1

Timber as a Structural Material

In this chapter, the most important physical properties of wood are described with regard to its use as a construction material. These include fibre structure, irregularities and moisture absorption and release. Timber and wood-based materials used in construction are introduced and their mechanical properties are presented.

With regard to the manifold topics of wood physics and wood chemistry, selected literature for further reading is recommended and listed.

1.1 Building with Timber: Advantages and Challenges

Alongside masonry using natural stones, timber construction is one of the oldest building methods known to humankind. Until the industrial production of steel profiles, timber was the only building material available for beam-type building components subjected to normal forces and bending moments. In the course of history, carpenters developed a multitude of applications for this comparatively easy-to-handle material. Timber has been used for roof constructions, timbered-framed buildings, bridges, ships and much more. Wood is locally available in most regions of the northern hemisphere and can be transported from the forest via the sawmill to the construction site in a short span of time. Timber is the only natural growing material that is widely used for building constructions and other load-bearing structures. Wood has excellent potential for optimised cascade use, as depicted schematically in Figure 1.1.

In Europe, approximately 35% of the land area is forested. Finland tops the list with over 70%, while Ireland with 10%, is among the countries with sparse forests. Monaco is the only country without any forests. Forests store significant amounts of CO_2 through photosynthesis. Burning or rotting of wood releases as much CO_2 as was absorbed from the atmosphere during its growth. When wood is used as a construction material in buildings or other structures, the CO_2 remains sequestered for the entire lifespan of the building. The management of forests follows the principle of sustainability: only as much wood is harvested per year as will regrow during that time. Wood, as a natural material, can be destroyed by fungi or insects under certain conditions. Thus, the service life of wooden structures depends significantly on

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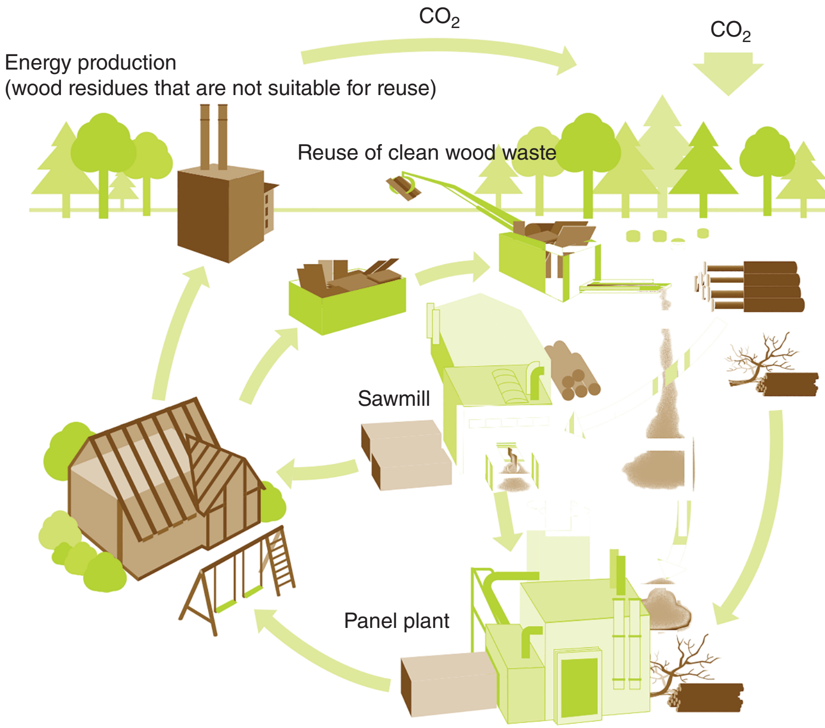


Figure 1.1 Cascade use of wood in the construction sector. Source: VHI Verband der deutschen Holzwerkstoffindustrie (Association of the German Wood-based Materials Industry).

the construction details and the selected preservation method. The fact that wooden buildings can last several hundred years with the right construction and care is evidenced by the numerous mediaeval roof constructions and half-timbered houses that have been preserved throughout Europe, some dating back more than 800 years.

The most characteristic feature of timber construction is in the connections. In addition to the traditional joints, the twentieth century witnessed an increasing development of new joining techniques in timber construction. The development of adhesive bonding technology, and the associated possibility of producing timber cross sections regardless of the dimensions of the trees, has continuously expanded the potential applications of timber construction. Today, sports halls and exhibition halls, multi-storey residential and commercial buildings, industrial buildings as well as towers and bridges are designed and constructed in timber.

1.2 Mechanical Properties of Solid Timber

Wood is a natural material, and every wooden component was once part of a tree. Since it is hardly possible to influence the 'production' of wood as a material, the mechanical properties are subject to the conditions of natural growth.

The properties of the subsequent timber component are fundamentally influenced by the direction of the fibres, the density, and the irregularities in the fibre structure.

