Chapter 1

Timber as a Structural Material

1.1 INTRODUCTION

Timber from well-managed forests is one of the most sustainable resources available and it is one of the oldest known materials used in construction. It has a very high strength to weight ratio, is capable of transferring both tension and compression forces and is naturally suitable as a flexural member. Timber is a material that is used for a variety of structural forms such as beams, columns, trusses, girders, and is also used in building systems such as piles, deck members, railway sleepers and in formwork for concrete.

There are a number of inherent characteristics that make timber an ideal construction material. These include its high strength to weight ratio, its impressive record for durability and performance and good insulating properties against heat and sound. Timber also benefits from its natural growth characteristics such as grain patterns, colours and its availability in many species, sizes and shapes that make it a remarkably versatile and an aesthetically pleasing material. Timber can easily be shaped and connected using nails, screws, bolts and dowels or adhesively bonded together.

The limitations in maximum cross-sectional dimensions and lengths of solid sawn timbers, due to available log sizes and natural defects, are overcome by the recent developments in composite and engineered wood products. Finger jointing and various lamination techniques have enabled timbers (elements and systems) of uniform and high quality in any shape, form and size to be constructed; being only limited by the manufacturing and/or transportation boundaries.

Timber structures can be highly durable when properly treated, detailed and built. Examples of this are seen in many historic buildings all around the world. Timber structures can easily be reshaped or altered, and if damaged they can be repaired. Extensive research over the past few decades has resulted in comprehensive information on material properties of timber and its reconstituted and engineered products and their effects on structural design and service performance. Centuries of experience of use of timber in buildings has shown us the safe methods of construction, connection details and design limitations.

This chapter provides a brief description of the engineering properties of timber that are of interest to design engineers and architects, and it highlights that, unlike some structural materials such as steel or concrete, the properties of timber are very

Structural Timber Design to Eurocode 5, Second Edition. Jack Porteous and Abdy Kermani.

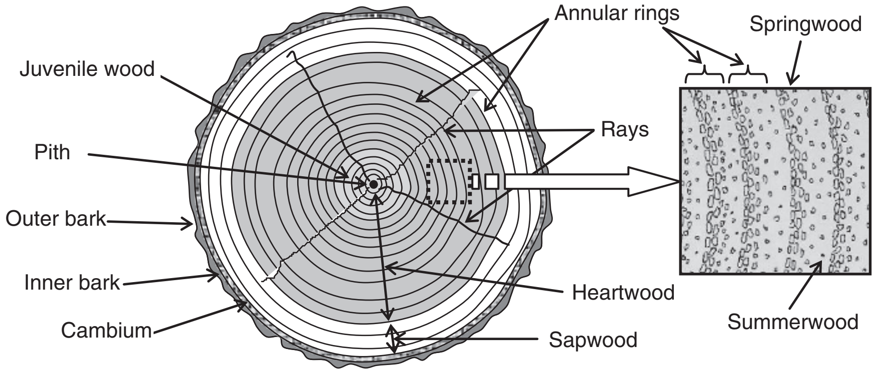


Fig. 1.1. Cross-section of tree trunk.

sensitive to environmental conditions; for example moisture content, which has a direct effect on the strength and stiffness, swelling or shrinkage of timber. A proper understanding of the physical characteristics of timber enables the building of safe and durable timber structures.

1.2 THE STRUCTURE OF TIMBER

Structural timber is sawn (milled) from the trunk of the tree, which provides rigidity, mechanical strength and height to maintain the crown. *Trunk* resists loads due to gravity and wind acting on the tree and also provides for the transport of water and minerals from the tree roots to the crown. *Roots*, by spreading through the soil and acting as a foundation, absorb moisture-containing minerals from the soil and transfer them via the trunk to the crown. *Crown*, comprising branches and twigs to support leaves, provides a catchment area producing chemical reactions that form sugar and cellulose that allow the growth of the tree.

As engineers we are mainly concerned with the trunk of the tree. A typical cross-section of a tree trunk, shown in Figure 1.1, illustrates its main features such as *bark*, the outer part of which is a rather dry and corky layer and the inner living part. The *cambium*, a very thin layer of cells underside the inner bark, is the growth centre of the tree. New wood cells are formed on the inside of the cambium (over the old wood) and new bark cells are formed on the outside and as such increase the diameter of the trunk. Although tree trunks can grow to a large size, in excess of 2 m in diameter, commercially available timbers are more often around 0.5 m in diameter.

Wood, in general, is composed of long thin tubular cells. The cell walls are made up of cellulose and the cells are bound together by a substance known as lignin. Most cells are oriented in the direction of the axis of the trunk except for cells known as *rays*, which run radially across the trunk. The rays connect various layers from the pith to the bark for storage and transfer of food. Rays are present in all trees but are more pronounced in some species such as oak. In countries with a temperate climate, a tree produces a new layer of wood just under the cambium in the early part of every growing season. This growth ceases at the end of the growing season or during winter months. This process results in clearly visible concentric rings known as *annular* *rings*, *annual rings* or *growth rings*. In tropical countries, where trees grow throughout the year, a tree produces wood cells that are essentially uniform. The age of a tree may be determined by counting its growth rings [1, 2].

The annular band of the cross-section nearest to the bark is called *sapwood*. The central core of the wood, which is inside the sapwood, is *heartwood*. The sapwood is lighter in colour compared to heartwood and is 25–170 mm wide depending on the species. It contains both living and dead cells and acts as a medium for transportation of sap from the roots to the leaves, whereas the heartwood, which consists of inactive cells, functions mainly to give mechanical support or stiffness to the trunk. As sapwood changes to heartwood, the size, shape and the number of cells remain unchanged. In general, in hardwoods the difference in moisture content of sapwood and heartwood depends on the species but in softwoods the moisture content of sapwood is usually greater than that of heartwood. The strength and weights of the two are nearly equal. Sapwood has a lower natural resistance to attacks by fungi and insects and accepts preservatives more easily than heartwood.

In many trees and particularly in temperate climates, where a definite growing season exists, each annular ring is visibly subdivided into two layers: an inner layer made up of relatively large hollow cells called *springwood* or *earlywood* (due to the fast growth), and an outer layer of thick walls and small cavities called *summerwood* or *latewood* (due to a slower growth). Since summerwood is relatively heavy, the amount of summerwood in any section is a measure of the density of the wood; see Figure 1.1.

1.3 TYPES OF TIMBER

Trees and commercial timbers are divided into two types: *softwoods* and *hardwoods*. This terminology refers to the botanical origin of timber and has no direct bearing on the actual softness or hardness of the wood as it is possible to have some physically softer hardwoods like balsa from South America and wawa from Africa, and some physically hard softwoods like the pitchpines.

1.3.1 Softwoods

Softwoods, characterised by having naked seeds or as cone-bearing trees, are generally evergreen with needle-like leaves (such as conifers) comprising single cells called *tracheids*, which are like straws in plan, and they fulfil the functions of conduction and support. Rays, present in softwoods, run in a radial direction perpendicular to the growth rings. Their function is to store food and allow the convection of liquids to where they are needed. Examples of the UK grown softwoods include spruce (whitewood), larch, Scots pine (redwood) and Douglas fir.

1.3.1.1 Softwood characteristics

- Quick growth rate (trees can be felled after 30 years) resulting in low-density timber with relatively low strength.
- Generally poor durability qualities, unless treated with preservatives.
- Due to the speed of felling they are readily available and comparatively cheaper.

1.3.2 Hardwoods

Hardwoods are generally broad-leaved (deciduous) trees, which often lose their leaves at the end of each growing season. The cell structure of hardwoods is more complex than that of softwoods with thick-walled cells, called fibres, providing the structural support and thin-walled cells, called *vessels*, providing the medium for food conduction. Due to the necessity of growing new leaves every year the demand for sap is high and in some instances larger vessels may be formed in the springwood, these are referred to as ‘ring-porous’ woods such as oak and ash. When there is no definite growing period the pores tend to be more evenly distributed, resulting in ‘diffuse-porous’ woods such as poplar and beech. Examples of the UK grown hardwoods include oak, beech, ash, alder, birch, maple, poplar and willow.

1.3.2.1 Hardwood characteristics

- Hardwoods grow at a slower rate than softwoods, which generally results in a timber of high density and strength, which takes time to mature, over 100 years in some instances.
- There is less dependence on preservatives for durability qualities.
- Due to the time taken to mature and the transportation costs of hardwoods, as most are tropical, they tend to be expensive in comparison with softwoods.

British Standard BS 7359:1991 [3] provides a list of some 500 timbers of economic interest in the United Kingdom and tabulates softwoods and hardwoods including their standard names, botanical names/species type and also, where relevant, their alternative commercial names with sources of supply and average densities.

1.4 NATURAL CHARACTERISTICS OF TIMBER

Wood as a natural material is highly varied in its structure and has many natural characteristics or defects which are introduced during the growing period and during the conversion and seasoning process. Often such characteristics or defects can cause problems in timber in use either by reducing its strength or impairing its appearance.

1.4.1 Knots

These are common features of the structure of wood. A knot is a portion of a branch enclosed by the natural growth of the tree, normally originating at the centre of the trunk or a branch. The influence of knots depends on their size, shape, frequency and location in the structural member. The presence of knots has adverse effects on most mechanical properties of timber as they distort the fibres around them, causing fibre discontinuity and stress concentrations or non-uniform stress distributions. Their effects are further magnified in members subjected to tensile stress either due to direct or bending stresses. For example, the presence of a knot on the lower side of a flexural member, being subjected to tensile stresses due to bending, has a greater effect on the load capacity of the member than a similar knot on the upper side being subjected to compressive stresses.

Table 1.1 Effect of grain deviation on strength properties of timber

Slope of grain	Bending strength (%)	Compression parallel to grain (%)	Impact loading (%)
Straight grain	100	100	100
1 in 20 (3°)	93	100	95
1 in 10 (6°)	81	99	62
1 in 5 (11.5°)	55	93	36

The presence of knots in round timber has much less effect on its strength properties than those in a sawn timber. When a log is sawn, the knots and fibres surrounding it will no longer be continuous – thus adversely affecting the strength properties; whereas in the round timber there are no discontinuities in the wood fibres and often the angle of grain to the longitudinal axis is smaller than that in the sawn timber.

In general, the size, shape, frequency and location of knots influence the quality and hence the grade of softwood timbers for structural use, with better grades having fewer and smaller knots.

1.4.2 Slope of grain

Wood grain refers to the general direction of the arrangement of fibres in wood and is expressed with respect to the longitudinal axis of the sawn timber or the round timber (log or pole). In general, the direction of the fibres does not lie truly parallel to the longitudinal axis of the sawn or round timbers. In softwoods, the deviation with respect to the log (longitudinal) axis is often constant, resulting in the production of *spiral* grain. *Interlocked* grains are often produced in tropical hardwoods where the grain direction changes routinely from one direction to another.

A *cross* grain occurs when the grain direction is at an angle to the longitudinal axis of the sawn section. A cross grain occurs during conversion (sawing process) as a result of conversion of a bent or heavily tapered log or a log with spiral or interlocked grain.

Grain deviation can severely impair the strength properties of timber. Visual grading rules limit the grain deviation; in general, a grain deviation of 1 in 10 is accepted for high-grade timber whereas 1 in 5 often relates to a low-grade one. The effect of grain deviation on some properties of timber is shown in Table 1.1.

1.4.3 Reaction wood

Reaction wood refers to abnormal wood tissues produced in tree trunks subjected to strong wind pressures. Horizontal branches and leaning branches are believed to form reaction wood in an attempt to prevent them from excessive bending and cracking under their own weight. There are two types of reaction wood: in softwoods it is referred to as *compression wood* and in hardwoods as *tension wood*. Compression wood, Figure 1.2, forms on the underside of branches of leaning softwoods and contains more lignin than normal wood. Tension wood forms on the upper sides of leaning hardwoods and contains more cellulose than normal wood.

Fig. 1.2. Compression wood (dark patch).

Reaction wood is much denser than normal wood with the specific gravity of around 35% greater in compression wood and 7% greater in tension wood. Longitudinal shrinkage is also greater, 10 times more than normal for compression wood and 5 times for tension wood. Timber containing compression wood is liable to excessive distortion during drying and tends to fail in a brittle manner. It is harder to drive a nail in compression wood, there is a greater chance of it splitting, and compression wood may take a strain differently than normal wood. Most visual strength grading rules limit the amount of compression wood in high quality grades.

1.4.4 Juvenile wood

This is a wood that is produced early in the first 5–20 rings of any trunk cross-section (Figure 1.1) and, in general, exhibits lower strength and stiffness than the outer parts of the trunk and much greater longitudinal shrinkage than mature, normal wood. Juvenile wood is mainly contained within the heartwood. In this regard, in young, fast grown trees with a high proportion of juvenile wood, heartwood may be inferior to sapwood, but is not normally considered a problem.

1.4.5 Density and annual ring widths

Density is an important physical characteristic of timber affecting its strength properties. *Annual ring width* is also critical in respect of strength in that excessive width of such rings can reduce the density of the timber. Density can be a good indicator of the mechanical properties provided that the timber section is straight grained, free from knots and defects. The value of density as an indicator of mechanical properties can also be reduced by the presence of gums, resins and extractives, which may adversely affect the mechanical properties. In this regard, the prediction of strength on the basis of density alone is not always satisfactory. Research studies show a coefficient of determination, R^2, ranging between 0.16 and 0.4 for density and 0.2 and 0.44 for the annual ring width [4].

Specific gravity or relative density is a measure of timber's solid substance. It is generally expressed as the ratio of the oven-dry weight of the timber to the weight of an equal volume of water. Because water volume varies with the moisture content of the timber, the specific gravity of timber is normally expressed at a certain moisture content. Basic oven-dry specific gravity of commercial timber ranges from 0.29 to 0.81, most falling between 0.35 and 0.60.

1.4.6 Conversion of timber

Once the tree is felled in the forest, the crown is removed and often it is also debarked in the forest. Logs are then classed and stockpiled under water sprays to prevent them from drying out. Some of the better quality ones are sent to peeling plants for the manufacture of veneers but the majority (depending on the quality) are sent to sawmillers to convert round logs to sawn timber. There are many cutting patterns used to produce timber, but the first step in most sawmill operations is to scan the log for the best alignment and cutting pattern for optimum return; then remove one or two wings (slabs) from the logs to give some flat surfaces to work from. The log, referred to as a *cant*, is turned on a flat face and sawn through and through to give boards (sections) of the required thickness.

Each sawmill establishes its own cutting patterns for different sized logs; maximising the number of pieces cut in the most popular sizes. *Through conversion* produces mostly tangentially sawn timber and some quarter sawn sections. Tangential timber is economical to produce because of the relatively fewer repetitive production methods. Boxing the heart (Figure 1.3) eliminates the heartwood from the boards that would otherwise produce shakes, juvenile wood or may even be rotten.

The *quarter sawn* techniques are more expensive processes, with more wastage, because of the need to double (or more) handle the log. They are, however, more decorative and less prone to cupping or distortion.

There are several alternative variations of tangential and radial cuts to obtain the best or most economical boards for the end use. Examples of methods of log breakdown and different cutting patterns are shown in Figure 1.3.

