2 Receipt and inspection

Inspect the wood on receipt of the delivery.

- Packaging: check that any packaging is intact.
- Quantity: make a rough estimate of the quantity.
- Dimensions: check that they match the order and the delivery note.
- Quality: check the delivery and note any visible damage. Check the type and labelling against the order and the delivery note.
- Check that the wood is free from soil and dirt.
- Moisture content: check a number of pieces with a moisture meter to get an indication that the moisture content matches the order. *See also section 3.2.6, page 30.*

Put in a complaint about the wood immediately if, on delivery, it has a moisture content or grade that does not match the order.

If a complaint is not registered on receipt of the goods, it can be difficult to resolve a dispute at a later date. In the event of a dispute, sampling is to be performed in line with the prevailing SIS-CEN/TS 12169, with the moisture content requirements set out in SS-EN 14298.

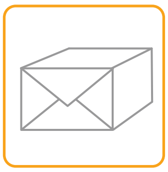
Note
The whole content of the wood package must be available for inspection in the event of a complaint.

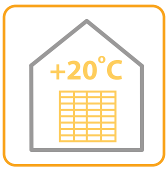
Table 3.6 **Weight figures for handling.**
Use the following weight figures when handling solid wood and glulam:

Material	Weight (kg/m³)
Spruce	approx. 470
Pine	approx. 500

3.4.3 Waste

Sort wood waste as a separate category that can then be chipped and burned for energy recovery. Waste from treated wood should be handled in line with instructions from the municipal environmental office.


Six-sided packaging



Wood for indoor use should be stored indoors


Waste

Woodworking

Woodworking involves processing wood into dimensioned pieces and production elements through sawing and planing. There are many ways of working on wood — manual and individual or large-scale and industrial. Whichever approach is taken, however, there are some features of wood that are always the same and that people have had to deal with and have explored through tried and tested experience over millennia. Even the operator of a CNC milling machine has to be aware of the material's properties.

There are machines that require manual and individual calibration and handling. Other machines are designed for large-scale and high-capacity production, and here the requirements for individual and manual assistance differ. *Sections 4.1.1, page 38, and 4.1.2, page 39,* relate to general woodworking, whether the manufacture relies on hand tools or machinery, on a small or large scale. From *section 4.1.3, page 40*, the text focuses on manufacture in machines, i.e. manufacturing processes where the principle is that the workpiece moves in relation the tool. The different machines are presented by category: saws, planes, milling machines, drills and sanders, and within each group there is a specification of the various machines that are available for a range of specialist purposes.

4.1 Basic cutting

Whether the work involves sawing, planing, sanding or some other action, and whether the processing is manual on a small scale with hand tools or on an industrial scale, fibre density and fibre direction must be taken into account.

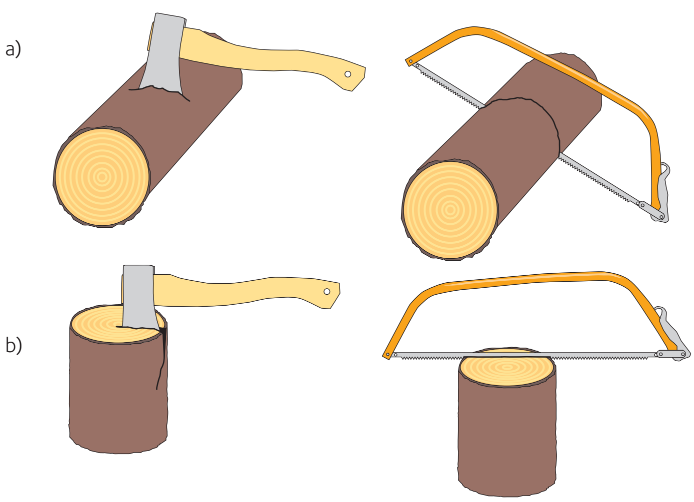


Figure 4.1 It is important to use the right tools, depending on the direction of the grain.
a) Across the grain.
b) Along the grain.