Anatomy, physics and chemistry of wood are comprehensively explained by Fengel and Wegener (2011), Shmulsky and Jones (2019) and by Rowell (2005). The standard work by Kollmann and Côté (1968) is available in antiquarian form or as print on demand. In the following, the most important mechanical properties are described with regard to their application in load-bearing structures and building constructions.

1.2.1 Influence of the Fibre Direction

Wood is an anisotropic material, a characteristic that is clearly evident in its cell structure (see Figure 1.2a). In coniferous wood, also known as softwood, the tubular thick-walled tracheids (latewood) form the load-bearing element parts, imparting strength to the wood. Consequently, the strength of the wood is greatest in the direction of the grain. However, perpendicular to the grain, the strength is relatively low. The structure of wood can be explained as a tube model – like a bundle of straws (see Figure 1.2b). This tube model can serve as an effective tool for explaining the different types of failure in wood material (Figure 1.3).

Tension: In the longitudinal direction, the individual fibres fail only when they reach their tensile strength. Conversely, in the transverse direction, the fibres can be easily separated.

Compression: Compression stress in the longitudinal direction leads to buckling of the individual fibres. However, in the transverse direction, the fibres can be crushed under comparatively low stresses.

Bending: When a beam is bent, both tensile and compression strength are mobilised in the longitudinal direction.

Shear: Shear stress aligned with the fibre direction is more favourable than rolling shear stress, which occurs perpendicular to the fibre direction.

1.2.2 Strength Values of Solid Timber

The decisive factor for the strength of the timber is how densely the fibres are ‘packed’. In this context, the density of the wood is an important reference value. This is determined using oven-dried samples (compare Section 1.2.4).

$$\rho = \frac{m_0(\text{kg})}{V(\text{m}^3)} \tag{1.1}$$

Other properties that influence the strength of the timber components include cracks, knots and twisted growth, as well as infestation by plants (e.g. fungi, mistletoe) or insects. All timber components are afflicted with more or less major wood defects. Some are an exclusion criterion with regard to the use of the timber for load-bearing components, while others can be tolerated to a certain extent. The

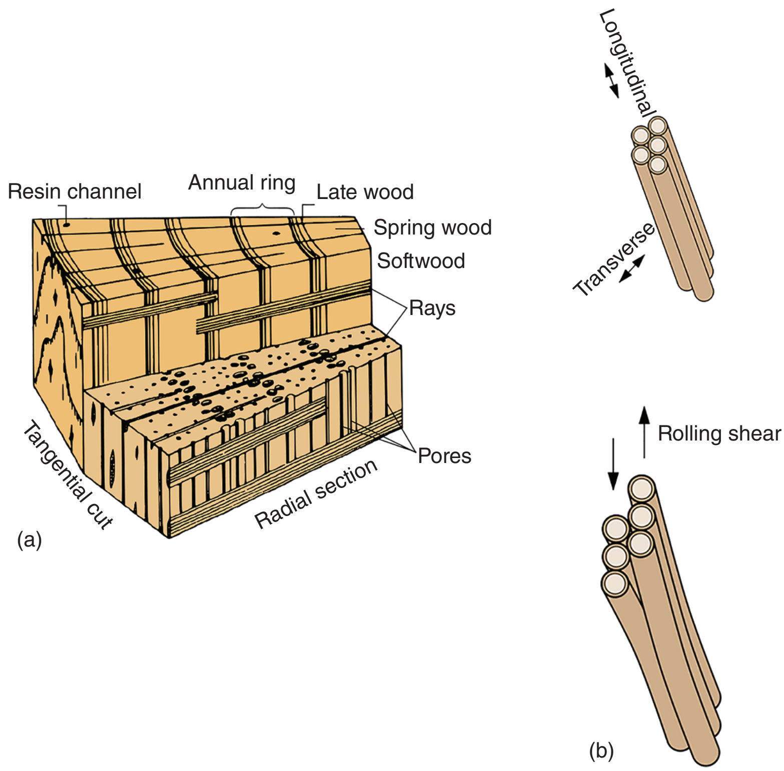


Figure 1.2 (a) Wood structure of softwood and hardwood in comparison. Source: Fengel and Wegener (2011); (b) Tube model with different stresses.

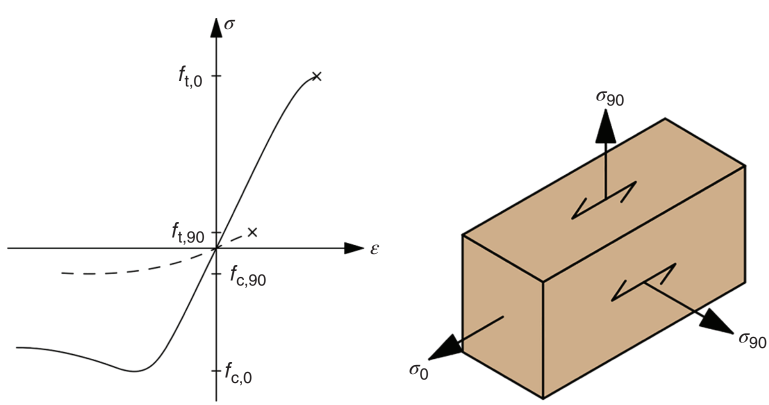


Figure 1.3 Schematic of stress–strain curve of defect-free wood under compression and tensile stress parallel and perpendicular to the grain.