In growing trees, all cell walls including their voids, in both heartwood and sapwood, are saturated with water (moisture content in excess of 100%). When a tree is cut and its moisture content falls to around 27%, the only moisture left is the bound water, which is the moisture that is part of the cell wall. This state is referred to as *fibre saturation point*. Wood, in general, is dimensionally stable when its moisture content is greater than the fibre saturation point. The process of drying (seasoning) timber should ideally remove over a third of the moisture from the cell walls. Timber at this stage is referred to as *seasoned* with a moisture content of between 12 and 25% (depending on the method and duration of drying, i.e. air, kiln, solar, microwave, etc.). Wood changes dimensionally with change in moisture below its fibre saturation point: it shrinks when it loses moisture and swells as it gains moisture. These dimensional changes are mostly in the direction of the annual

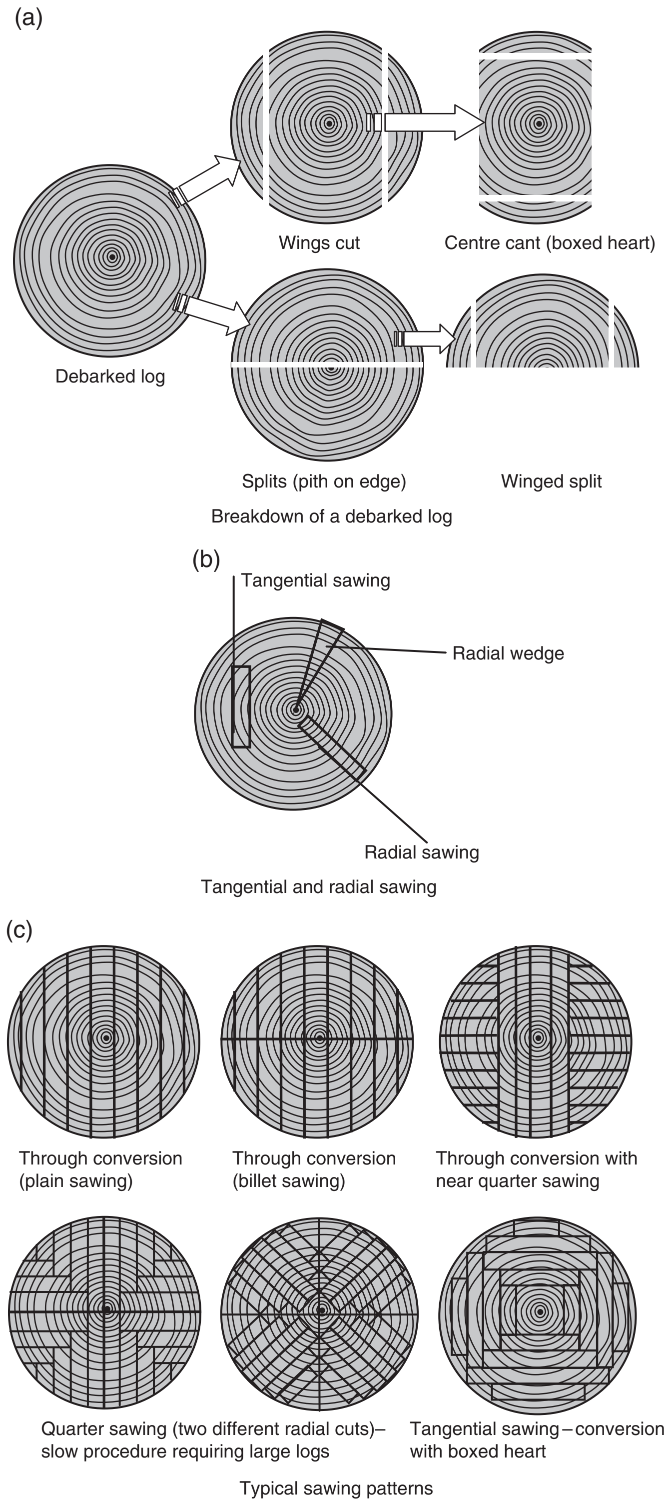


Fig. 1.3. Examples of log breakdown and cutting pattern.

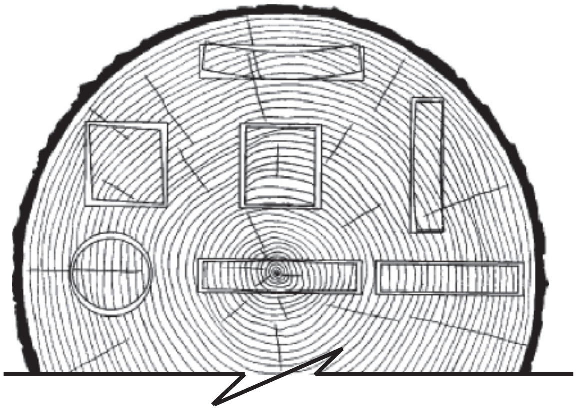


Fig. 1.4. Distortion of various cross-sections [5].

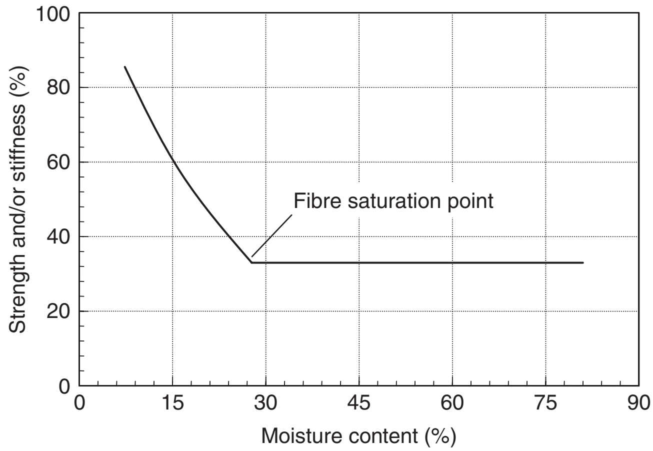


Fig. 1.5. General relationship between strength and/or stiffness and moisture content.

growth rings (tangentially), with about half as much across the rings (radially) and as such mainly affect cross-sectional dimensions (perpendicular to the grain) and can result in warping, checking or splitting of wood. Longitudinal shrinkage of wood (shrinkage parallel to the grain) for most species is generally very small. The combined effects of radial and tangential shrinkage (differential shrinkage) can distort the sawn timber. The major types of distortion as a result of these effects after drying for various cross-sections cut from different locations in a log are shown in Figure 1.4.

The change in moisture content of timber also affects its strength, stiffness and resistance to decay. Most timber in the United Kingdom is air-dried to a moisture content of between 17 and 23% (which is generally below the fibre saturation point) at which the cell walls are still saturated but moisture is removed from the cell cavities. Figure 1.5 highlights a general relationship between strength and/or stiffness characteristics of timber and its moisture content. The figure shows that there is an almost linear loss in strength and stiffness as moisture content increases to about

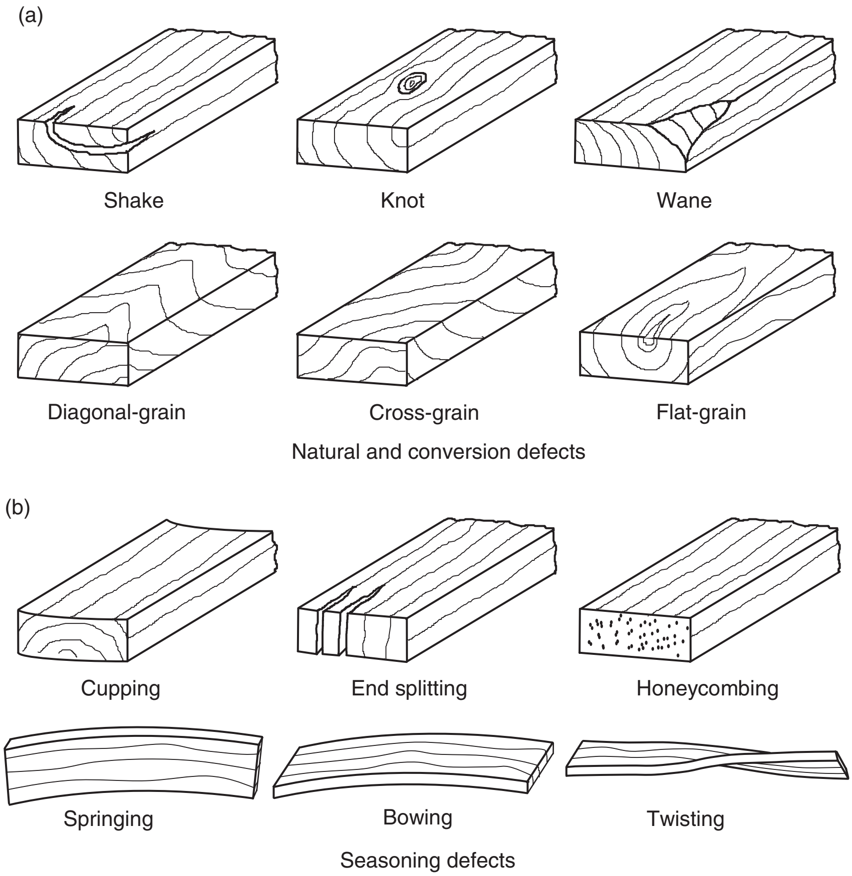


Fig. 1.6. Defects in timber.

27%, corresponding to the fibre saturation point. Further increase in moisture content has no influence on either strength or stiffness. It should be noted that although for most mechanical properties the pattern of change in strength and stiffness characteristics with respect to change in moisture content is similar, the magnitude of change is different from one property to another. It is also to be noted that as the moisture content decreases shrinkage increases. Timber is described as being hygroscopic, which means that it attempts to attain an equilibrium moisture content with its surrounding environment, resulting in a variable moisture content. This should always be considered when using timber, particularly softwoods, which are more susceptible to shrinkage than hardwoods.

As logs vary in cross-section along their length, usually tapering to one end, a board that is rectangular at one end of its length might not be so at the other end. The rectangular cross-section may intersect with the outside of the log, the *wane* of the log, and consequently have a rounded edge. The effect of a wane is a reduction in the cross-sectional area resulting in reduced strength properties. A wane is an example of a conversion defect and this, as well as other examples of conversion or natural defects, is shown in Figure 1.6a.

1.4.7 Seasoning

Seasoning is the controlled process of reducing the moisture content of the timber so that it is suitable for the environment and intended use. There are two main methods of seasoning timber in the United Kingdom, air-drying and kiln-drying; other less common methods include solar and microwave techniques. All methods require the timber to be stacked uniformly, separated by spacers of around 25 mm to allow the full circulation of air etc. around the stack. Often, ends of boards are sealed by a suitable sealer or cover to prevent rapid drying out through the end grains. However, with air-drying it is not possible to obtain less than 16–17% moisture content in the United Kingdom. Further seasoning would need to be carried out inside a heated and ventilated building.

The kiln-drying method relies on a controlled environment that uses forced air circulation through large fans or blowers, heating of some form provided by piped steam together with a humidity control system to dry the timber. The amount and duration of air, heat and humidity depend on species, size, quantity, etc.

1.4.8 Seasoning defects

Seasoning defects are directly related to the movements which occur in timber due to changes in moisture content. Excessive or uneven drying, as well as the presence of compression wood, juvenile wood or even knots, exposure to wind and rain, and poor stacking and spacing during seasoning can all produce defects or distortions in timber. Examples of seasoning defects such as cupping (in tangential cuts), end splitting, springing, bowing, twisting, etc. are illustrated in Figure 1.6. All such defects have an effect on structural strength as well as on fixing, stability, durability and finished appearance.

1.4.9 Cracks and fissures

These are caused by separation of the fibres along the grain forming fissures and cracks that appear on one face or at the end grain but do not necessarily continue through to the other side. Their presence may indicate decay or the beginnings of decay.

1.4.10 Fungal decay

This may occur in growing mature timber or even in recently converted timber, and in general it is good practice to reject such timber.

1.5 STRENGTH GRADING OF TIMBER

The strength capability of timber is difficult to assess as often there is no control over its quality and growth. The strength of timber is a function of several parameters including the species type, density, size and form of members, moisture content, duration of the applied load and presence of various strength reducing characteristics such as slope of grain, knots, fissures and wane. To overcome this difficulty, the strength grading method of strength classification has been devised. Several design properties are associated with a strength grade; these include modulus of elasticity and bending strength parallel to the grain, strength properties in tension and compression parallel and perpendicular to the grain, shear strength parallel to the grain and density. The design properties of timber are determined non-destructively through *visual strength grading* criteria or by *machine strength grading* via measurements such as the following: flatwise bending stiffness, using a three-point or four-point loading system; density, using x-rays or gamma rays techniques; and modulus of elasticity, by means of resonant vibrations (dynamic response) using one or a combination of these methods.

The requirements for strength grading of timber are detailed in the following standards:

- BS EN 14081-1:2005+A1:2011 [6]
- BS EN 14081-2:2010 [7].

Most European Union countries have their own long-established visual grading rules and as such guidance for visual strength grading of softwoods and hardwoods is provided in the following British Standards:

- BS 4978:2007+A1:2011 [8]
- BS 5756:2007 [9].

1.5.1 Visual grading

Visual grading is a manual process carried out by an approved grader. The grader examines each piece of timber to check the size and frequency of specific physical characteristics or defects, e.g. knots, slope of grains, rate of growth, wane, resin pockets and distortion.

The required specifications are given in BS 4978 and BS 5756 to determine if a piece of timber is accepted into one of the two visual stress grades or rejected. These are general structural (GS) and special structural (SS) grades. *Table 2* of BS 5268-2:2002 [10] (reproduced here as Table 1.2) refers to main softwood combinations of species (available in the United Kingdom) visually graded in accordance with BS 4978.

1.5.2 Machine grading

Machine grading of timber sections is carried out on the principle that stiffness is related to strength; where the relationship between the modulus of elasticity, E, and the modulus of rupture of a species of timber from a certain geographical location is determined from a statistical population, based on a substantial number of laboratory controlled tests. There are a number of ways of determining the modulus of elasticity, including resonant vibration (dynamic response), but the most common methods are either load- or deflection-controlled bending tests. The machine exerts pressure and bending is induced at increments along the timber length. The resulting deflection (or the load to induce a known deflection) is then automatically measured and compared

Table 1.2 Softwood combinations of species and visual grades that satisfy the requirements for various strength classes*

Timber species	Grade and related strength classes
British grown timber	
Douglas fir	GS (C14), SS (C18)
Larch	GS (C16), SS (C24)
British pine	GS (C14), SS (C22)
British spruce	GS (C14), SS (C18)
Imported timber	
Parana pine	GS (C16), SS (C24)
Caribbean pitch pine	GS (C18), SS (C27)
Redwood	GS (C16), SS (C24)
Whitewood	GS (C16), SS (C24)
Western red cedar	GS (C14), SS (C18)
Douglas fir-larch (Canada and USA)	GS (C16), SS (C24)
Hem-fir (Canada and USA)	GS (C16), SS (C24)
Spruce-pine-fir (Canada and USA)	GS (C16), SS (C24)
Sitka spruce (Canada)	GS (C14), SS (C18)
Western white woods (USA)	GS (C14), SS (C18)
Southern pine (USA)	GS (C18), SS (C24)

*Timber graded in accordance with BS 4978:1996; based on Table 1.2, BS 5268-2:2002.

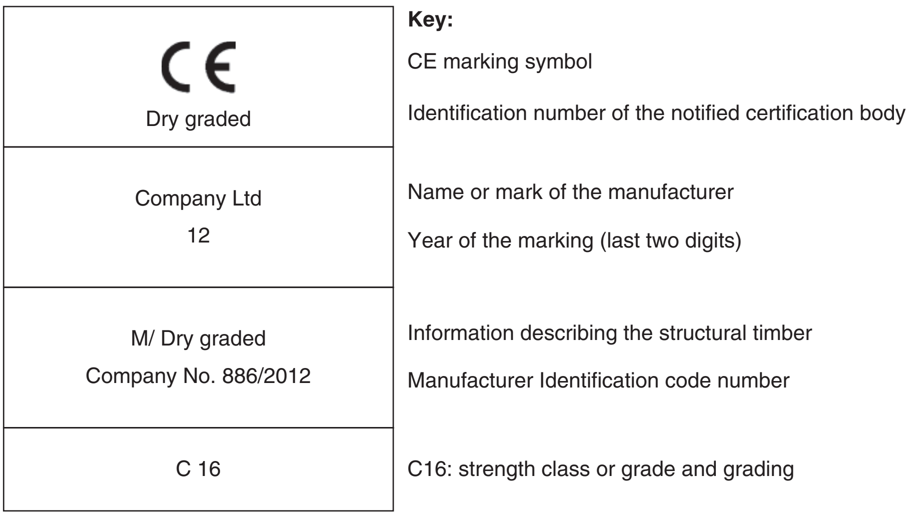


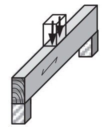
Fig. 1.7. Example of simplified grading marking.

with pre-programmed criteria, which leads to the direct grading of the timber section and marking with the appropriate strength class. An example of the grading marking, based on the requirements of BS EN 14081-1:2005+A1:2011, is shown in Figure 1.7.