Knot-free pine.

4.1.1 Different cutting directions

As we have seen previously, a piece of wood can be worked either with a rotary tool or a non-rotary tool. When cutting, it is important to take account of the angle between the cutting edge of the tool and the grain, the angle between the blade's direction of travel and the grain and the choice of material in terms of wood type. This becomes abundantly clear when you try to cut up firewood crossways with an axe, *see fig. 4.1 a)*. It is much easier with a saw.

Splitting along the grain is easy with an axe, *see fig. 4.1 b)*, and significantly harder with a saw. This is because the strength of wood varies in different directions. The growth rings also have an impact on cutting. There are basically three groups of cutting directions.

When working along the grain the tool acts as a chisel, with the wood fibres parting just ahead of the sharp edge of the tool's blade. This is called the cleaving effect. The force required to push the tool forward, the cutting force, is moderate. If the cleaving effect becomes too great, the fibres will split in the direction of the wood's growth rather than the working direction. This then gives an uneven surface with chipping. To combat chipping, fit the tool with a chip breaker to reduce the cleaving effect. If the wood grain is not parallel with the surface being worked on, it is important that the piece is fed in the direction where the grain forms an acute angle in the cutting direction, *see fig. 4.2 a)*.

When working across the grain the tool acts in more or less the same way as when working with the grain. The cutting force is lower because of wood's low strength across the grain. The cleaving effect is less, but the fibres tear at the edge of the tool. To prevent this, tools intended for working across the grain are fitted with a side cutter. The side cutter cuts the fibres at the edges of the tool a little deeper than the leading edge of the tool does. Wood with an irregular structure where the direction of growth varies is usually easier to work across the grain. This approach always produces a poorer surface, however, *see fig. 4.2 b)*.

Working across end wood requires a tool in top condition, as there is no cleaving effect to help split the fibres. The cutting forces therefore have to be stronger and the tool is subjected to harder wear. Cases where you might work end wood with a cutting tool include milling mortises and tenons for doors and windows and chiselling operations of various kinds, *see fig. 4.2 c)*.

Summary – cleaving effect

Note that:

- working with the grain requires less cleaving force and produces a smoother surface and clean end wood.
- working across the grain increases the cleaving force required and produces an uneven surface and chipped end wood.
- working across end wood does not produce a cleaving effect, a smooth surface or chipped end wood.

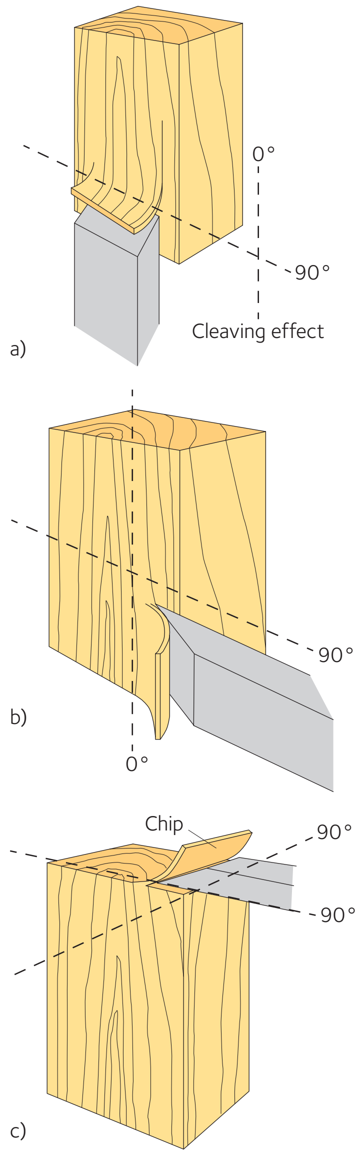


Figure 4.2 a) Cutting along the grain.
b) Cutting across the grain.
c) Cutting the end wood. No cleaving effect.