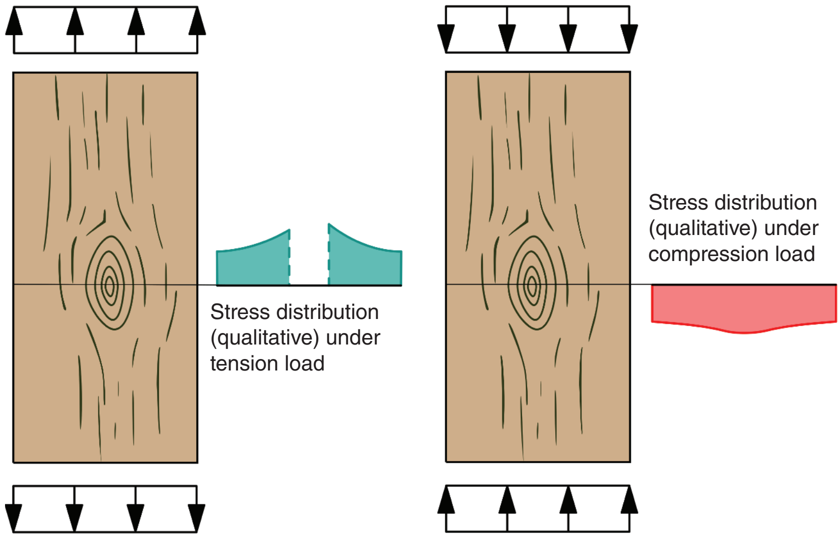


Figure 1.4 Influence of a knot under tension and compression loading.

influence of irregularities on the strength of the timber can be well explained using knottiness as an example.

Under a tensile load, the area of the knot becomes a void. This implies that the tensile strength of a real wood cross section is lower than the tensile strength of a defect-free wood sample. In contrast, the influence of a knot on the compression strength is rather small, as clearly illustrated in Figure 1.4. This is because the knot, having a higher density compared to the surrounding wood, is resistant to compression.

To specify the strength of different types of wood, sawn timber is classified into grades. These grades can be determined visually or by machines. Table 1.1 provides an example of the criteria for visual grading, according to German code regulations. The strength classes C16, C24 and C30 are assigned to the characteristic value of the bending strength. The meaning of the term characteristic and the statistical basis to calculate characteristic values will be explained in Section 2.1. Other strength values, which depend on the direction of stress, are summarised in Table 1.2. Figure 1.5 provides an example of how knottiness is defined in relation to the visible side surfaces of a rectangular cross section.

Knottiness A is determined as the ratio of diameter of the knot to cross-sectional width or height.

$$A = \max\left\{\frac{d_1}{b}; \frac{d_2}{h}; \frac{d_3}{b}; \frac{d_4}{h}\right\} \tag{1.2}$$

1.2.3 Deformation Properties of Solid Timber

Similar to strength, the deformation properties of wood also depend on the direction of loading in relation to the grain. Up to a load level that corresponds

Table 1.1 Grading criteria for solid timber according to DIN 4074-1.

Grading criteria	Grade		
	S 7	**S 10**	**S 13**
1. Knots			
– Single knot	≤1/2	≤1/3	≤1/5
– Group of knots	≤2/3	≤1/2	≤1/3
– Edge knots[a)]	—	≤2/3	≤1/3
2. Inclination of grain	≤16%	≤12%	≤7%
3. Pith	Allowed	Allowed	Not allowed
4. Growth ring width			
– General	≤6 mm	≤6 mm	≤4 mm
– For Douglas fir	≤8 mm	≤8 mm	≤6 mm
5. Cracks			
– Shrinkage cracks[b)]	Allowed	Allowed	Not allowed
– Lightening cracks, ring shake	Not allowed	Not allowed	Not allowed
6. Wane	≤1/3	≤1/3	≤1/4
7. Warping[b)]			
– Longitudinal	≤12 mm	≤8 mm	≤8 mm
– Twist	2 mm/25 mm	1 mm/25 mm	1 mm/25 mm
– Transverse	Width ≤ 1/20	Width ≤ 1/30	Width ≤ 1/50
8. Discolourations, rot			
– Blue stain	Allowed	Allowed	Allowed
– Nailable brown/red strips	≤3/5	≤2/5	≤1/5
– Brown rot, white rot	Not allowed	Not allowed	Not allowed
9. Compression wood	≤3/5	≤2/5	≤1/5
10. Damage from greenwood insects	Worm holes until 2 mm diameter: allowed		

a) Criteria do not have to be applied to boards for glulam.
b) Criteria are not considered for wood that has not been dry sorted.

to approximately 70–80% of the strength, wood exhibits almost linearly elastic deformations in all stress directions. Mean values for the modulus of elasticity E_0, which are applied for tensile, compression and bending stress, as well as for the shear modulus G and the modulus of elasticity E_{90} are provided in Table 1.2. The characteristic values for moduli of elasticity and shear moduli are obtained by reducing the mean values by one-third.