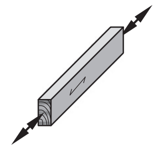
In general less material is rejected if machine graded; however, timber is also visually inspected during machine grading to ensure that major, strength-reducing, defects do not exist.

Table 1.3 Strength and stiffness properties and density values for structural timber strength classes, (in accordance with **Table 1**, of BS EN 338: 2009)

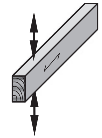
	Strength class	Characteristic strength properties (N/mm²)						Stiffness properties (kN/mm²)				Density (kg/m³)	
		Bending ($f_{m,k}$)	Tension 0 ($f_{t,0,k}$)	Tension 90 ($f_{t,90,k}$)	Compression 0 ($f_{c,0,k}$)	Compression 90 ($f_{c,90,k}$)	Shear ($f_{v,k}$)	Mean modulus of elasticity 0 ($E_{0,mean}$)	5% modulus of elasticity 0 ($E_{0.05}$)	Mean modulus of elasticity 90 ($E_{90,mean}$)	Mean shear modulus (G_{mean})	Density (ρ_k)	Mean density (ρ_{mean})
Softwood and poplar species	C14	14	8	0.4	16	2.0	3.0	7.0	4.7	0.23	0.44	290	350
	C16	16	10	0.4	17	2.2	3.2	8.0	5.4	0.27	0.50	310	370
	C18	18	11	0.4	18	2.2	3.4	9.0	6.0	0.30	0.56	320	380
	C20	20	12	0.4	19	2.3	3.6	9.5	6.4	0.32	0.59	330	390
	C22	22	13	0.4	20	2.4	3.8	10.0	6.7	0.33	0.63	340	410
	C24	24	14	0.4	21	2.5	4.0	11.0	7.4	0.37	0.69	350	420
	C27	27	16	0.4	22	2.6	4.0	11.5	7.7	0.38	0.72	370	450
	C30	30	18	0.4	23	2.7	4.0	12.0	8.0	0.40	0.75	380	460
	C35	35	21	0.4	25	2.8	4.0	13.0	8.7	0.43	0.81	400	480
	C40	40	24	0.4	26	2.9	4.0	14.0	9.4	0.47	0.88	420	500
	C45	45	27	0.4	27	3.1	4.0	15.0	10.0	0.50	0.94	440	520
	C50	50	30	0.4	29	3.2	4.0	16.0	10.7	0.53	1.00	460	550
Hardwood species	D18	18	11	0.6	18	7.5	3.4	9.5	8.0	0.63	0.59	475	570
	D24	24	14	0.6	21	7.8	4.0	10.0	8.5	0.67	0.62	485	580
	D30	30	18	0.6	23	8.0	4.0	11.0	9.2	0.73	0.69	530	640
	D35	35	21	0.6	25	8.1	4.0	12.0	10.1	0.80	0.75	540	650
	D40	40	24	0.6	26	8.3	4.0	13.0	10.9	0.86	0.81	550	660
	D50	50	30	0.6	29	9.3	4.0	14.0	11.8	0.93	0.88	620	750
	D60	60	36	0.6	32	10.5	4.5	17.0	14.3	1.13	1.06	700	840
	D70	70	42	0.6	34	13.5	5.0	20.0	16.8	1.33	1.25	900	1080



Bending parallel to grain: f_m and E_0
Shear: f_v and G



Tension or compression parallel to grain: $f_{t,0}$, $f_{c,0}$ and E_0



Tension or compression perpendicular to grain: $f_{t,90}$, $f_{c,90}$ and E_{90}

Subscripts used are: 0, direction parallel to grain; 90, direction perpendicular to grain; m, bending; t, tension; c, compression; v, shear; k, characteristic.

1.5.3 Strength classes

The concept of grouping timber into strength classes was introduced into the United Kingdom with BS 5268-2 in 1984. Strength classes offer a number of advantages both to the designer and the supplier of timber. The designer can undertake the design without the need to check on the availability and price of a large number of species and grades that might be used. Suppliers can supply any of the species/grade combinations that meet the strength class called for in a specification. The concept also allows new species to be introduced to the market without affecting existing specifications for timber.

BS EN 338:2009 [11] defines a total of 20 strength classes: 12 for softwoods – C14, C16, C18, C20, C22, C24, C27, C30, C35, C40, C45 and C50; and 8 for hardwoods – D18, D24, D30, D35, D40, D50, D60 and D70. The letters C and D refer to coniferous species (C classes) or deciduous species (D classes), and the number in each strength class refers to its 'characteristic bending strength' in N/mm^2 units; for example, C40 timber has a characteristic bending strength of 40 N/mm^2. It ranges from the weakest grade of softwood, C14, to the highest grade of hardwood, D70, often used in Europe.

1.5.3.1 Material properties

Section 3 of BS EN 1995-1-1:2004+A1:2008 (referred to in the text as EC5) [12] deals with the material properties and defines the strength and stiffness parameters, stress–strain relations and gives values for modification factors for strength and deformation under various service classes and/or load duration classes. EC5, in common with other Eurocodes, does not contain the material property values and this information is given in a supporting standard, i.e. in *Table 1* of BS EN 338:2009, reproduced here as Table 1.3.

The characteristic values are defined as the population 5th-percentile values obtained from the results of tests with a duration of approximately 5 min at the equilibrium moisture content of the test pieces relating to a temperature of 20 °C and a relative humidity of 65%.

In addition to providing characteristic strength and stiffness properties and density values for each strength class (and the rules for allocation of timber populations, i.e. combinations of species, source and grade, to the classes), BS EN 338:2009 lists the equations that form the relations between some of the characteristic values given in Table 1.3 for properties other than bending strength, mean modulus of elasticity in bending and density.

The relationships between the characteristic strength and stiffness properties are given as follows:

- Tensile strength parallel (0) to grain, $f_{t,0,k} = 0.6\, f_{m,k}$
- Compression strength parallel (0) to grain, $f_{c,0,k} = 5(f_{m,k})^{0.45}$
- Shear strength, $f_{v,k}$ shall be taken from Table 1.3 (Table 1, BS EN 338:2009)
- Tensile strength perpendicular (90) to grain

  $f_{t,90,k} = 0.4\ N/mm^2$ for softwoods

  $f_{t,90,k} = 0.6\ N/mm^2$ for hardwoods
- Compression strength perpendicular (90) to grain,

  $f_{c,90,k} = 0.007\rho_k$ for softwoods

  $f_{c,90,k} = 0.015\rho_k$ for hardwoods

- Modulus of elasticity parallel (0) to grain,
  $E_{0.05} = 0.67\ E_{0,\ mean}$ for softwoods
  $E_{0.05} = 0.84\ E_{0,\ mean}$ for hardwoods
- Mean modulus of elasticity perpendicular (90) to grain,
  $E_{90,\ mean} = E_{0,\ mean}/30$ for softwoods
  $E_{90,\ mean} = E_{0,\ mean}/15$ for hardwoods
- Mean shear modulus, $G_{mean} = E_{0,\ mean}/16$
- Mean density, $\rho_{mean} = 1.2\ \rho_k$.

1.6 SECTION SIZES

In general, it is possible to design timber structures using any size of timber. However, since the specific use is normally not known at the time of conversion, sawmills tend to produce a range of standard sizes known as 'common target' sizes. Specifying such common target sizes will often result in greater availability and savings in cost.

There are a number of alternative sizes and finishes of cross-sections. BS EN 1313:2010 [13] specifies permitted deviations for thickness and width at reference moisture content of 20% and adjustments for changes in section sizes due to change in moisture content. The deviation in *sawn* sections at a moisture content of 20% are as follows: for thicknesses and widths up to 100 mm, –1 mm and +3 mm, and for over 100 mm sizes, –2 mm and +4 mm. Sawn sections should only be used in situations where dimensional tolerances are of no significance. Planing two parallel edges to a specified dimension is referred to as *regularising* and if all four edges are planed to specified sizes, the process is referred to as *planed all round*. The requirements of EC5 for timber target sizes (i.e. specified sizes) are those given in BS EN 336:2003 [14] and in its National Annex. This standard specifies two tolerance classes: tolerance class 1 (T1) is applicable to sawn surfaces, and tolerance class 2 (T2) applicable to planed timber. Regularised timber can be achieved by specifying T1 for the thickness and T2 for the width. For T1, dimensions of up to 100 mm are limited to –1/+3 mm and dimensions of over 100 mm to –2/+4 mm. For T2, dimensions of up to 100 mm are limited to –1/+1 mm and those over 100 mm to –1.5/+1.5 mm.

The commonly available lengths and cross-section sizes are also listed in the UK National Annex of BS EN 336, and are referred to as target sizes. The 'target size' is defined as the specified timber section size at a reference moisture content of 20%, and to which the deviations, which would ideally be zero, are to be related. The target sizes can be used, without further modification, in design calculations.

The common target sizes, whose sizes and tolerances comply with BS EN 336, for sawn softwood structural timber, for structural timber machined on the width and for structural timber machined on all four sides are given in Table 1.4. In Table 1.5 the range of lengths of sawn softwood structural timber are detailed.

1.7 ENGINEERED WOOD PRODUCTS (EWPs)

The readily available sawn sections of softwood are limited in size and quality. The largest section sizes available are 75 mm thick × 225 mm wide and at most 5 m in length. Any larger section sizes would suffer from both conversion and seasoning

Table 1.4 Common target sizes of structural timber (softwoods)*

Sawn thickness (to tolerance class 1) (mm)	Machined thickness (to tolerance class 2) (mm)	Sawn width (to tolerance class 1) (mm)									
		75	100	125	150	175	200	225	250	275	300
		Machined width (to tolerance class 2) (mm)									
		72	97	120	145	170	195	220	245	270	295
22			√								
38	35		√		√	√	√	√			
47	44	√	√	√	√	√	√	√	√		×
63	60				√	√	√	√			
75	72		√		√	√	√	√	√	√	√
100	97		√		√		√	√	√		√
150	145				√						√
300											×

Certain sizes may not be obtainable in the customary range of species and grades that are generally available.
BS EN 336 has a lower limit of 35 mm for machined thicknesses.
× applies only to sections with sawn width or thickness.
* In accordance with Tables NA.2, NA.3 and NA.4 of BS EN 336:2003; for (i) sawn to tolerance class 1, (ii) machined on the width to tolerance class 2, (iii) machined on all four sides to tolerance class 2.

Table 1.5 Commonly available lengths of structural softwood timber*

Length (m)
2.40
3.00, 3.30, 3.60 or 3.90
4.20, 4.50 or 4.80
5.10 or 5.40

Lengths of 5.40 m and over may not be readily available without finger jointing.
* In accordance with Table NA.1, BS EN 336:2003.

defects. EWPs are developed to overcome the limitations of sawn timber and are produced, in combination with adhesives, in a variety of forms:

- dried thin planks of wood are glued together to form glued-laminated timber or glulam; or
- dried thin planks of wood are bonded together in different layouts, consisting of several layers of timber planks stacked crosswise and glued together either on wide faces only, or on both wide and narrow faces to form multi-layered cross-laminated timber (CLT) panels;
- veneered, by peeling logs, and bonded together in different layouts to produce plywood or laminated veneer lumber (LVL);
- chipped, to different sizes, to produce fibreboards, chipboards or oriented strand board (OSB); and
- sliced in different forms to produce parallel strand lumber (PSL) known as Parallam® or laminated strand lumber (LSL) known as TimberStrand®.

These products are engineered and tested to predetermined design specifications to meet national or international standards.

EWPs may also include products that are made by bonding or mechanically fixing together two or more of the above products to form structurally efficient composite members or systems such as I-beams and box beams or in combination with other materials to make a range of value-added systems such as structural insulated panels (SIPs).

EWPs may be selected over solid sawn timber in many applications due to certain comparative advantages:

- They can be manufactured to meet application-specific performance requirements.
- Large sections or panels in long lengths can be manufactured from small logs with defects being removed or dispersed.
- They are often stronger and less prone to humidity-induced warping than equivalent solid timbers, although most particle- and fibre-based boards readily soak up water unless they are treated with sealant or painted.

EWPs are more expensive to produce than solid timber, but offer advantages, including economic ones, when manufactured in large sizes due to the rarity of trees suitable for cutting large sections.

1.7.1 Glued-laminated timber (glulam)

Glued-laminated timber, glulam, is fabricated from small sections of timber boards (called laminates) bonded together with adhesives and laid up so that the grain of all laminates is essentially parallel to the longitudinal axis. Individual laminates are typically 19–50 mm in thickness, 1.5–5 m in length, end-jointed by the process of finger jointing as shown in Figure 1.8a and then placed randomly throughout the glulam component. Normally, the laminates are dried to around 12–18% moisture content before being machined and assembled. Edge-gluing permits beams wider and larger sections than those commercially available to be manufactured after finger jointing. Assembly is commonly carried out by applying a carefully controlled adhesive mix to the faces of the laminates. They are then placed in mechanical or hydraulic jigs of the appropriate shape and size, and pressurised at right angles to the glue lines and held until curing of the adhesive is complete. Glulam is then cut, shaped and any specified preservative and finishing treatments are applied.

Timber sections with a thickness of around 33 mm to a maximum of 50 mm are used to laminate *straight* or *slightly curved* members, whereas much thinner sections (12 or 19 mm, up to about 33 mm) are used to laminate *curved* members. Glued-laminated members can also be constructed with variable sections to produce tapering beams, columns, arches and portals (Figure 1.8).

The laminated lay-up of glulam makes it possible to match the lamination quality to the level of design stresses. Beams can be manufactured with the higher grade laminates at the outer highly stressed regions and the lower grade of laminates in the inner parts. Such combined concepts permit the timber resource to be used more efficiently.

Design of glued-laminated timber members is covered in Chapter 6 where the strength, stiffness and density properties of homogeneous (single grade) and combined (having outer laminations of higher grade) glued-laminated members are detailed.