4.1.2 Chip breaking

The wood grain will often be distorted at least to some extent and can become twisted around knots. The result is an alternating grain direction, with the risk of tearing out fibres when working against the grain. This makes it more difficult to achieve a good cut surface. With a chip breaker, you can achieve a smooth surface even against the grain.

The same chip breaking principle that applies to hand tools can be used on machine tools, but it is more difficult to achieve small-scale chip breaking. For the shavings to be carried away on a large scale, the chip breaking needs to be bigger. The chip breaker has to fit tightly against the blade. The smallest gap between the chip breaker and the tool's cutting face will allow shavings to get caught and impede the cutting work.

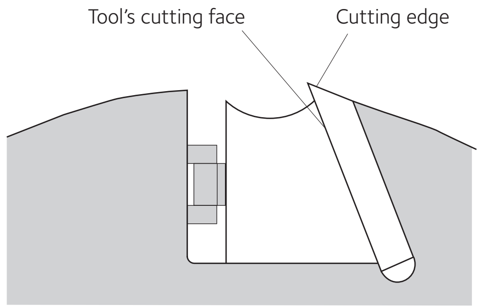


Figure 4.3 Chip breaker.

Key terms

As we continue, we will be using a number of words and terms that are explained in *fig. 4.4*.

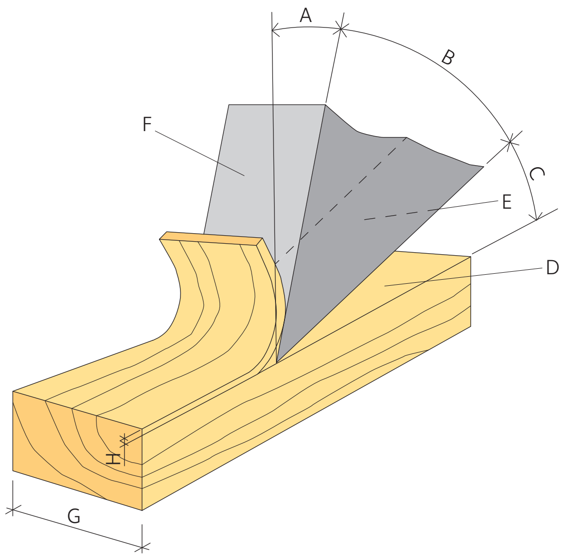


Figure 4.4 Key terms for chip-forming cutting
A = rake angle
B = wedge angle
C = clearance angle
D = cut surface
E = flank
F = cutting face
G = chip width
H = chip thickness.

Chip cutting

For the machine tool to cut freely when forming grooves and rebates, another two clearance angles are required. This makes a total of three clearance angles. To differentiate between them, they have different names:

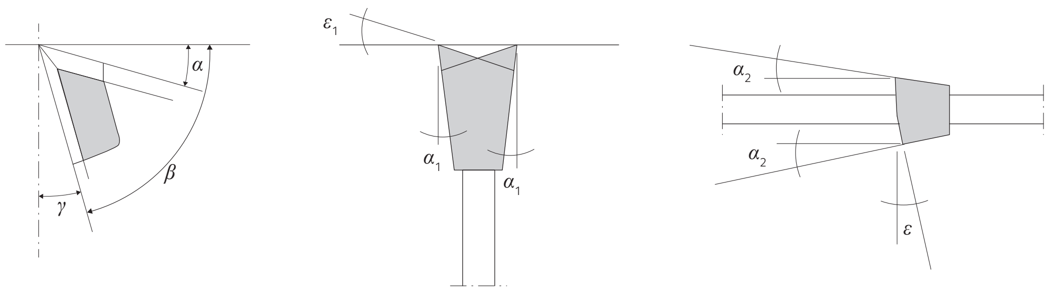
- radial clearance angle, *see fig. 4.5*
- side clearance
- tangential side clearance.