Typical characteristics of wood are its swelling and shrinkage deformations due to changes in humidity. While this effect is relatively small in the longitudinal direction, shrinkage in the radial and tangential directions can lead to considerable deformations along the cross section.

Table 1.2 Mechanical parameters for solid timber according to EN 338.

Wood class	C16	C18	C24	C30
			(N/mm^2)	
Bending $f_{m,k}$	16	18	24	30
Tension parallel $f_{t,0,k}$	8.5	10	14.5	19
Tension perpendicular $f_{t,90,k}$	0.4	0.4	0.4	0.4
Compression parallel $f_{c,0,k}$	17	18	21	24
Compression perpendicular $f_{c,90,k}$	2.2	2.2	2.5	2.7
Shear and torsion $f_{v,k}$	3.2	3.4	4.0	4.0
Modulus of elasticity parallel $E_{0,mean}$	8 000	9 000	11 000	12 000
Modulus of elasticity perpendicular $E_{90,mean}$	270	300	370	400
Shear modulus G_{mean}	500	560	690	750
			(kg/m^3)	
Density ρ_k	310	320	350	380
Density (mean) ρ_m	370	380	420	460

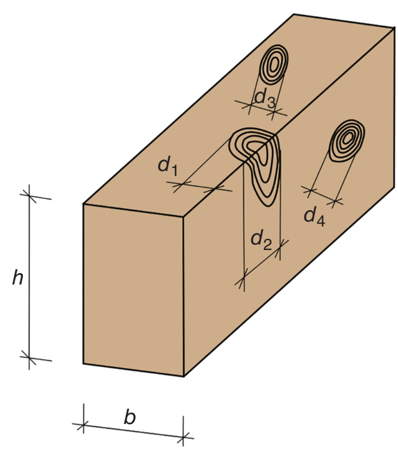


Figure 1.5 Definition of knottiness according to DIN 4074-1.

The wood moisture content is defined as the moisture content in relation to the oven-dried wood sample:

$$u\,(\%) = \frac{m_u - m_0}{m_0} \cdot 100 \tag{1.3}$$

with

m_u Mass of the moist wood sample

m_0 Mass of the oven-dried wood sample ($u = 0\%$)

It becomes particularly critical when wooden components are installed with excessive moisture content and subsequently dry out. If the wood moisture content of a building component is more than 3% above, the so-called equilibrium moisture content, cracks in the building component are inevitable. In heated and well-ventilated buildings, the equilibrium moisture content usually reaches values between 6 and 8%.

1.2.4 Influence of Load Duration and Humidity

The mechanical properties of the timber depend on the load application time and the wood moisture content. An increase in wood moisture leads to lower strength (see Figure 1.6) and also lower moduli of elasticity. This effect can be partly attributed to the swelling of the cell wall, which implies that less cell wall material is available per unit area. More importantly, however, water penetrates the cell wall and weakens the hydrogen bonds that hold the cell walls together. Moisture changes above the fibre saturation point do not impact the mechanical properties, as only free water is stored in the cell cavities at this stage.

In long-term tests, the reduction of the strength under permanent load could be quantified (see Figure 1.7). The design takes into account the influence of wood moisture and loading duration on the strength through the modification factor k_{mod} (see Section 2.1.2). Service classes SC1, SC2 and SC3 are defined to categorise the expected equilibrium moisture content (see Table 1.3). The load duration is described by five classes, ranging from permanent to instantaneous, for various actions (see Table 1.4).

Under a constant load, deformations of timber increase over time. The key factors influencing creep are the loading duration and the wood moisture. Further influencing factors are the temperature and the stress level. A sufficiently precise consideration of creep for engineering practice is made by deformation factors k_{def} for the different service classes. The calculation procedure will be explained in Section 2.1.2.

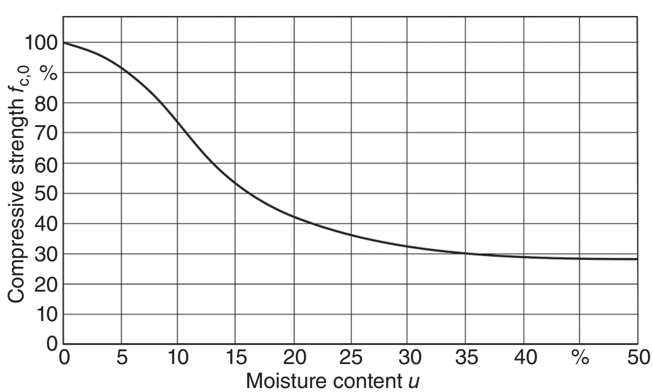


Figure 1.6 Compression strength of spruce as a function of wood moisture content according to Kollmann and Côté (1968).