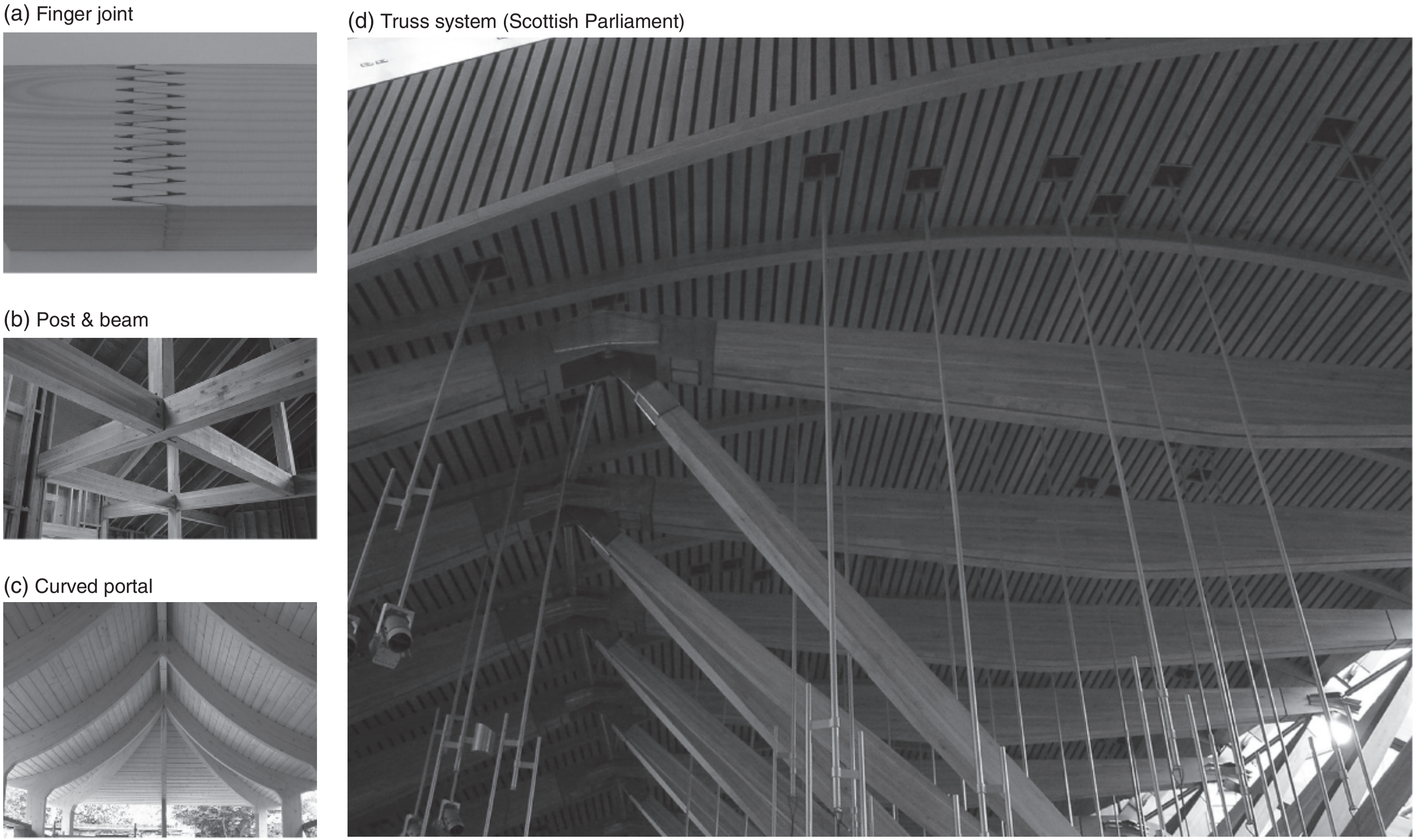


Fig. 1.8. Glued-laminated structures. (Part (b) photo courtesy of APA, The Engineered Wood Association. (c) photo courtesy of Axis Timber Limited, a member of the Glued Laminated Timber Association, UK.)

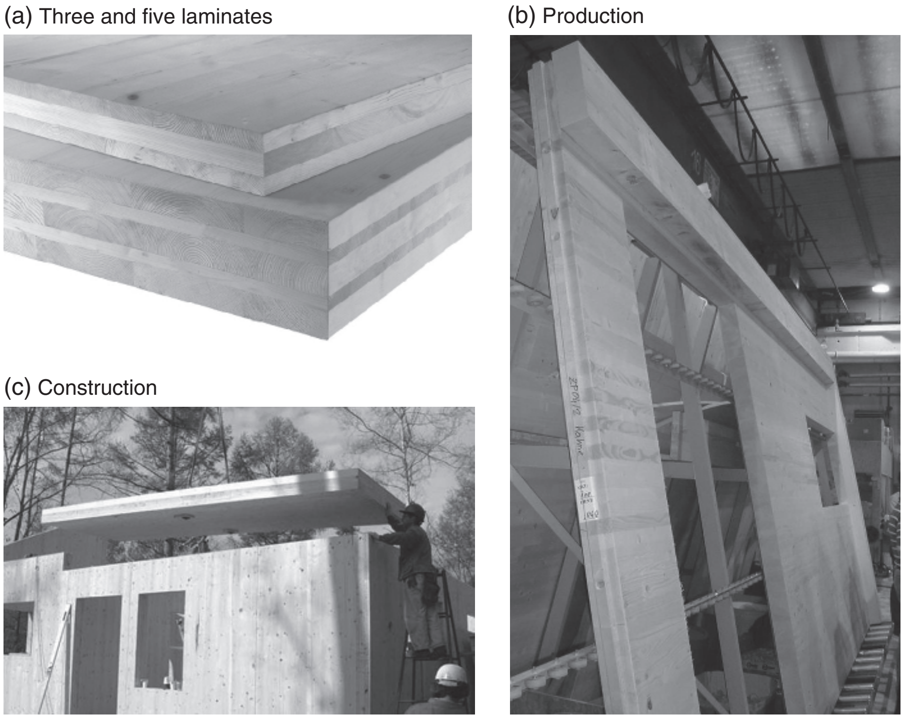


Fig. 1.9. Cross-laminated timber.

1.7.2 Cross-laminated timber (CLT or X-Lam)

Cross-laminated timber, known as CLT or X-Lam, is a prefabricated solid timber panel, formed with a minimum of three orthogonally bonded layers of solid timber boards (laminates). For improved performance, long continuous lengths of timber boards can be produced by the finger jointing process. Cross-laminated timber panels can have three, five, seven or more layers in odd numbers, symmetrically formed around the middle layer (Figure 1.9). The layers are stacked perpendicular to one another and are glued together either on their wide faces only or on both wide and narrow faces and then pressed together over their entire surface area mechanically, or by means of a vacuum bag.

The European standard prEN 16351:2011 [15] deals with the performance requirements and minimum requirements for the production of the cross-laminated timber products for use in buildings and bridges. CLT laminations comprise timber boards that are strength graded according to EN 14081-1 or wood-based panels such as LVL. The common panel thicknesses range between 50 to 300 mm, but panels as thick as 500 mm are also produced. Various panel sizes from 0.6 m wide up to 3 m wide by 16 m long, 4.8 m wide by 20 m long, or even 1.2 m wide by 24 m long are possible and are produced by a number of manufacturers. However, often the ability to transport, shipping or crane lifting of the panels, is the limiting factor governing their size. In the UK, CLT is currently imported from mainland Europe (e.g. Austria, Germany and Switzerland) and Scandinavia, see Table 1.6. But the situation is likely

Table 1.6 Examples of European suppliers or producers of cross-laminated timber (CLT)

Supplier/Producer	Width (mm)	Length (mm)	Thickness (mm)	Species used	Country of origin	Product
Eurban	3400	13 500	60–500	Spruce, Larch, Douglas fir	Austria	Crosslam panels
Binderholz	1250	24 000	66–34	Spruce, Larch, Pine, Douglas fir	Austria	BBS
Metsa Wood (Finnforest Merk)	4800	14 800	51–300	Spruce	Germany	Leno
KLH	2950	16 500	57–500	Spruce, Pine, Fir	Austria	KLH solid timber panels
Stora Enso	2950	2950	57–296	Spruce, Larch, Pine	Austria	CLT
Kaufmann	3000	16500	78–278	Spruce	Austria	BSP Crossplan

to change as the UK market for CLT develops; it is likely that a number of factories will be established using UK grown timber.

The CLT panels have improved dimensional stability compared to that of solid timber and provide relatively high strength and stiffness properties in both longitudinal and transverse directions, i.e. enabling two-way spanning capability. As panels can be manufactured with their outer layers orientated in either direction relative to the production length, to minimise waste and offcuts the design and manufacturing should be coordinated such that for walls the outer layers of CLT panels are oriented in the vertical direction and for floors and roofs in the direction of their major span.

CLT based structures also provide a number of other benefits, including: enhanced connector strength and splitting resistance, increased dead weight and robustness, high axial load capacity for walls due to large bearing areas, as well as offering high thermal, acoustic and fire performance and having a very low carbon footprint.

For structural design the characteristic strength and stiffness values of CLT products with CE certification (marking) should be obtained from the manufacturers or suppliers. Often such information is available from manufacturers' websites. CLT elements and systems can be designed using the rules in EC5 and they are also available as proprietary systems.

1.7.3 Plywood

Plywood is a flat panel made by bonding together, under pressure, a number of thin layers of veneer, often referred to as plies (or laminates). Plywood was the first type of EWP to be invented. Logs are debarked and steamed or heated in hot water for about 24 hours. They are then rotary-peeled into veneers of 2–4 mm in thickness and clipped into sheets of some 2 m wide. After kiln-drying and gluing, the veneers are laid up with the grain perpendicular to one another and bonded under pressure in an odd number of laminates (at least three), as shown in Figure 1.10a. The outside plies, always made of veneer, are referred to as faces (face ply or back ply) and the inner laminates, which could be made of either veneers or sliced/sawn

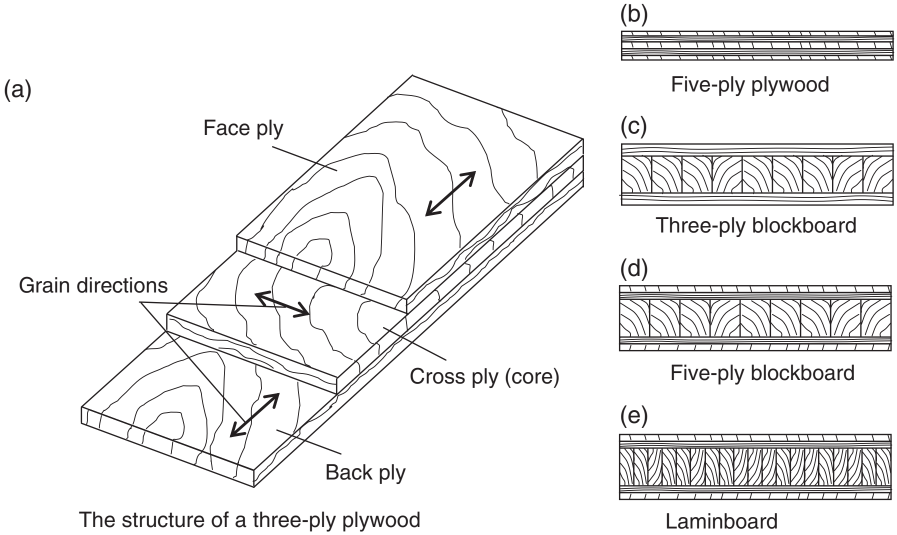


Fig. 1.10. Examples of plywood and wood core plywood.

wood, are called core. Examples of wood core plywood include blockboards and laminboards, as shown in Figures 1.10c–1.10e.

Plywood is produced in many countries from either softwood or hardwood or a combination of both. The structural grade plywoods that are commonly used in the United Kingdom are as follows:

- American construction and industrial plywood
- Canadian softwood plywood and Douglas fir plywood
- Finnish birch-faced (combi) plywood, Finnish birch plywood and Finnish conifer plywood
- Swedish softwood plywood.

The plywood sheet sizes available sizes are 1200 mm × 2400 mm or 1220 mm × 2440 mm. The face veneer is generally oriented with the longer side of the sheet except for Finnish made plywoods in which face veneers run parallel to the shorter side. Structural plywood and plywood for exterior use are generally made with waterproof adhesive that is suitable for severe exposure conditions.

The structural properties and strength of plywood depend mainly on the number and thickness of each ply, the species and grade and the arrangement of the individual plies. As with timber, the structural properties of plywood are functions of the type of applied stresses, their direction with respect to grain direction of face ply and the duration of load.

Plywood may be subjected to bending in two different planes, depending on its intended use, and the direction of the applied stress and, therefore, it is important to differentiate between them:

(i) Bending about either of the axes (i.e. x–x or y–y) in the plane of the board, as shown in Figure 1.11a; for example, in situations where it is used as shelving or as floor board.

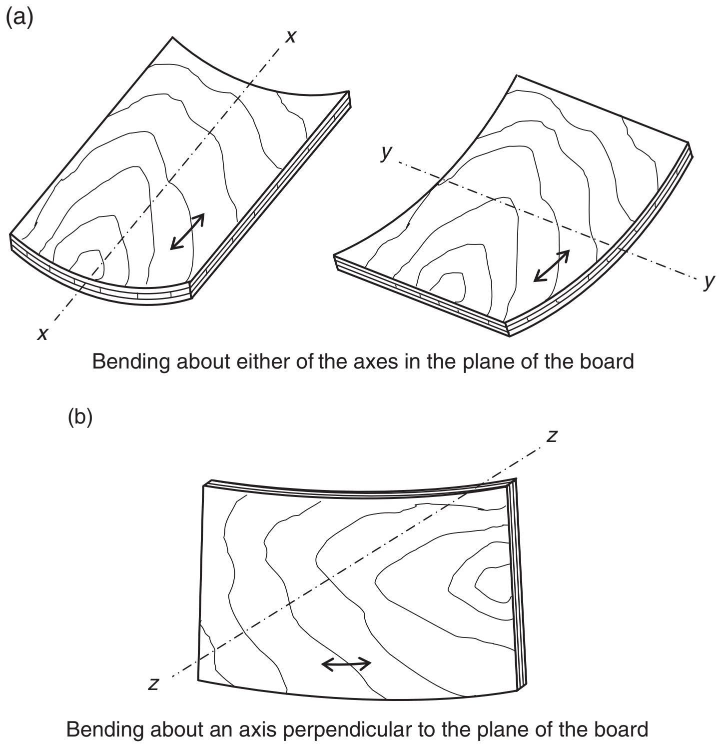


Fig. 1.11. Plywood – axes of bending.

(ii) Bending about an axis perpendicular to the plane of the panel (i.e. z–z axis as shown in Figure 1.11b); for example, when it is acting as a web of a flexural member such as in ply-webbed beams.

BS EN 636:2003 [16] details the requirements for plywood for general purposes and for structural application in dry, humid or exterior conditions. It also gives a classification system based on the bending properties. The information on how to utilise the classification system of BS EN 636 in order to determine the characteristic values for plywood panels for use in structural design, in accordance with EN 1995-1-1 (EC5), is given in BS EN 12369-2:2011 [17].

BS EN 12369-2 includes the characteristic values of the mechanical properties for load-bearing plywood panels, complying with BS EN 636, under service class 1 conditions and provides the class designations of F3, F5, F10, F15, F20, F25, F30, F40, F50, F60, F70 and F80 with corresponding characteristic strength values in bending of 3 N/mm^2 to 80 N/mm^2 respectively as set out in Table 2 of the Standard together with tensile and compressive strength values parallel and perpendicular to the face grain of the panels. Similarly, *Table 3* of the Standard provides the classification for modulus of elasticity in bending, tension and compression with designations of classes E5 to E140 corresponding to mean modulus of elasticity in bending of 500 N/mm^2 to 14 000 N/mm^2 respectively as well as their corresponding values in tension and compression parallel and perpendicular to the face grain of the panels. Shear properties

Table 1.7 Details of the commonly used structural grade plywoods in the United Kingdom

American plywood grades			Canadian plywood grades			Finnish plywood grades			Swedish plywood grades		
Grade	American standard	Quality control agency	Grade	Canadian standard	Quality control agency	Grade	Finnish and CEN standards	Quality control agency	Grade	Swedish standard	Quality control agency
C-D Exposure 1 (CDX)	PS1-95	APA and TECO	CSP Select Tight Face Exterior	CSA 0151-M 1978	CANPLY (Formerly COFI)	Birch (Finply all birch)	SFS 2413 EN 635-2 EN 636-2&3	VTT	P30	SBN 1975.5	The National Swedish Testing Institute (Statens Provningsanstalt)
C-C Exterior (CCX)	PS1-95	APA and TECO	CSP Select Exterior			Birch-faced (Finply combi)	SFS 2413 EN635-2 EN636-2&3	VTT			
A-C Exterior (ACX)	PS1-95	APA and TECO	CSP Sheathing Grade Exterior			Conifer plywood (Finply conifer)	EN635-3 EN 636-3	VTT			
B-C Exterior (BCX)	PS1-95	APA and TECO	DFP Select Tight Face Exterior	CSA 0121-M 1978		Birch-faced (Finply combi mirror)	SFS 2413 EN635-2 EN636-2&3	VTT			
Sturd-I-Floor Exposure 1 and Exterior	PS1-95	APA	DFP Select Exterior			Birch-faced (Finply twin)	SFS 2413 EN 635-2 EN636-2&3	VTT			
Floor span Exposure 1 and Exterior	PS1-95	TECO	DFP Sheathing Grade Exterior								
C-D Plugged Exposure 1	PS1-95	APA and TECO									
C-C Plugged Exterior	PS1-95	APA and TECO									

Quality control agencies: APA, The Engineered Wood Association; Canadian Plywood Association (CANPLY); Technical Research Centre of Finland (VTT); The National Swedish Testing Institute (Statens Provningsanstalt); TECO Corporation (TECO).

are detailed in *Table 4* of the Standard. Plywood of these classes can also be used under service classes 2 and 3 in accordance with the requirements of EC5.