Another angle which may occur is the helix angle, also known as the spiral angle. This is the angle of the tracks in the groove cutters. The most important tool angles are the clearance angle, the wedge angle and the rake angle, where:

α	is the clearance angle = the angle between the flank and the cut surface.
β	is the wedge angle = the angle between the cutting face and the flank.
γ	is the rake angle = the angle between the cutting face and the normal to the cut surface.

The normal is an imagined line that forms a right-angle with the cut surface and touches the tip of the tool. It thus follows that:
$\alpha + \beta + \gamma = 90°$.

On machine tools that rotate, the normal goes from the tip of the tool to the centre of the tool.



α = clearance angle
α_1 = radial clearance angle
α_2 = tangential clearance angle
β = wedge angle
γ = rake angle
ε = front bevel angle
ε_1 = back bevel angle

Figure 4.5 Definition of a sawtooth's cutting angles. The example shows a tooth with a soldered tip.

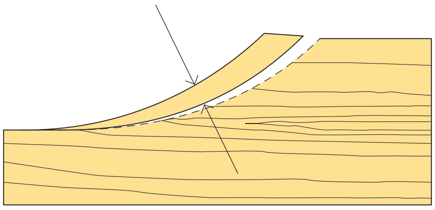
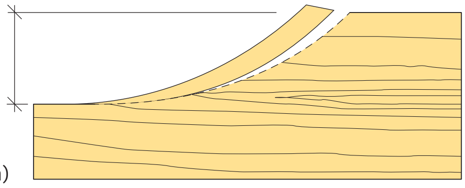
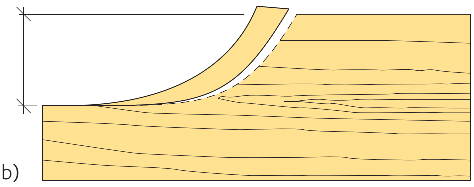


Figure 4.6 Average chip thickness.



a)

Tool diameter = 150 mm
Cutting depth = 1 mm
Chip length approx. 41 mm



b)

Tool diameter = 75 mm
Cutting depth = 12 mm
Chip length approx. 27 mm

Figure 4.7 Friction and wear
a) Long chips mean that the cutting edge moves a long way through the material. This causes greater friction and greater wear on the cutting edge.

b) A tool with a smaller diameter produces shorter chips, which is preferable if all the other cutting data is the same.

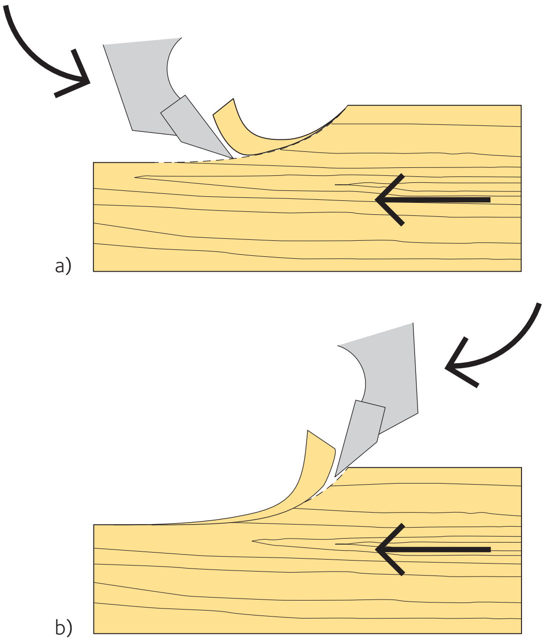


Figure 4.8 a) Counter-climb cutting, b) climb cutting.

Radial side clearance

This angle should fall in the range 0.5° – 1°. Some milling bits are made without radial side clearance so that the cutting width does not change during sanding. Such a milling bit will burn easily. To avoid burning, the tangential side clearance should be slightly increased.

Tangential side clearance

The tangential side clearance is usually 4° – 6°. If there is no radial side clearance, it is 5° – 7°.

Average chip thickness

When a machine tool cuts a chip, it is initially thin. The thickness then increases once the cutting has properly started.