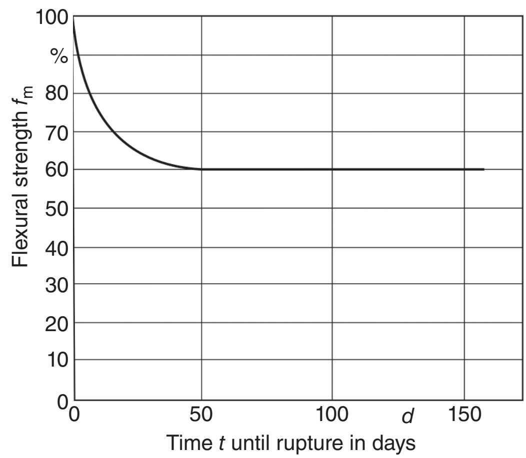


Figure 1.7 Flexural bending long-term strength of defect-free softwood in relation to short-term strength according to Möhler (1980).

Table 1.3 Service classes with reference to EN 1995-1-1.

Service class	Equilibrium moisture content ω_u (%)	Relative humidity of the surrounding air at 20 °C	Examples of structures
SC1	10 ± 5	65%[a)]	Inside insulated and heated buildings
SC2	15 ± 5	85%[a)]	Under shelter, not exposed to rain, unheated
SC3	18 ± 6	95%[a)]	Exposed to weather, water will run off

a) Upper limit should not be exceeded for more than a period of a few consecutive weeks per year.

Fact Sheet 1.1

The fibre structure of the wood leads to anisotropic material characteristics of the timber

$$f_{t,90} \cong 0.03 \cdot f_{t,0}$$
$$f_{c,90} \cong 0.10 \cdot f_{c,0}$$

⇒ Strength and MOE depend on the angle between grain and acting stresses
⇒ Tension perpendicular to the grain (and rolling shear) should be avoided whenever possible!

Quality control needs grading criteria

⇒ Grade classes and strength classes

Improvement of wood properties is possible with wood-based products and wood-based materials

⇒ Lower moisture content, lower tendency for cracking
⇒ Fewer defects (knots)
⇒ Improved scattering of irregularities

Fact Sheet 1.2

Ambient conditions (humidity) and load application time influence strength

⇒ Modification factor k_{mod}

Long-term acting loads lead to additional deformations

⇒ Deformation factor k_{def}

Table 1.4 Classes of load duration of action according to EN 1995-1-1.

Classes of load duration	Order of accumulated duration of characteristic load	Examples of loading
Permanent	More than 10 yr	Self-weight
Long term	6 mo–10 yr	Storage
Medium term	1 wk–6 mo	Imposed floor load, snow[a)]
Short term	Less than 1 wk	Snow[a)], wind[a)]
Instantaneous	Less than 1 min	Wind[a)], impact, seismic action

a) To be specified in national regulations.

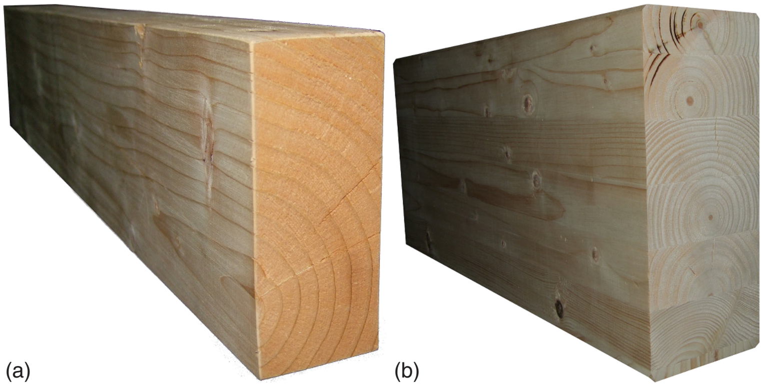
1.3 Wood-based Products

Construction timber is obtained by cutting round wood stems into rectangular timber sections. The cross sections are categorised into battens, boards, planks and squared timber depending on the dimensions. The dimensions of these cross sections correspond to a wood moisture content of 30%. Generally, construction timber is not further processed after cutting. With squared timber made of sawn construction timber (see Figure 1.8a), longitudinal cracks due to shrinkage deformation must always be expected.

Due to these reasons, and because of the significant effort that would be required to dry beam cross sections down to a wood moisture content of less than 20 or 15%, sawn timber is mainly used for subordinate components with small dimensions (e.g. roof beams and planks). Sawn timber is further processed through industrial drying and gluing.