However, the Standard also recommends that, where optimised values are required, the characteristic values are determined directly by testing in accordance with BS EN 789:2004 [18] and BS EN 1058:2009 [19] or by a combination of testing to these two standards and calculation to BS EN 14272:2011 [20]. In this regard, the characteristic strength and stiffness values of products with CE certification (marking) should be obtained from the manufacturers or suppliers. Often such information is available from manufacturers' websites.

The relevant grades, national standards and the quality control agencies relating to the structural grade plywoods that are commonly used in the United Kingdom are detailed in Table 1.7.

Indicative strength, stiffness and density values for the American plywood grade: C-D exposure 1 (CDX) and Swedish plywood grade P30 are given in Table 1.8.

In Tables 1.9, 1.10, 1.11 and 1.12 characteristic values for a range of Finnish plywoods that are used in the United Kingdom are given, based on the *Handbook of Finnish Plywood* [21].

In Tables 1.13 and 1.14 strength, stiffness and density values for unsanded CANPLY Canadian Douglas fir plywood and Canadian softwood plywood are given, respectively, based on data published by CANPLY Canadian Plywood Association [22].

1.7.4 Laminated Veneer Lumber (LVL)

LVL, shown in Figure 1.12, is an engineered timber composite manufactured by laminating wood veneers using exterior-type adhesives. In production, LVL is made with thin veneers similar to those in most plywoods. Veneers, 3–4 mm in thickness, are peeled off good quality logs and vertically laminated, but unlike plywood, successive veneers are generally oriented in a common grain direction, which gives orthotropic properties similar to those in sawn timber. Certain grades of LVL also include a few sheets of veneer in its lay-up in the direction perpendicular to the long direction of the member to enhance the strength properties. LVL was first produced some 40 years ago and currently it is being manufactured by a number of companies in the United States, Finland, Australia, New Zealand and Japan.

In the USA, LVL is manufactured from species such as southern yellow pine or Douglas fir by Weyerhaeuser under the name Microllam® LVL; and in Finland LVL is manufactured from Spruce by Metsa Wood (Finnforest) under the name Kerto. Kerto is produced as a standard product when all veneers are parallel (Kerto-S®) and also as Kerto-Q® in which approximately every fifth veneer is in the perpendicular direction. Kerto-T, a new product by Metsa Wood, is similar to Kerto-S but is made from lighter veneers and is produced for use as a stud in both load-bearing and non load-bearing walls.

Standard dimensions of cross-section for Kerto-LVLs are shown in Table 1.15 and the characteristic values for their strength and stiffness properties are given in Table 1.16.

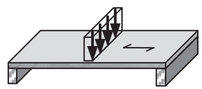
1.7.5 Laminated Strand Lumber (LSL), TimberStrand®

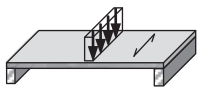
LSL, shown in Figure 1.13, is manufactured in the USA by Weyerhaeuser under the registered name TimberStrand®. LSL is produced from strands of wood species (often

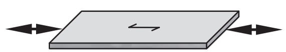
Table 1.8 Strength and stiffness properties and density values of selected American and Swedish structural plywoods

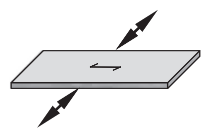
Section properties		Characteristic strength (N/mm^2)								Density (kg/m^3)		Mean modulus of rigidity (N/mm^2)	Mean modulus of elasticity (N/mm^2)			
		Bending		Compression		Tension		Panel shear	Planar (rolling) shear	Characteristic	Mean	Panel shear	Bending		Tension and compression	
Plywood type	Nominal thickness (mm)	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,k}$	$f_{r,k}$	ρ_k	ρ_{mean}	$G_{v,mean}$	$E_{m,0,mean}$	$E_{m,90.mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
American plywood Grade: C-D Exposure 1 (CDX)	12.5	23.5	12.2	13.9	8.1	13.6	7.2	3.2	0.9	410	460	500	10 300	2500	6800	4600
	21	14.8	10.1	10.6	7.7	10.5	6.9	3.2	0.9	410	460	500	7800	2500	5200	3900
Swedish plywood Grade: P30	12	23.0	11.4	15.0	12.0	15.0	12.0	2.9	0.9	410	460	500	9200	4600	7200	4800
	24	21.6	12.4	15.4	11.4	15.4	11.4	2.9	0.9	410	460	500	8700	5000	7400	4600

Note: 1. Characteristic value of modulus of elasticity, $E_{i,k} = 0.8 \times E_{i,mean}$.
2. Number of plies ≥ 5.


Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$


Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$


Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$


Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$

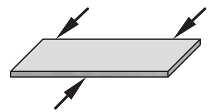

Panel shear: $f_{v,k}$

Table 1.9 Finnish plywood: density values

Plywood	Mean density (kg/m^3) ρ_{mean}	Characteristic density (kg/m^3) ρ_k
Birch (1.4 mm plies)	680	630
Birch-faced (1.4 mm plies)	620	560
Conifer (1.4 mm (thin) plies)	520	460
Conifer (thick plies)	460	400

aspen), up to 300 mm in length and 30 mm in width, or species combinations blended with a polyurethane-based adhesive. The strands are oriented in a parallel direction and formed into mats 2.44 m wide by up to 14.63 m long, of various thicknesses of up to 140 mm. The mats are then pressed by steam injection to the required thickness. TimberStrands are available in dimensions of up to 140 mm thick × 1220 mm deep × 14.63 m long. Design values for the strength and stiffness properties of TimberStrand are given in Table 1.17.

1.7.6 Parallel Strand Lumber (PSL), Parallam®

PSL, shown in Figure 1.14, is manufactured in the USA by Weyerhaeuser under the registered name Parallam®. The manufacturing process involves peeling small-diameter logs into veneer sheets. The veneers are then dried to a moisture content of 2–3% and then cut into thin long strands oriented parallel to one another.

The process of stranding reduces many of the timber's natural growth and strength-reducing characteristics such as knots, pitch pockets and slope of grain. This results in a dimensionally stable material that is more uniform in strength and stiffness characteristics and also in density than its parent timbers. For bonding strands, waterproof structural adhesive, mixed with a waxed component, is used and redried under pressure in a microwave process to dimensions measuring 275 × 475 mm^2 in section by up to 20 m in length.

1.7.7 Oriented Strand Board (OSB)

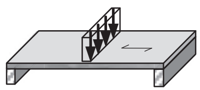
OSB is an engineered structural board manufactured from thin wood strands, flakes or wafers sliced from small-diameter round timber logs and bonded with an exterior-type adhesive (comprising 95% wood, 5% resin and wax) under heat and pressure; see Figure 1.15.

OSB panels comprise exterior or surface layers that are composed of strands oriented in the long panel direction, with inner layers comprising randomly oriented strands. Their strength is mainly due to their multi-layered make-up and the cross-orientation of the strands. The use of water and boil-proof resins/adhesives provide strength, stiffness and moisture resistance.

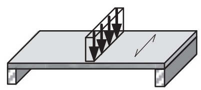
In the United Kingdom, OSB is often referred to as Sterling board or Sterling OSB. OSB has many applications and often is used in preference to plywood as a more cost-effective, environmentally friendly and dimensionally stable panel. It is available

Table 1.10 Finnish birch plywood: Strength and stiffness properties

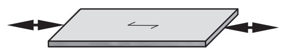
Section properties			Characteristic strength (N/mm^2)									Mean modulus of rigidity (N/mm^2)			Mean modulus of elasticity (N/mm^2)			
			Bending		Compression		Tension		Panel shear	Planar (rolling) shear		Panel shear	Planar shear		Bending		Tension and compression	
Nominal thickness (mm)	Number of plies	Mean thickness (mm)	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,k}$	$f_{r,0,k}$	$f_{r,90,k}$	$G_{v,mean}$	$G_{r,0,mean}$	$G_{r,90,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
4	3	3.6	65.9	10.6	31.8	20.2	45.8	29.2	9.5	2.77	–	620	169	–	16 471	1029	10 694	6806
6.5	5	6.4	50.9	29.0	29.3	22.8	42.2	32.8	9.5	3.20	1.78	620	169	123	12 737	4763	9844	7656
9	7	9.2	45.6	32.1	28.3	23.7	40.8	34.2	9.5	2.68	2.35	620	206	155	11 395	6105	9511	7989
12	9	12.0	42.9	33.2	27.7	24.3	40.0	35.0	9.5	2.78	2.22	620	207	170	10 719	6781	9333	8167
15	11	14.8	41.3	33.8	27.4	24.6	39.5	35.5	9.5	2.62	2.39	620	207	178	10 316	7184	9223	8277
18	13	17.6	40.2	34.1	27.2	24.8	39.2	35.8	9.5	2.67	2.34	620	206	183	10 048	7452	9148	8352
21	15	20.4	39.4	34.3	27.0	25.0	39.0	36.0	9.5	2.59	2.41	620	206	186	9858	7642	9093	8407
24	17	23.2	38.9	34.4	26.9	25.1	38.8	36.2	9.5	2.62	2.39	620	206	189	9717	7783	9052	8448
27	19	26.0	38.4	34.5	26.8	25.2	38.7	36.3	9.5	2.57	2.43	620	205	190	9607	7893	9019	8481
30	21	28.8	38.1	34.6	26.7	25.3	38.5	36.5	9.5	2.59	2.41	620	205	192	9519	7981	8993	8507
35	25	34.4	37.6	34.7	26.6	25.4	38.4	36.6	9.5	2.57	2.43	620	204	193	9389	8111	8953	8547
40	29	40.0	37.2	34.7	26.5	25.5	38.3	36.8	9.5	2.56	2.44	620	204	195	9296	8204	8925	8575
45	32	44.2	37.0	34.7	26.5	25.5	38.2	36.8	9.5	2.55	2.46	620	203	195	9259	8241	8914	8586
50	35	48.4	36.8	34.8	26.4	25.6	38.1	36.9	9.5	2.54	2.46	620	203	196	9198	8302	8895	8605



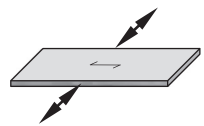
Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$ and $G_{r,0,mean}$



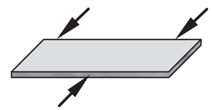
Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$ and $G_{r,90,mean}$



Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$



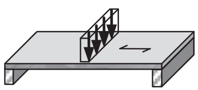
Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$



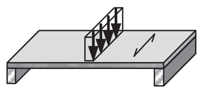
Panel shear: $f_{v,k}$ and $G_{v,mean}$

Table 1.11 Finnish combi plywood: Strength and stiffness properties

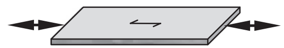
Section properties			Characteristic strength (N/mm^2)									Mean modulus of rigidity (N/mm^2)			Mean modulus of elasticity (N/mm^2)			
			Bending		Compression		Tension		Panel shear	Planar (rolling) shear		Panel shear	Planar shear		Bending		Tension and compression	
Nominal thickness (mm)	Number of plies	Mean thickness (mm)	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,k}$	$f_{r,0,k}$	$f_{r,90,k}$	$G_{v,mean}$	$G_{r,0,mean}$	$G_{r,90,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
6.5	5	6.4	50.8	29.0	24.5	22.8	19.1	32.8	7.0	3.20	1.14	600	169	41	12 690	4763	8859	7656
9	7	9.2	43.9	32.1	22.5	23.7	17.5	34.2	7.0	2.68	1.51	593	206	52	10 983	6105	8141	7989
12	9	12.0	40.0	33.2	21.5	24.3	16.7	35.0	7.0	2.78	1.42	589	207	57	10 012	6781	7758	8167
15	11	14.8	37.5	33.8	20.8	24.6	16.2	35.5	7.0	2.62	1.53	586	207	59	9386	7184	7520	8277
18	13	17.6	35.8	34.1	20.4	24.8	15.8	35.8	7.0	2.67	1.50	584	206	61	8950	7452	7358	8352
21	15	20.4	34.5	34.3	20.0	25.0	15.6	36.0	7.0	2.59	1.55	583	206	62	8628	7642	7240	8407
24	17	23.2	32.9	34.4	19.8	25.1	15.4	36.2	7.0	2.62	1.53	582	206	63	8381	7783	7151	8448
27	19	26.0	31.2	34.5	19.6	25.2	15.3	36.3	7.0	2.57	1.56	581	205	63	8185	7893	7081	8481
30	21	28.8	29.9	34.6	19.5	25.3	15.1	36.5	7.0	2.59	1.54	581	205	64	8026	7981	7024	8507



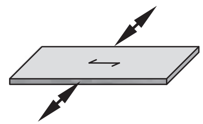
Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$ and $G_{r,0,mean}$



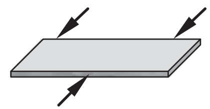
Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$ and $G_{r,90,mean}$



Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$



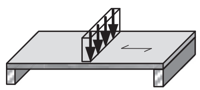
Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$



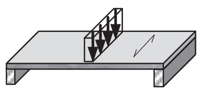
Panel shear: $f_{v,k}$ and $G_{v,mean}$

Table 1.12 Finnish conifer plywood with thin veneers: strength and stiffness properties

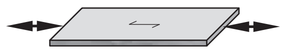
Section properties			Characteristic strength (N/mm^2)									Mean modulus of rigidity (N/mm^2)			Mean modulus of elasticity (N/mm^2)			
			Bending		Compression		Tension		Panel shear	Planar (rolling) shear		Panel shear	Planar shear		Bending		Tension and compression	
Nominal thickness (mm)	Number of plies	Mean thickness (mm)	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,k}$	$f_{r,0,k}$	$f_{r,90,k}$	$G_{v,mean}$	$G_{r,0,mean}$	$G_{r,90,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
4	3	3.6	37.6	6.0	22.0	14.0	17.1	10.9	7.0	1.77	–	530	56	–	12 235	765	7944	5056
6.5	5	6.4	29.1	16.6	20.3	15.8	15.8	12.3	7.0	2.05	1.14	530	66	41	9462	3538	7313	5688
9	7	9.2	26.0	18.3	19.6	16.4	15.2	12.8	7.0	1.72	1.51	530	69	52	8465	4535	7065	5935
12	9	12.0	24.5	19.0	19.2	16.8	14.9	13.1	7.0	1.78	1.42	530	69	57	7963	5037	6933	6067
15	11	14.8	23.6	19.3	19.0	17.0	14.8	13.2	7.0	1.68	1.53	530	69	59	7663	5337	6851	6149
18	13	17.6	23.0	19.5	18.8	17.2	14.6	13.4	7.0	1.71	1.50	530	69	61	7464	5536	6795	6205
21	15	20.4	22.5	19.6	18.7	17.3	14.5	13.5	7.0	1.66	1.55	530	69	62	7323	5677	6755	6245
24	17	23.2	22.2	19.7	18.6	17.4	14.5	13.5	7.0	1.68	1.53	530	69	63	7218	5782	6724	6276
27	19	26.0	22.0	19.7	18.6	17.4	14.4	13.6	7.0	1.65	1.56	530	68	63	7137	5863	6700	6300
30	21	28.8	21.8	19.8	18.5	17.5	14.4	13.6	7.0	1.66	1.54	530	68	64	7072	5928	6681	6319



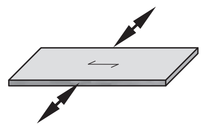
Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$ and $G_{r,0,mean}$



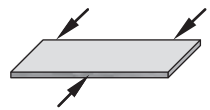
Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$ and $G_{r,90,mean}$



Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$



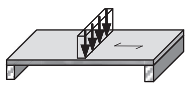
Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$