Since the chip theoretically has a wedge shape, the thickness is calculated at the middle. When we talk about chip thickness in this handbook, we mean an average value – the average chip thickness, *see fig. 4.6*.

Studies have concluded that the average chip thickness should not fall below 0.1 mm. If the tool cuts thinner chips, the wood will push up for much of the cutting work and create considerable friction. This will blunt the tool more quickly, as well as causing a poor cut surface and sometimes burning.

The diameter of the tool also affects the cutting work. A large diameter produces long chips and a small diameter gives short chips.

4.1.3 Feed

Feed is the speed at which the workpiece is fed past the tool. Feed is measured in m/min. A distinction is drawn between feeding by hand and machine feeding. Machine feeding usually makes use of rollers and feed mats. Obviously, machine feeding provides the smoothest and best feed, plus it is preferable for safety reasons. The feeding usually goes against the direction of the cutting edge, which is called counter-climb cutting. In rare cases, feeding with the direction of the cutting edge, climb cutting, may occur. The advantage of climb cutting is that you get fine cut surfaces, particularly when milling profiles from cross-grained wood types. The tool is keen to dig in, which causes the workpiece to buck rapidly. This entails an increased risk of accidents and so climb cutting is best avoided. In principle, you want to feed as quickly as possible. If the cutting speed and the number of cuts are increased, the feed rate can also be increased. The speed depends on how fine a surface you require. When high standards of surface quality are required, it does not make financial sense to have such a high feed rate that the wood requires extensive finishing work.

4.1.4 Cutting circle

The cutting circle is the path described by the edge of a rotating tool.

4.1.5 Cutting speed

The cutting speed is the speed that the cutting edge runs at through the tool's rotation. The cutting speed is measured in metres per second (m/s) and is dependent on the rotational speed and diameter of the tool.

The cutting speed can be calculated using the formula:

$$\frac{v = d \cdot \pi \cdot n}{60} \ \text{m/s}$$

where:

v	is the cutting speed in m/s.
d	is the tool's diameter in m.
n	is the revolutions per minute (rpm).
π	is 3.14.

Example:
What is the cutting speed if the tool has a diameter of 110 mm and runs at 6,000 rpm?

$$\frac{0.110 \cdot \pi \cdot 6000}{60} \approx 34.5\ \text{m/s}$$

Large-scale production requires high cutting speeds. The focus is therefore on maintaining as high a speed as possible, while also having to take account of what the tools and machines can handle in terms of strength, stability, concentricity and safety.

It is essential to always used sharpened tools. A sharp tool:

- always gives a perfect cut surface
- in most cases ensures no tear-out
- reduces or in many cases eradicates the need for extra finishing
- makes the feed easier and less labour-intensive
- cuts the noise level
- reduces wear on all the machine's functions
- saves the company money.

Note that:

- a clean tool stays sharp for longer
- resins create a hard coating on tools, which generates high heat
- the temperature can get so high that the steel deforms in the cutting zone.

Cutter marks

All machining with rotating tools causes cutter marks. The length of the cutter marks relates to the feed per tooth and is called cutter mark distribution. You can make the cutter marks more or less visible to the eye. There are differing opinions on suitable cutter mark distribution. A smooth surface, for example, can have 0.3 – 0.8 mm distribution, while a distribution of 2.6 – 5.0 mm may be called a rough planed surface. It is naturally best if the cutter marks have a regular distribution. All the cuts should thus leave the same mark on the wood, although this is very difficult in practice. It requires the cutters to have precise rotation.

The depth of the wave depends on the diameter of the cutting circle. A smaller diameter gives a greater wave depth. If you want good surface smoothness with small cutting circle diameters, you need to reduce the cutter mark distribution.