1.3.1 Solid Structural Timber and Glued Solid Timber

Solid structural timber (ST) is characterized by industrial drying (wood moisture content 15% ± 3%), dimensional stability, heart-cut or heart-free cutting, bevelled edges and restrictions on shrinkage cracks. These quality characteristics also apply to glued solid timber (GST), where a cross section is made of up to five lamellae glued together. The thickness of each lamella is between 45 and 85 mm. Dimensions of the



(a) (b)

Figure 1.8 (a) Solid timber; (b) glulam.

Figure 1.9 Glued finger joint.

cross section should not exceed 280 × 280 mm. The principle of finger-jointing, with which quasi-endless cross sections can be produced, is illustrated in Figure 1.9.

For ST and GST, mainly spruce is used, but beams made of fir, pine, larch and Douglas fir are also available upon request. The beams are typically supplied in preferred cross sections with a length of about 13 m. In the longitudinal direction of the components, finger joints may be arranged as full joints across the entire height of the cross section. The values for strength, modulus of elasticity, shear modulus and the density correspond to those of strength classes C18, C24 and C30.

1.3.2 Glued Laminated Timber

Glued laminated timber (glulam or GL) is composed of at least three lamellae glued together. The thickness of a board lamella ranges between 6 and 45 mm. Compared to solid timber, glulam achieves higher characteristic strength values (see Table 1.5), as the board lamellae are pre-sorted and defects are limited to a certain level and distributed over the entire cross section due to the layered construction. The mean values of the modulus of elasticity and shear modulus also deviate from those of solid timber. Due to the layered structure, glulam has less material scatter. Therefore, mean values of the modulus of elasticity and shear modulus are reduced by only one-sixth to derive characteristic values.

Table 1.5 Material properties of glulam according to EN 14080.

Strength class	GL 24h	GL 24c	GL 28h	GL 28c	GL 30h	GL 30c
			(N/mm^2)			
Bending $f_{m,k}$	24	24	28	28	30	30
Tension parallel $f_{t,0,k}$	19.2	17	22.3	19.5	24	19.5
Tension perpendicular $f_{t,90,k}$			0.5			
Compression parallel $f_{c,0,k}$	24.0	21.5	28	24	30	24.5
Compression perpendicular $f_{c,90,k}$			2.5			
Shear und torsion $f_{v,k}$			3.5			
Modulus of elasticity parallel $E_{0,mean}$	11 500	11 000	12 600	12 500	13 600	13 000
Modulus of elasticity perpendicular $E_{90,mean}$			300			
Shear modulus G_{mean}			650			
			(kg/m^3)			
Density ρ_k	385	365	425	390	430	390
Density (mean) ρ_m	420	400	460	420	480	430

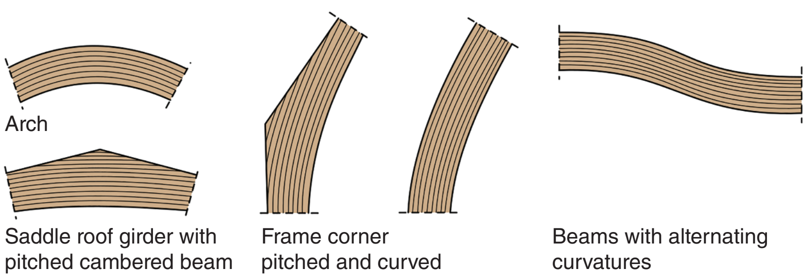


Figure 1.10 Shaping options for glulam.

Production is carried out exclusively by companies that have demonstrated in their proficiency in gluing load-bearing components and can present a so-called ‘gluing approval’. The individual lamellae are sorted into strength classes based on the sorting criteria. Larger knots are cut, then the boards are joined using finger joints. After drying, the lamellae are planed and immediately glued together. Due to the lamella structure, beams can also be produced in tapered or curved forms (see Figure 1.10 and Section 6.1). For the higher stressed edge areas of beams, lamellae of a higher strength class can be used. This is called ‘combined glulam’ (GLc), in contrast to ‘homogeneous glulam’ (GLh), where all lamellae of the cross section belong to the same strength class (see Figure 1.11). The proportion and strength class of the higher-grade lamellae are specified in EN 14080. Usually, the proportion of an edge area ranges between one-sixth and one-third of the total cross section.