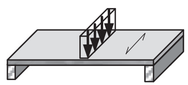
Panel shear: $f_{v,k}$ and $G_{v,mean}$

Table 1.13 Canadian Douglas fir plywood (unsanded CANPLY): strength and stiffness properties and density values

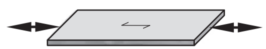
Section properties		Mean density (kg/m³)	Characteristic strength (N/mm²)									Mean modulus of rigidity (N/mm²)	Mean modulus of elasticity (N/mm²)			
			Bending		Compression		Tension		Panel shear	Planar (rolling) shear		Panel shear	Bending		Tension and compression	
Nominal thickness (mm)	Number of plies	ρ_{mean}	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,0,k}$	$f_{r,0,k}$	$f_{r,90,k}$	$G_{v,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
7.5	3	460	26.4	5.5	25.4	8.1	16.8	4.4	3.5	1.07	0.33	500	12 950	510	9730	3300
9.5	3	460	24.9	5.4	20.1	8.0	13.3	4.3	3.5	0.89	0.33	500	12 290	490	7680	3250
12.5	4	460	22.1	7.0	15.2	11.7	10.1	6.4	3.5	0.95	0.48	500	10 980	1230	5840	4780
12.5	5	460	29.5	10.4	20.4	9.7	13.5	7.4	3.5	1.25	0.64	500	11 050	2270	7810	3960
15.5	4	460	25.5	7.8	19.7	12.4	13.1	6.7	3.5	0.91	0.51	500	12 830	1460	7550	5050
15.5	5	460	26.2	9.6	16.5	7.8	10.9	5.9	3.5	1.31	0.68	500	9930	2110	6300	3190
18.5	5	460	31.0	11.1	21.1	10.1	14.0	7,7	3.5	1.27	0.66	500	11 840	2510	8080	4120
18.5	6	460	23.8	10.7	17.3	6.5	11.4	5.0	3.5	1.07	0.63	500	9100	2640	6620	2670
18.5	7	460	25.2	10.8	17.3	9.8	11.4	7.5	3.5	1.13	0.83	500	9620	2670	6620	4010
20.5	5	460	24.0	14.4	17.0	11.1	11.3	8.4	3.5	1.06	0.59	500	9170	3760	6520	4520
20.5	6	460	22.2	10.8	16.6	5.9	11.0	4.5	3.5	1.09	0.68	500	8490	2820	6370	2410
20.5	7	460	23.4	10.9	15.6	8.9	10.3	6.7	3.5	1.14	0.89	500	8930	2840	5970	3620
22.5	7	460	25.3	10.3	16.3	8.5	10.8	6.5	3.5	1.16	0.94	500	9650	2800	6250	3480
22.5	8	460	26.2	10.3	16.3	10.8	10.8	8.2	3.5	0.89	0.98	500	10010	2790	6250	4390
25.5	7	460	24.0	12.6	16.6	10.6	1.1.0	8.1	3.5	1.12	0.97	500	9210	3610	6360	4320
25.5	8	460	24.1	10.8	14.4	10.6	9.5	8.1	3.5	0.90	1.04	500	9260	3070	5520	4320
25.5	9	460	24.7	10.8	16.9	9.5	11.2	7.2	3.5	1.18	0.85	500	9490	3090	6480	3880
25.5	10	460	25.5	11.6	19.5	9.5	12.9	7.2	3.5	1.19	0.66	500	9800	3320	7450	3880
28.5	8	460	22.8	12.7	13.8	12.2	9.2	9.3	3.5	0.90	1.07	500	8790	3760	5300	4990
28.5	9	460	22.8	10.4	15.2	8.5	10.0	6.5	3.5	1.20	0.90	500	8800	3100	5800	3470
28.5	10	460	23.5	11.2	17.4	8.5	11.5	6.5	3.5	1.21	0.69	500	9050	3320	6670	3470
28.5	11	460	24.4	11.7	17.4	10.6	11.5	8.1	3.5	1.12	0,90	500	9410	3490	6670	4340
31.5	8	460	23.2	14.1	15.2	10.6	10.1	10.2	3.5	0.86	1.10	500	8930	3490	5830	5490
31.5	9	460	21.8	12.3	15.1	10.1	10.0	7.7	3.5	1.18	0.91	500	8400	3750	5770	4120
31.5	10	460	21.6	10.7	15.8	7.7	10.4	5.9	3.5	1.22	0.72	500	8330	3280	6030	3140
31.5	11	460	22.6	11.2	15.8	9.6	10.4	7.3	3.5	1.13	0.94	500	8690	3420	6030	3920
31.5	12	460	23.3	11.8	15.8	11.5	10.4	8.8	3.5	0.87	0.96	500	8990	3600	6030	4710



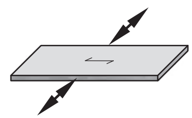
Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$ and $G_{r,0,mean}$



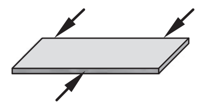
Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$ and $G_{r,90,mean}$



Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$



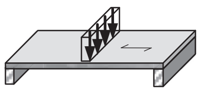
Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$



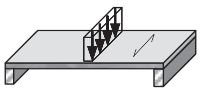
Panel shear: $f_{v,k}$ and $G_{v,mean}$

Table 1.14 Canadian Softwood plywood (unsanded CANPLY): strength and stiffness properties and density values

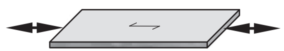
Section properties		Mean density (kg/m³)	Characteristic strength (N/mm²)									Mean modulus of rigidity (N/mm²)	Mean modulus of elasticity (N/mm²)			
			Bending		Compression		Tension		Panel shear	Planar (rolling) shear		Panel shear	Bending		Tension and compression	
Nominal thickness (mm)	Number of plies	ρ_{mean}	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,0,k}$	$f_{r,0,k}$	$f_{r,90,k}$	$G_{v,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
7.5	3	420	24.0	5.5	16.1	8.1	12.3	4.4	3.5	1.07	0.33	430	8780	510	6590	3300
9.5	3	420	22.6	5.4	12.7	8.0	9.7	4.3	3.5	0.89	0.33	430	8330	490	5200	3250
12.5	4	420	22.3	7.0	12.1	11.7	9.2	6.4	3.5	0.91	0.48	430	8320	1230	4940	4780
12.5	5	420	20.2	10.4	14.5	9.7	11.1	7.4	3.5	1.25	0.64	430	7510	2270	5930	3960
15.5	4	420	23.1	7.8	12.5	12.4	9.5	6.7	3.5	0.91	0.51	430	8690	1460	5120	5050
15.5	5	420	17.9	9.6	11.7	7.8	8.9	5.9	3.5	1.31	0.68	430	6740	2110	4780	3190
18.5	5	420	21.2	11.1	15.0	10.1	11.4	7,7	3.5	1.27	0.66	430	8040	2510	6120	4120
18.5	6	420	19.0	10.7	14.7	6.5	11.2	5.0	3.5	1.34	0.63	430	7210	2640	6010	2670
18.5	7	420	17.8	10.8	13.1	9.8	10.0	7.5	3.5	1.13	0.83	430	6740	2670	5340	4010
20.5	5	420	16.5	14.4	12.8	11.1	9.7	8.4	3.5	1.06	0.59	430	6260	3760	5230	4520
20.5	6	420	15.3	10.8	12.8	5.9	9.7	4.5	3.5	1.09	0.68	430	5820	2820	5230	2410
20.5	7	420	16.5	10.9	11.8	8.9	9.0	6.7	3.5	1.14	0.89	430	6260	2840	4820	3620
22.5	7	420	17.7	10.3	12.1	8.5	9.2	6.5	3.5	1.16	0.94	430	6720	2800	4940	3480
22.5	8	420	18.6	10.3	12.1	10.8	9.2	8.2	3.5	0.89	0.98	430	7080	2790	4940	4390
25.5	7	420	17.0	12.6	12.7	10.6	9.7	8.1	3.5	1.12	0.97	430	6500	3610	5210	4320
25.5	8	420	17.2	10.8	10.7	10.6	8.1	8.1	3.5	0.90	1.04	430	6550	3070	4360	4320
25.5	9	420	17.8	10.8	13.0	9.5	9.9	7.2	3.5	1.18	0.85	430	6780	3090	5330	3880
25.5	10	420	18.6	11.6	15.4	9.5	11.7	7.2	3.5	1.19	0.66	430	7090	3320	6300	3880
28.5	8	420	16.4	12.7	10.4	12.2	7.9	9.3	3.5	0.90	1.07	430	6280	3760	4260	4990
28.5	9	420	16.4	10.4	11.7	8.5	8.9	6.5	3.5	1.20	0.90	430	6290	3100	4770	3470
28.5	10	420	17.1	11.2	13.8	8.5	10.5	6.5	3.5	1.21	0.69	430	6540	3320	5640	3470
28.5	11	420	18.0	11.7	13.8	10.6	10.5	8.1	3.5	1.12	0,90	430	6900	3490	5640	4340
31.5	8	420	17.0	14.1	11.8	10.6	9.0	10.2	3.5	0.86	1.10	430	6490	3490	4840	5490
31.5	9	420	15.9	12.3	11.8	10.1	9.0	7.7	3.5	1.18	0.91	430	6080	3750	4840	4120
31.5	10	420	15.7	10.7	12.5	7.7	9.5	5.9	3.5	1.22	0.72	430	6010	3280	5100	3140
31.5	11	420	16.7	11.2	12.5	9.6	9.5	7.3	3.5	1.13	0.94	430	6380	3420	5100	3920



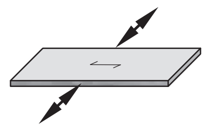
Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$ and $G_{r,0,mean}$



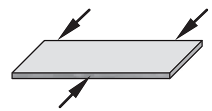
Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$ and $G_{r,90,mean}$



Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$



Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$



Panel shear: $f_{v,k}$ and $G_{v,mean}$

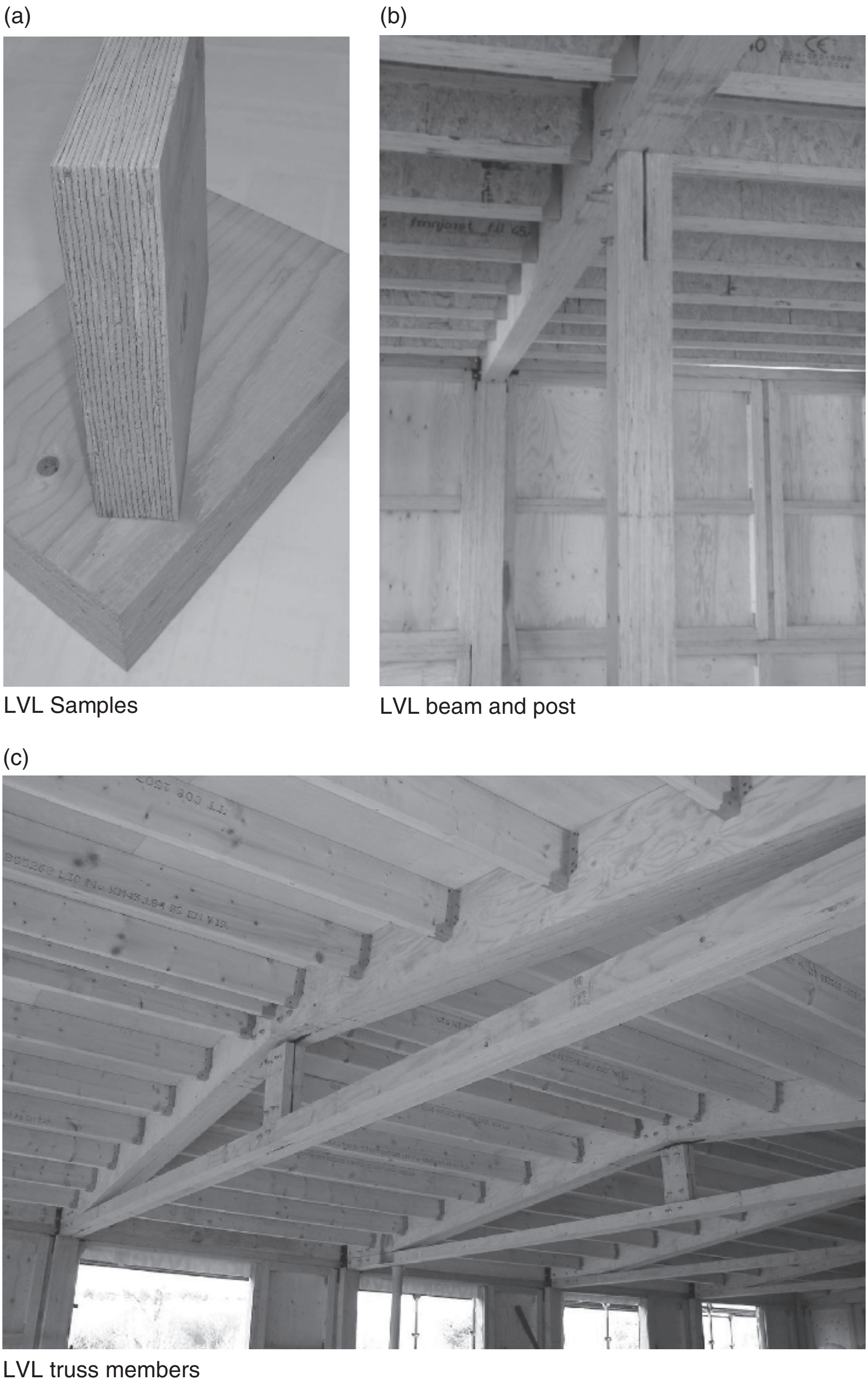


Fig. 1.12. Laminated veneer lumber (LVL).

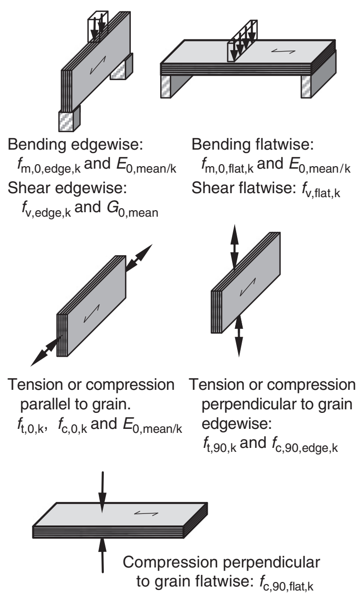
Table 1.15 Standard dimensions of cross-section for Kerto-LVL

Kerto-LVL type	Thickness (mm)	Width or depth (mm)								
		200	225	260	300	360	400	450	500	600
S/Q	27	√	√							
S/Q	33	√	√	√						
S/Q	39	√	√	√	√					
S/Q	45	√	√	√	√	√				
S/Q	51	√	√	√	√	√	√			
S/Q	57	√	√	√	√	√	√	√		
S/Q	63	√	√	√	√	√	√	√	√	
S/Q	69	√	√	√	√	√	√	√	√	√
S	75	√	√	√	√	√	√	√	√	√
S	90	√	√	√	√	√	√	√	√	√

Note: Kerto (LVL) may also be supplied in widths up to 2500 mm; for availability contact Metsa Wood.