Calculation formulae:

$$\text{Cutter mark distribution} = \frac{\text{feed [m/min]} \cdot 1{,}000}{\text{rpm} \cdot \text{no. of cuts}}$$

$$\begin{array}{c}\text{Average}\\ \text{chip thickness}\end{array} = \sqrt{\frac{\text{cutting depth [mm]}}{\text{cutting circle diameter [mm]}}} \cdot \begin{array}{l}\text{cutter mark}\\ \text{distribution [mm]}\end{array}$$

Table 4.1 **Guidelines for cutting speed (m/s).**

Tool diameter (mm)	Revolutions (rpm)																
	1500	2000	2500	3000	3500	4000	4500	5000	6000	7000	8000	9000	10000	12000	14000	16000	18000
5	0,4	0,5	0,7	0,8	0,9	1,1	1,2	1,3	1,6	1,8	2,1	2,4	2,6	3,1	3,7	4,2	4,7
10	0,8	1,0	1,3	1,6	1,8	2,1	2,4	2,6	3,1	3,7	4,2	4,7	5,2	6,3	7,3	8,4	9,4
15	1,2	1,6	2,0	2,4	2,7	3,1	3,5	3,9	4,7	5,5	6,3	7,1	7,9	9,4	11	13	14
20	1,6	2,1	2,6	3,1	3,7	4,2	4,7	5,2	6,3	7,3	8,4	9,4	10	13	15	17	19
25	2,0	2,6	3,3	3,9	4,6	5,2	5,9	6,5	7,9	9,2	10	12	13	16	18	21	24
30	2,4	3,1	3,9	4,7	5,5	6,3	7,1	7,9	9,4	11	13	14	16	19	22	25	28
35	2,7	3,7	4,6	5,5	6,4	7,3	8,2	9,2	11	13	15	16	18	22	26	29	33
40	3,1	4,2	5,2	6,3	7,3	8,4	9,4	10	13	15	17	19	21	25	29	34	38
45	3,5	4,7	5,9	7,1	8,2	9,4	11	12	14	16	19	21	24	28	33	38	42
50	3,9	5,2	6,5	7,9	9,2	10	12	13	16	18	21	24	26	31	37	42	47
55	4,3	5,8	7,2	8,6	10,1	12	13	14	17	20	23	26	29	35	40	46	52
60	4,7	6,3	7,9	9,4	11	13	14	16	19	22	25	28	31	38	44	50	57
65	5,1	6,8	8,5	10	12	14	15	17	20	24	27	31	34	41	48	54	61
70	5,5	7,3	9,2	11	13	15	16	18	22	26	29	33	37	44	51	59	66
75	5,9	7,9	10	12	14	16	18	20	24	27	31	35	39	47	55	63	71
80	6,3	8,4	10	13	15	17	19	21	25	29	34	38	42	50	59	67	75
85	6,7	8,9	11	13	16	18	20	22	27	31	36	40	45	53	62	71	80
90	7,1	9,4	12	14	16	19	21	24	28	33	38	42	47	57	66	75	85
95	7,5	10	12	15	17	20	22	25	30	35	40	45	50	60	70	80	90
100	7,9	10	13	16	18	21	24	26	31	37	42	47	52	63	73	84	94
110	8,6	12	14	17	20	23	26	29	35	40	46	52	58	69	81	92	104
120	9,4	13	16	19	22	25	28	31	38	44	50	57	63	75	88	101	113
130	10	14	17	20	24	27	31	34	41	48	54	61	68	82	95	109	123
140	11	15	18	22	26	29	33	37	44	51	59	66	73	88	103	117	132
150	12	16	20	24	27	31	35	39	47	55	63	71	79	94	110	126	141
160	13	17	21	25	29	34	38	42	50	59	67	75	84	101	117	134	151
170	13	18	22	27	31	36	40	45	53	62	71	80	89	107	125	142	160
180	14	19	24	28	33	38	42	47	57	66	75	85	94	113	132	151	170
190	15	20	25	30	35	40	45	50	60	70	80	90	99	119	139	159	179
200	16	21	26	31	37	42	47	52	63	73	84	94	105	126	147	168	188
210	16	22	27	33	38	44	49	55	66	77	88	99	110	132	154	176	198
220	17	23	29	35	40	46	52	58	69	81	92	104	115	138	161	184	207
230	18	24	30	36	42	48	54	60	72	84	96	108	120	145	169	193	217
240	19	25	31	38	44	50	57	63	75	88	101	113	126	151	176	201	226
250	20	26	33	39	46	52	59	65	79	92	105	118	131	157	183	209	236
260	20	27	34	41	48	54	61	68	82	95	109	123	136	163	191	218	245
270	21	28	35	42	49	57	64	71	85	99	113	127	141	170	198	226	254
280	22	29	37	44	51	59	66	73	88	103	117	132	147	176	205	235	264
290	23	30	38	46	53	61	68	76	91	106	121	137	152	182	213	243	273