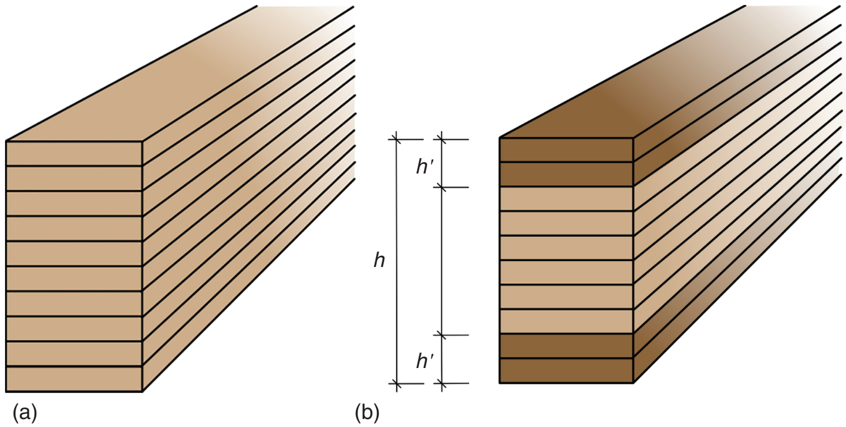


Figure 1.11 (a) Homogeneous and; (b) combined glued laminated timber.

Glulam is predominantly made from softwood. Nevertheless, some companies have also specialised in producing glulam from hardwood species such as beech, chestnut or oak.

1.3.3 Cross-laminated Timber

Like glulam, cross laminated timber (CLT) is composed of lamellae glued together. The crosswise bonding of the individual lamellae creates flat components for use as wall or slab elements (see Figure 1.12). The production steps correspond to those in the production of glulam. Softwood of strength class C24 is predominantly used. With regard to bending stress, the cross sections have a strong axis (aligned with the grain direction of the top layers) and a weak axis (perpendicular to the grain direction of the top layers). Constructions using CLT are comprehensively explained in Section 7.2.

Figure 1.12 Cross-laminated timber (CLT).

1.4 Wood-based Materials

1.4.1 Laminated Veneer Lumber

Laminated veneer lumber (LVL) is composed of approximately 3 mm thick, glued rotary cut softwood veneers. The fibres of the veneers run exclusively or predominantly in the longitudinal direction of the boards (see Figure 1.13a). Veneers are obtained by peeling softwood logs that have been stored in hot water for about 24 hours. The peeled veneers are cut into veneer sheets of the same width, sorted according to strength and, after drying, assembled with staggered joints. The components are then pre-pressed (usually cold) after an adhesive is applied and then pressed at temperatures of up to 150 °C, depending on the type of wood. By using special presses, curved shaped parts can also be formed. Due to the homogenisation of the material, laminated veneer lumber achieves higher load-bearing capacities than solid wood or glulam of the same dimensions.

Laminated veneer lumber, with only parallel layers, is used for slender, beam-shaped components. Laminated veneer lumber with transverse layers is also used for panels. In Europe, product properties and dimensioning are regulated in general approvals.

1.4.2 Plywood

Plywood is composed of an odd number, at least three, of crosswise glued layers (see Figure 1.13b). The two outer layers of plywood are always veneers, while the middle layers vary depending on the type of plywood. Veneer plywood panels consist of peeled veneers which, after drying, are glued together crosswise in heated presses. For blockboard, the middle layer consists of glued-together wooden strips with widths of 24–30 mm. Laminboard has a middle layer of upright wooden strips with a maximum thickness of 8 mm.

Plywood products are categorised into ‘technical classes’. The technical class determines service classes in which the products may be used.

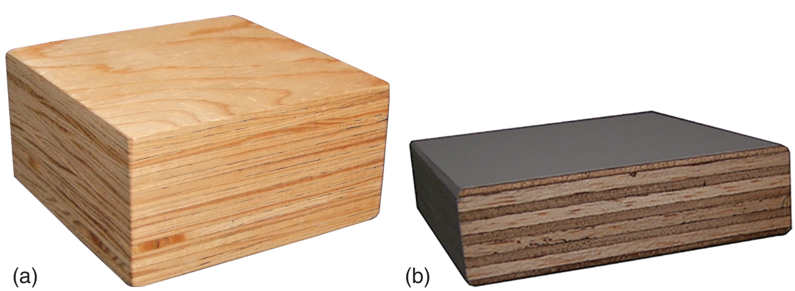


Figure 1.13 (a) Laminated veneer lumber (LVL); (b) plywood.

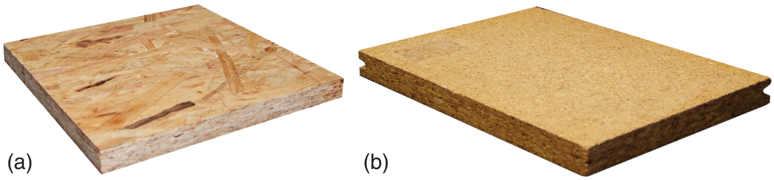


Figure 1.14 (a) OSB board; (b) particle board.