Table 1.16 Kerto (LVL): strength and stiffness properties and density values

	Symbol	Units	Kerto-S® 21–90 mm	Kerto-Q® 27–69 mm	Kerto-T®
Characteristic values					
Bending					
Edgewise	$f_{m,0,edge,k}$	N/mm²	44.0	32.0	$27(300/h)^{s}$
Size effect parameter*	s		0.12	0.12	0.15
Flatwise, parallel to grain	$f_{m,0,flat,k}$	N/mm²	50.0	36.0	32.0
Flatwise, perpendicular to grain	$f_{m,90,flat,k}$	N/mm²	–	8.0	–
Tension					
Parallel to grain	$f_{t,0,k}$	N/mm²	35.0	26.0	$24(3000/L)^{S/2}$
Perpendicular to grain	$f_{t,90,k}$	N/mm²	0.8	6.0	–
Compression					
Parallel to grain	$f_{c,0,k}$	N/mm²	35.0	26.0	26.0
Perpendicular to grain edgewise	$f_{c,90,edge,k}$	N/mm²	6.0	9.0	4.0
Perpendicular to grain flatwise	$f_{c,90,flat,k}$	N/mm²	1.8	2.2	1.0
Shear					
Edgewise	$f_{v,0,edge,k}$	N/mm²	4.1	4.5	2.4
Flatwise	$f_{v,0,flat,k}$	N/mm²	2.3	1.3	1.3
Modulus of elasticity					
Parallel to grain	$E_{0,k}$	N/mm²	11600	8800	8400
Shear modulus					
Edgewise	$G_{0,k}$	N/mm²	400	400	270
Density	ρ_k	kg/m³	480	480	410
Mean values					
Modulus of elasticity					
Parallel to grain	$E_{0,mean}$	N/mm²	13800	10500	10000
Shear modulus					
Edgewise	$G_{0,mean}$	N/mm²	600	600	400
Density	ρ_{mean}	kg/m³	510	510	440

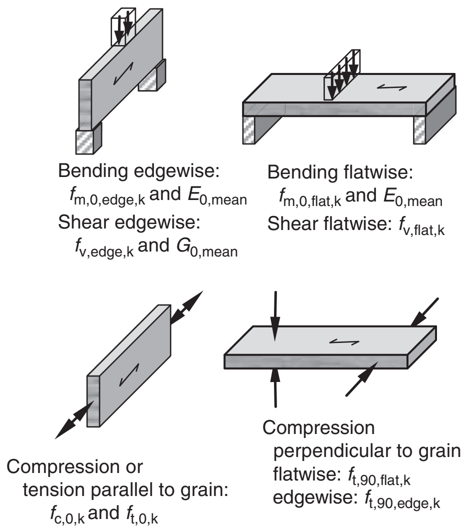


*s is the size effect exponent referred to in Clause 3.4 of EC5 [12].

Fig. 1.13. TimberStrand (LSL), courtesy of Weyerhaeuser.

Table 1.17 TimberStrand® (LSL): Strength and stiffness properties and density values

	Symbol	Units	Grade: 1.5E	Grade: 1.7E
Characteristic values				
Bending				
Edgewise	$f_{m,0,edge,k}$	N/mm²	32.4	37.6
Flatwise	$f_{m,0,flat,k}$	N/mm²	36.3	42.0
Tension				
Parallel to grain	$f_{t,0,k}$	N/mm²	24.4	28.9
Compression				
Parallel to grain	$f_{c,0,k}$	N/mm²	25.4	31.0
Perpendicular to grain edgewise	$f_{c,90,edge,k}$	N/mm²	8.9	10.1
Perpendicular to grain flatwise	$f_{c,90,flat,k}$	N/mm²	5.4	5.9
Shear				
Edgewise	$f_{v,0,edge,k}$	N/mm²	8.6	8.6
Flatwise	$f_{v,0,flat,k}$	N/mm²	3.2	3.2
Density	ρ_k	kg/m³	420	420
Mean values				
Modulus of elasticity				
Parallel to grain	$E_{0,mean}$	N/mm²	10300	11700
Shear modulus				
Edgewise	$G_{0,mean}$	N/mm²	645	730
Density	ρ_{mean}	kg/m³	650	690



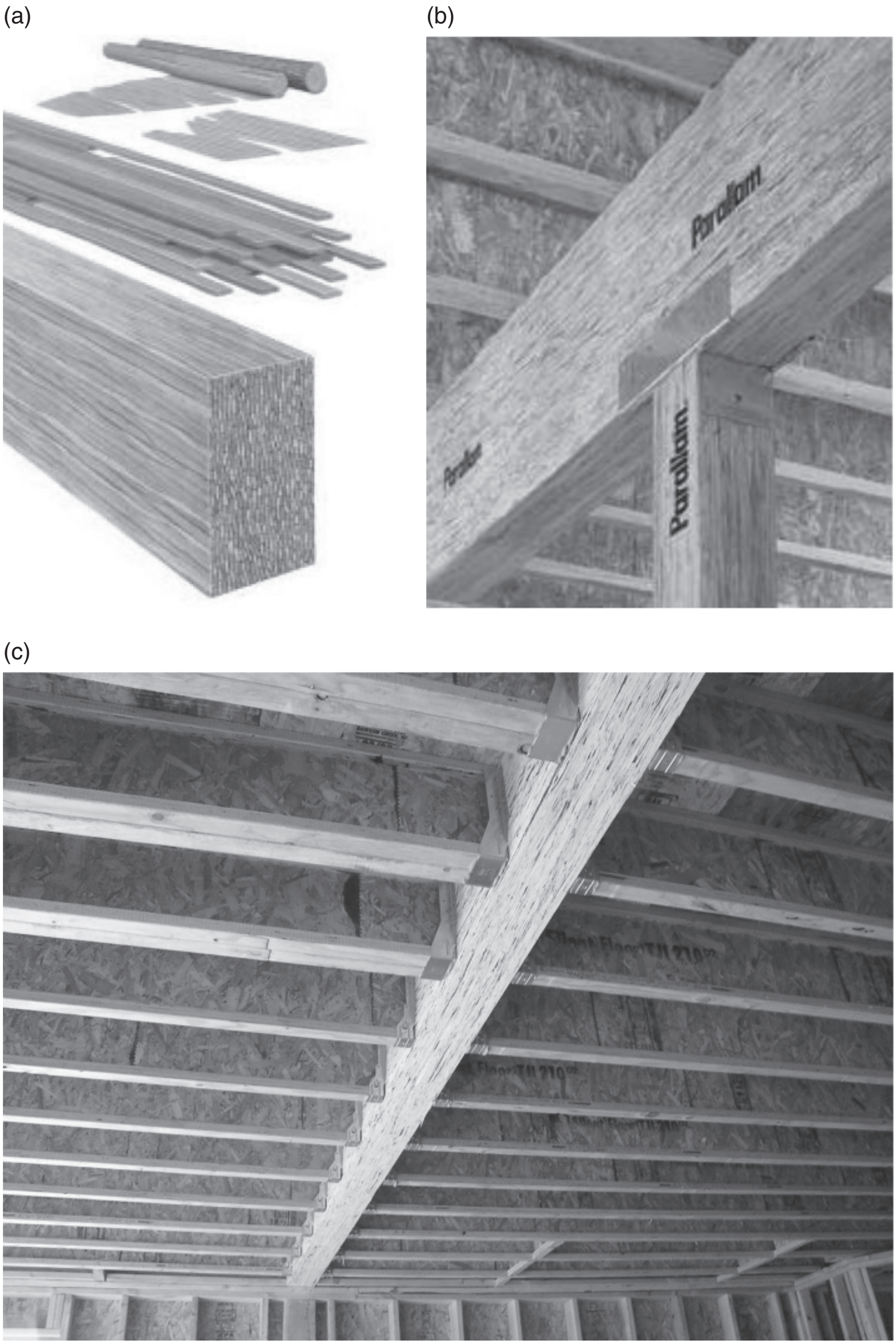


Fig. 1.14. Parallam (PSL) – manufacturing process and in construction; photos (a) and (b) courtesy of Weyerhaeuser.

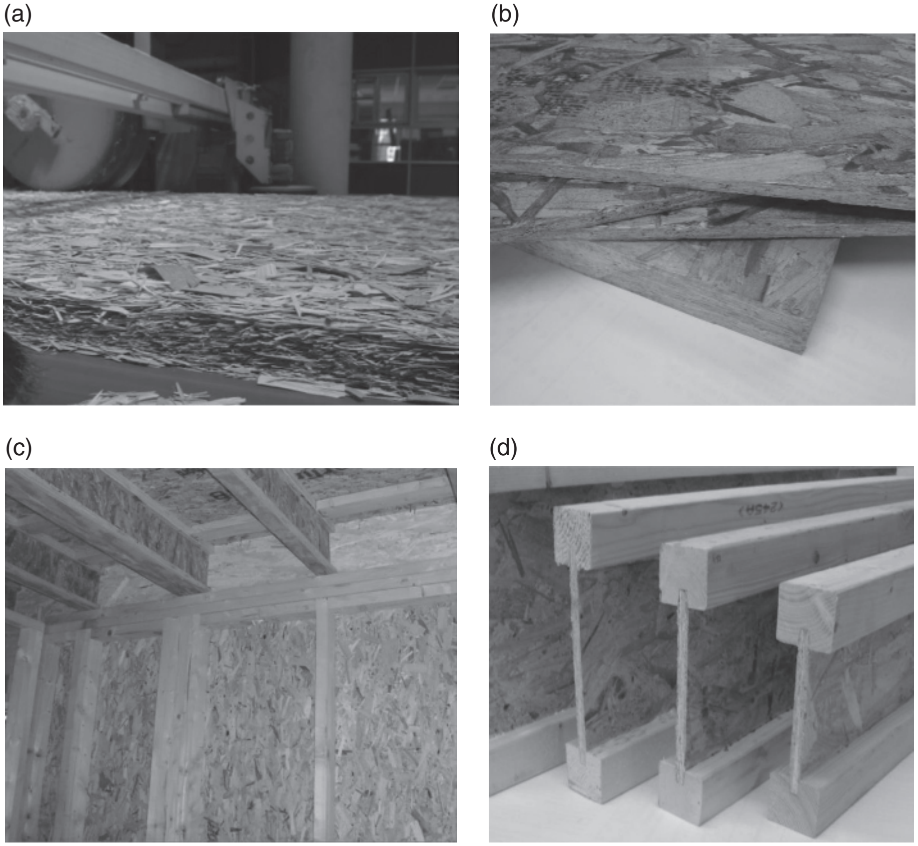


Fig. 1.15. OSB: (a) production before the press (photo courtesy of Wikipedia Foundation); (b) and (c) OSB boards and wall panels; (d) OSB webs in I-joists.

in various thicknesses of 8–25 mm with panel sizes of up to 2.4 m wide × 4.8 m long, which makes it an attractive product for floor decking, roof cladding, wall sheathing and for composite constructions such as SIPs, etc.

BS EN 12369-1:2001 [23] provides information on the characteristic values for the three grades of OSB complying with BS EN 300:2006 [24] for use in designing structures to EC5:

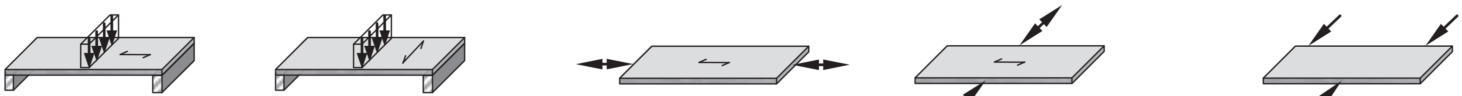
- OSB/2 is a general purpose (unconditioned) load-bearing panel for use in dry conditions only (service class 1).
- OSB/3 is a load-bearing structural panel for use in humid conditions (service classes 1 or 2).
- OSB/4 is a heavy-duty load-bearing structural panel for use in humid conditions (service classes 1 and 2).

OSB/3 and OSB/4 grades are intended for use in design and construction of load-bearing or stiffening building elements such as walls, flooring, roofing and I-beams. BS EN 12369-1 gives the minimum characteristic values for OSB complying with BS EN 300, which are summarised in Table 1.18.

Table 1.18 Strength and stiffness properties and density values for OSB boards complying with EN 300: 2006 (based on BS EN 12369-1:2001)

Section properties	Characteristic strength (N/mm^2)								Characteristic Density (kg/m^3)	Mean modulus of rigidity (N/mm^2)		Mean modulus of elasticity (N/mm^2)					
	Bending		Compression		Tension		Panel shear	Planar (rolling) shear		Panel shear	Planar shear	Bending		Tension		Compression	
Thickness (mm)	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,k}$	$f_{r,k}$	ρ_k	$G_{v,mean}$	$G_{r,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t,0,mean}$	$E_{t,90,mean}$	$E_{c,0,mean}$	$E_{c,90,mean}$
OSB/2: load-bearing boards for use in dry conditions; OSB/3: load-bearing boards for use in humid conditions																	
> 6–10	18.0	9.0	15.9	12.9	9.9	7.2	6.8	1.0	550	1080	50	4930	1980	3800	3000	3800	3000
> 10–18	16.4	8.2	15.4	12.7	9.4	7.0	6.8	1.0	550	1080	50	4930	1980	3800	3000	3800	3000
> 18–25	14.8	7.4	14.8	12.4	9.0	6.8	6.8	1.0	550	1080	50	4930	1980	3800	3000	3800	3000
OSB/4: heavy-duty load-bearing boards for use in humid conditions																	
> 6–10	24.5	13.0	18.1	14.3	11.9	8.5	6.9	1.1	550	1090	60	6780	2680	4300	3200	4300	3200
> 10–18	23.0	12.2	17.6	14.0	11.4	8.2	6.9	1.1	550	1090	60	6780	2680	4300	3200	4300	3200
> 18–25	21.0	11.4	17.0	13.7	10.9	8.8	6.9	1.1	550	1090	60	6780	2680	4300	3200	4300	3200

The 5% characteristic values for stiffness (i.e. G_k and E_k) should be taken as 0.85 times the mean values given in this table. Other properties not given in this table shall comply with the requirements given in EN 300 for the grades OSB/2, OSB3 or OSB/4



Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$ Planar shear: $f_{r,k}$ and $G_{r,mean}$

Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$ Planar shear: $f_{r,k}$ and $G_{r,mean}$

Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$

Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$

Panel shear: $f_{v,k}$ and $G_{v,mean}$

1.7.8 Particleboards and fibre composites

Particle and fibre composites are usually available in panel form and are widely used in housing construction and furniture manufacture. There are several products in this category and all are processed in a similar way. Examples include high-density fibreboard, medium-density fibreboard, tempered hardboard, cement-bonded particleboard, etc. For fibreboards, chips are refined to wood fibres by the aid of steam and then dried and adhesive is added to form a mat of wood particles and pressed until the adhesive is cured. After cooling the boards are cut to the required sizes. Wood chipboard is a particular derivative of this product family, and is made from small particles of wood and binder.

In BS EN 312:2010 [25] seven types of particleboards (chipboards) are classified and are distinguished as follows:

- P1 general purpose boards for use in dry conditions
- P2 boards for interior fitments (including furniture) for use in dry conditions
- P3 non-load-bearing boards for use in humid conditions
- P4 load-bearing boards for use in dry conditions
- P5 load-bearing boards for use in humid conditions
- P6 heavy-duty load-bearing boards for use in dry conditions
- P7 heavy-duty load-bearing boards for use in humid conditions.

Note that dry conditions refer to service class 1 only and humid conditions refer to service classes 1 and 2.

The P1, P2 and P3 grade particleboards (chipboards) are for general applications including furniture manufacturing and kitchen worktops. Boards of type P4–P7 are intended for use in design and construction of load-bearing or stiffening building elements such as walls, flooring, roofing and I-beams. For dry internal applications grade P4 can be used. The P4 grade is adequate where no moisture will be encountered during or after construction. The moisture-resistant grade P5 is the most commonly specified flooring in the United Kingdom. It is used extensively in new build house building and refurbishment projects. Durability is achieved by using advanced moisture-resistant resins. A green identification dye is added to the surface of the P5 grade to visually differentiate it on-site.

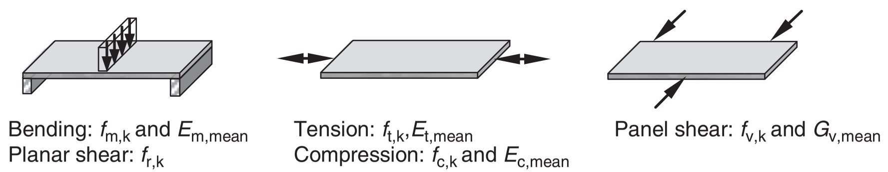
BS EN 12369-1 gives the minimum characteristic values for particleboards complying with BS EN 312, which are summarised in Table 1.19.