Cont. >>>

Table 4.1 Cont. >>>

Tool diameter (mm)	Revolutions (rpm)																
	1500	2000	2500	3000	3500	4000	4500	5000	6000	7000	8000	9000	10000	12000	14000	16000	18000
300	24	31	39	47	55	63	71	79	94	110	126	141	157	188	220	251	283
310	24	32	41	49	57	65	73	81	97	114	130	146	162	195	227	260	292
320	25	34	42	50	59	67	75	84	101	117	134	151	168	201	235	268	302
330	26	35	43	52	60	69	78	86	104	121	138	156	173	207	242	276	311
340	27	36	45	53	62	71	80	89	107	125	142	160	178	214	249	285	320
350	27	37	46	55	64	73	82	92	110	128	147	165	183	220	257	293	330
360	28	38	47	57	66	75	85	94	113	132	151	170	188	226	264	302	339
370	29	39	48	58	68	77	87	97	116	136	155	174	194	232	271	310	349
380	30	40	50	60	70	80	90	99	119	139	159	179	199	239	279	318	358
390	31	41	51	61	71	82	92	102	123	143	163	184	204	245	286	327	368
400	31	42	52	63	73	84	94	105	126	147	168	188	209	251	293	335	377
410	32	43	54	64	75	86	97	107	129	150	172	193	215	258	301	343	386
420	33	44	55	66	77	88	99	110	132	154	176	198	220	264	308	352	396
430	34	45	56	68	79	90	101	113	135	158	180	203	225	270	315	360	405
440	35	46	58	69	81	92	104	115	138	161	184	207	230	276	323	369	415
450	35	47	59	71	82	94	106	118	141	165	188	212	236	283	330	377	424
460	36	48	60	72	84	96	108	120	145	169	193	217	241	289	337	385	434
470	37	49	62	74	86	98	111	123	148	172	197	221	246	295	345	394	443
480	38	50	63	75	88	101	113	126	151	176	201	226	251	302	352	402	452
490	38	51	64	77	90	103	115	128	154	180	205	231	257	308	359	410	462
500	39	52	65	79	92	105	118	131	157	183	209	236	262	314	367	419	471

4.2 Mechanical processing

Work in the wood industry is always affected to a large degree by the properties of the wood. Wood is not homogeneous, so its properties can vary greatly within the same piece. The material that is processed in the wood industry therefore demands the right tool for the job.

Technical advances in the wood industry have taken us from universal machines with various additions and aids to more specialised machines for each stage or type of production. As the use of various sheet materials, particularly MDF and particleboard, became more common in the furniture industry, new techniques for construction and assembly were developed and so the era of flat pack furniture was born. New types of machine lines for manufacturing large series meant long retooling times and low flexibility. A common approach was therefore to produce large volumes in different dimensions and variants at the factory to be held in stock.

The cost of stockpiling gets very high, however, if you count the interest on the money tied up in materials. And then there are the considerable costs of large warehouses and material handling. To cut these costs, the trend in the industry has been towards production that is led more by actual customer orders. Under this system, small series are manufactured based on immediate market demand and the products are sent directly to the customer instead of being stored by the company.