1.4.3 Oriented Strand Boards

Oriented strand board (OSB) is composed of long, narrow, aligned wood chips (strands). These strands with dimensions of approximately 35 × 75 mm and a thickness of 6 mm are arranged on the board surfaces approximately parallel to the longitudinal direction (see Figure 1.14a). In the centre of the board, the wood chips are mainly arranged crosswise. OSB boards are used in the building industry for sheathing of wall and slab elements and thus contribute significantly to the bracing of load-bearing structures.

The strength properties depend on the direction of loading with reference to the longitudinal direction and, due to the inhomogeneous structure, on the board's thickness (see Table 1.6). OSB boards are classified into technical classes. OSB/2 boards may only be used in service class 1. OSB/3 and OSB/4 boards can be used in service classes 1 and 2.

1.4.4 Particle Boards

Particle boards are generally made from a combination of coarse and fine wood chips, which are compacted using adhesives under pressure and heat. In the case of flat-pressed chipboard, the chips are sprayed with an adhesive, placed to a steel

Table 1.6 Material properties of OSB according to EN 12369-1.

	Thickness (mm)	Density ρ_k (kg/m³)	Loaded perpendicular to the plane $f_{m,k}$ (N/mm²)		$f_{v,k}$	$E_{\alpha,mean}$		Loaded parallel to the plane $f_{v,k}$	G_{mean}
			0°a)	90°a)		0°a)	90°a)		
OSB 2/3	10	550	18.0	9.0	1.0	4930	1980	6.8	1080
	>10 to 18		16.4	8.2					
	>18 to 25		14.8	7.4					
OSB 4	10		24.5	13.0	1.1	6780	2680	6.9	1090
	>10 to 18		23.0	12.2					
	>18 to 25		21.0	11.4					

a) In relation to the direction of the strands of the surface layer.

Table 1.7 Material properties of particle board class P6 according to EN 12369-1.

Thickness	**Density** ρ_k	**Loaded perpendicular to the plane** $f_{m,k}$	$f_{v,k}$	E_{mean}	**Loaded parallel to the plane** $f_{v,k}$	G_{mean}
(mm)	**(kg/m³)**			**(N/mm²)**		
>6 to 13	650	16.5	1.9	4400	7.8	1200
>13 to 20	600	15.0	1.7	4100	7.3	1150
>20 to 25	550	13.3	1.7	3500	6.8	1050
>25 to 30	550	12.5	1.7	3300	6.5	950
>32 to 40	500	11.7	1.7	3100	6.0	900
>40 to 50	500	10.0	1.7	2800	5.5	880

plate and then pressed. The pressing causes the outer chips to align themselves parallel to the plane of the board (see Figure 1.14b). In addition to resin-bonded particle boards, flat pressed particle boards are also produced with mineral binders such as cement, gypsum or anhydrite binder. Cement-bonded particle boards are advantageous if moisture-induced stresses are to be expected. Similar to OSB boards, particle boards are used for sheathing of wall and slab elements.

Particle board intended for load-bearing purposes is divided into the technical classes P4 to P7 according to EN 312. For P4 and P6, the application is limited to service class 1. Boards in classes P5 and P7 can be used in service class 1 and service class 2 (Table 1.7).

1.4.5 Fibreboards

Fibreboards can be produced without adding artificial binders. Primarily, softwoods are used for the production of wood fibreboards. These are chopped into chips, softened with steam under a pressure of 3–8 bar and then mechanically defibrated. In the wet process, the fibre pulp is placed in a mould, mechanically pressed out and then dried. Fibreboards are categorised into low-, medium-, and high-density fibreboards depending on the degree of compaction of the fibre pulp (see Figure 1.15). In addition to the aforementioned wet process, fibreboards can also be produced using the dry process with the addition of binders. Fibreboards with a specific certification can be used for a load-bearing function.

Figure 1.15 Medium density fibreboard (MDF).

References

Fengel, D. and Wegener, G. (ed.) (2011). *Wood: Chemistry, Ultrastructure, Reactions*. Walter de Gruyter.
Kollman, F. and Côté, W. (1968). *Principles of Wood Science and Technology*, 247–250. Berlin: Springer.
Möhler, K. (1980). Grundlagen der Holz-Hochbaukonstruktionen. In: *Holzbau-Atlas* (ed. K.-H. Götz, D. Hoor, K. Möhler, and J. Natterer), München: Institut für internationale Architektur-Dokumentation.
Rowell, R.M. (2005). *Handbook of Wood Chemistry and Wood Composites*. CRC Press.
Shmulsky, R. and Jones, P.D. (2019). *Forest Products and Wood Science: An Introduction*. Wiley.

Standards and Technical Building Regulations

EN 312:2010 Particleboards – Specifications.
EN 338:2016 Structural timber – Strength classes.
EN 12369-1:2001 Wood-based panels – Characteristic values for structural design – Part 1: OSB, particleboards and fibreboards.
EN 14080:2013 Timber structures – Glued laminated timber and glued solid timber – Requirements.
DIN 4074-1:2012 Strength grading of wood – Part 1: Coniferous sawn timber.