1.7.9 Thin webbed joists (I-joists)

I-joists are structurally engineered timber joists comprising flanges made from solid timber or LVL and a web made from OSB, plywood or particleboard. The flanges and web are bonded together to form an I-section member, a structurally efficient alternative to conventional solid timber. I-joists are economical and versatile structural elements in which the geometry permits efficient use of material by concentrating the timber in the outermost areas of the cross-section where it is required to resist the stresses. The flanges are commonly designed to provide the moment capacity of the beam and the web to predominantly carry the shear force; see Figure 1.16.

Table 1.19 Minimum strength, stiffness and density values for particleboards P4 and P5 complying with EN 312: 2003 (based on BS EN 12369-1:2001)

Section properties	Characteristic strength (N/mm^2)					Characteristic density (kg/m^3)	Mean modulus of rigidity (N/mm^2)	Mean modulus of elasticity (N/mm^2)		
	Bending	Compression	Tension	Panel shear	Planar shear		Panel shear	Bending	Tension	Compression
Thickness (mm)	$f_{m,k}$	$f_{c,k}$	$f_{t,k}$	$f_{v,k}$	$f_{r,k}$	ρ_k	$G_{v,mean}$	$E_{m,mean}$	$E_{t,mean}$	$E_{c,mean}$
Particleboard P4: load-bearing boards for use in dry conditions (service class 1 only)										
> 6–13	14.2	12.0	8.9	6.6	1.8	650	860	3200	1800	1800
> 13–20	12.5	11.1	7.9	6.1	1.6	600	830	2900	1700	1700
> 20–25	10.8	9.6	6.9	5.5	1.4	550	770	2700	1600	1600
> 25–32	9.2	9.0	6.1	4.8	1.2	550	680	2400	1400	1400
> 32– 40	7.5	7.6	5.0	4.4	1.1	500	600	2100	1200	1200
> 40	5.8	6.1	4.4	4.2	1.0	500	550	1800	1100	1100
Particleboard P5: load-bearing boards for use in humid conditions (service classes 1 and 2)										
> 6–13	15.0	12.7	9.4	7.0	1.9	650	960	3500	2000	2000
> 13–20	13.3	11.8	8.5	6.5	1.7	600	930	3300	1900	1900
> 20–25	11.7	10.3	7.4	5.9	1.5	550	860	3000	1800	1800
> 25–32	10.0	9.8	6.6	5.2	1.3	550	750	2600	1500	1500
> 32–40	8.3	8.5	5.6	4.8	1.2	500	690	2400	1400	1400
> 40	7.5	7.8	5.5	4.4	1.0	500	660	2100	1300	1300
The 5% characteristic values for stiffness (i.e. G_k and E_k) should be taken as 0.8 times the mean values given in this table. Other properties not given in this table should comply with the requirements given in EN 312:2003										



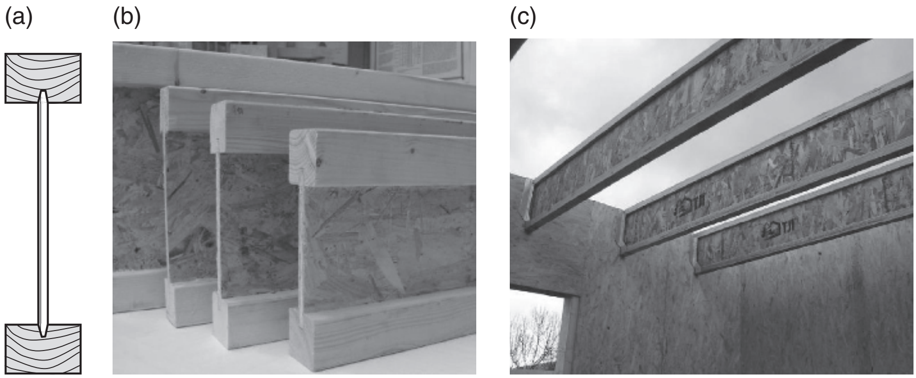


Fig. 1.16. Typical I-joists and their application.

I-joists are lightweight and can easily be handled by one or two persons, they generally possess higher strength and stiffness than comparable-sized solid timber, resist shrinkage, warping, splitting and checking, and are more efficient than solid timber for large spans and loads. They can be used as structural framing in floors, walls and in flat and pitched roofs. They are susceptible to shear buckling and are unstable until braced laterally. Compression flanges should be supported to prevent lateral deflection and buckling. Web stiffeners may be required at the bearing supports and positions of concentrated loads; service holes in the web should only be located in areas where shear loads are low.

I-joists can be designed using the rules in EC5 (see Chapter 7) and they are also available as proprietary systems. Manufacturers produce design guidance literature such as load span tables, permitted web hole requirements, joist hanger details, stiffener requirements, etc. In the United Kingdom, two main manufacturers or suppliers of I-joists are James Jones & Sons Ltd and Metsa Wood:

- James Jones JJI-joists® manufactured at the company's Timber Systems Division in Forres, Scotland, are available in a range of sizes familiar to the UK construction industry. Flanges are made with solid timber grade C24 and webs with 9-mm-thick OSB/3. Section depths range from 145 to 450 mm with flange widths from 47 to 97 mm all 45 mm deep.
- Metsa Wood Finnjoists or FJI-joists® manufactured at the company's factory in King's Lynn, England, have flanges produced from LVL, and a web of 10 mm thick OSB/3. Section depths range from 200 mm to 400 mm with flange widths from 38 mm to 89 mm all 39 mm deep.

1.7.10 Thin webbed beams (box beams)

Box beams comprise solid timber, LVL or glulam flanges with plywood or OSB webs. The webs are generally glued to the flanges on each side to form a box shape. Machine driven nails/staples can be used to aid fabrication.

Similar to I-joists, the larger parts of the cross-section (flanges) of box beams are at the top and bottom where the flexural stresses are highest. Plywood box beam showing veneer on its webs can be used as part of the aesthetic finish as well as the structure.

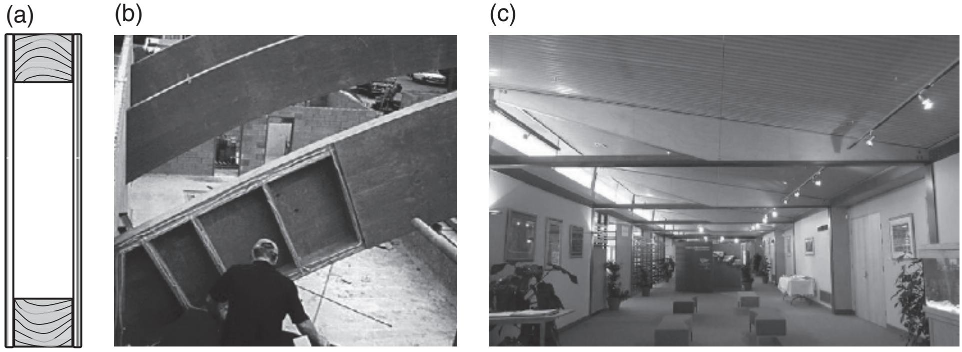


Fig. 1.17. Box beam: (a) cross-section, (b) curved ply-box beam during construction (photo courtesy of Peter Yttrup and Fred Bosveld), and (c) tapered ply-box beam (photo courtesy of Catriona McLeod and Port of Brisbane Corporation, Australia).

The hollow cross-section of the box profile also permits services to be run in the void inside the member giving a cleaner finish. It also gives the member torsional rigidity, which makes it more able to resist lateral torsional buckling or stresses due to eccentric loads.

Box beams are manufactured in depths up to 1.2 m. Web stiffeners are used to help control shear buckling of the web and provide convenient locations for web butt joints; see Figure 1.17. They are also located at positions of point loads to counter localised web buckling. In box beams, the web joint locations are ideally alternated from side to side and away from the areas of highest shear.

Unlike I-beams, which are factory produced in their final sections, it is not currently possible to buy box beams 'off the shelf'. Box beams are normally designed specifically for each contract requirement and assembled on-site.

The design of thin webbed joists and beams (I-joists and box beams) is covered in Chapter 7.

1.7.11 Structural Insulated Panels (SIPs)

SIPs are factory produced, pre-fabricated building panels that can be used as wall, floor and roof components in all types of residential and commercial buildings. They were developed in North America and have experienced wide-scale utilisation around the world. The biggest benefit with the system is that the structural support and the insulation are incorporated into a single system during manufacture. This enables high quality, more accurate thermal efficiency and a greater level of structural support to be achieved.

They are composed of a core of rigid foam insulation, which is laminated between two layers of structural timber panels (boards) by industrial adhesives. This process produces a single solid building element that provides both structural and insulation qualities. These panels are produced in varying sizes and thicknesses depending on the application and thermal/structural requirements.

The materials used to produce these building components can vary greatly in both the structural sheathing and the inner insulation core. Materials commonly used in the United Kingdom for the panels are OSB grade 3, or plywood combined with a variety of plastic foams including expanded polystyrene, extruded polystyrene,

Fig. 1.18. SIPs during construction.

urethane and other similar insulation cores. Typical SIPs can be seen in Figure 1.18. Further information on the structural performance of SIPs may be obtained from the Structural Insulated Panel Association (SIPA) website and relevant research publications [26, 27].

Table 1.20 Summary of the current engineered wood products and their structural applications

Product	Category	Application	Common sizes
Glulam	Laminate	• Beams, columns, trusses, bridges, portal frames, post and beam systems • Industrial, commercial, recreational, residential and institutional	No theoretical limits to size, length or shape
CLT (X-Lam)	Laminate	• Floors, walls, roofs, lift shafts, stairwells and bridge decks • Industrial, commercial, recreational, residential and institutional	Length: up to 24 m Width: up to 4.8 m Thickness: 50–500 mm available
LVL	Laminate	• Beams, columns, vehicle decking, door and window frame, formwork system, flanges of I-joists • Industrial, commercial, recreational, residential and institutional	Length: up to 24 m Width: 19–90 mm Depth: 200–600 mm up to 2.5 m available
TimberStrand	Composite	• Beams, columns, truss members, headers, portal frames, post and beam systems • Industrial, commercial, recreational, residential and institutional	Length: up to 14.6 m Width: 45–140 mm Depth: 1220 mm
Parallam	Composite	• Beams, columns, truss members, headers, portal frames, post and beam systems • Industrial, commercial, recreational, residential and institutional	Length: up to 20 m Width: 45–275 mm Depth: 200–475 mm
I-joists	System	• Floor and roof joists, formwork, ceiling ties, load-bearing stud wall units, available as complete systems (cassettes). • Industrial, commercial, recreational, residential and institutional.	Length: up to 15 m Width: 38–97 mm Depth: 0.2–0.6 m
Box beams	System	• Beams and columns • Industrial and residential buildings	Spans of 30–40 m are possible with portal frames

In Table 1.20 the available range of EWPs is summarised and their applications are outlined.

1.8 SUSPENDED TIMBER FLOORING

A suspended flooring system generally comprises a series of joists closely spaced, being either simply supported at their ends or continuous over load-bearing partition walls. The floor boarding or decking is applied on the top of the joists and underneath ceiling linings are fixed. A typical suspended floor arrangement is shown in Figure 1.19a.

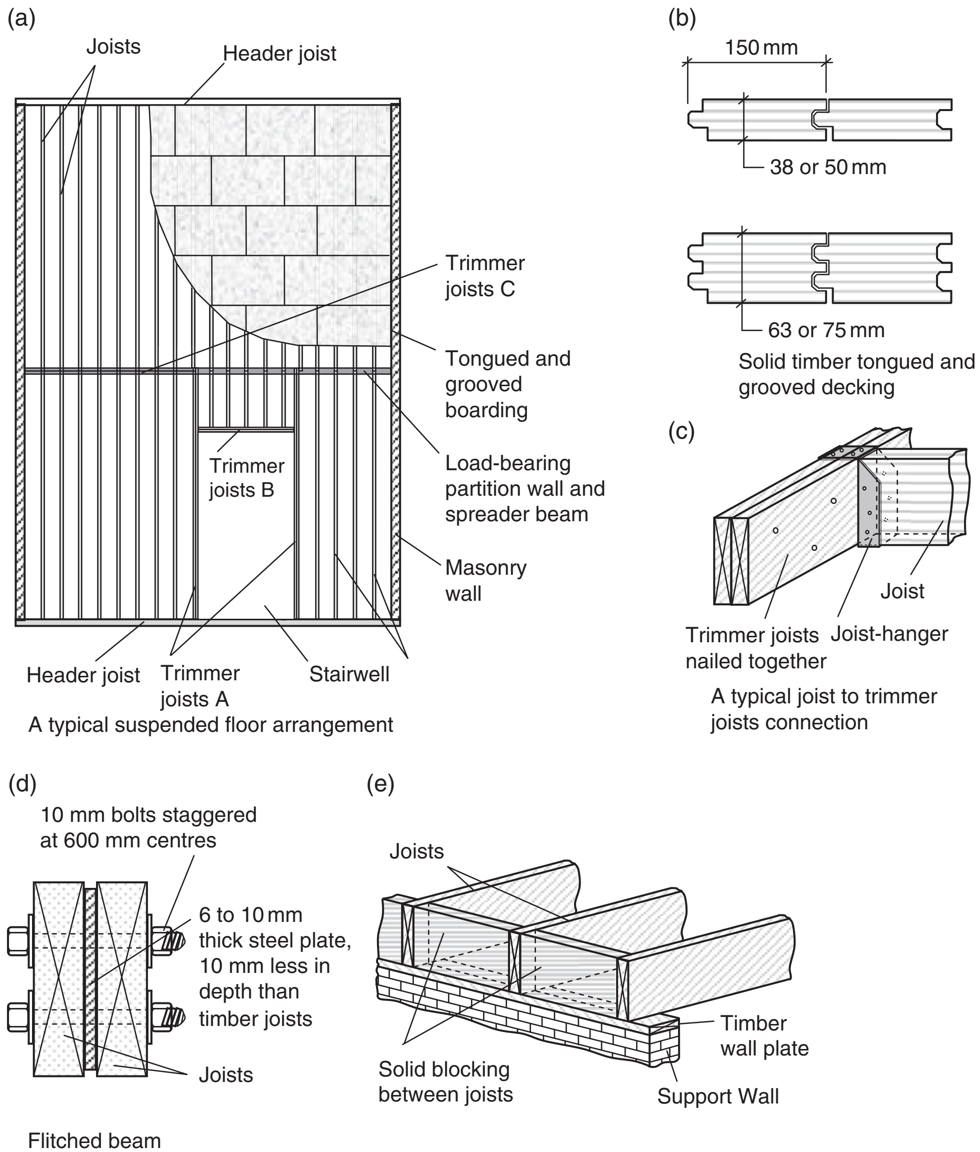


Fig. 1.19. Suspended timber flooring – typical components.

The distance between the centres of the joists is normally governed by the size of the decking and ceiling boards, which are normally available in dimensions of 1200 mm wide × 2400 mm long. The size of the decking and ceiling boards allows convenient joist spacings of 300 mm, 400 mm or 600 mm centre to centre. In addition, the choice of joist spacing may also be affected by the spanning capacity of the flooring material, joist span and other geometrical constraints such as an opening for a stairwell.

The most common floor decking in domestic dwellings and timber-framed buildings uses some form of wood-based panel products, for example chipboard, OSB or plywood. Solid timber decking such as softwood tongued and grooved (T&G) decking is often used in roof constructions, in conjunction with glued-laminated members, to produce a pleasant, natural timber ceiling with clear spans between the main structural members. The solid timber T&G boards are normally machined from 150-mm-wide sections with 38 to 75 mm basic thicknesses; see Figure 1.19b.

The supports for joists are provided in various forms depending on the type of construction. Timber wall plates are normally used to support joists on top of masonry walls and foundations; see Figure 1.19e. In situations where joists are to be supported on load-bearing timber-framed walls or internal partitions, header beams or spreader members are provided to evenly distribute the vertical loads. Joist hangers are often used to attach and support joists onto the main timber beams, trimmer members or masonry walls; see Figure 1.19c.

Timber trimmer joists are frequently used within timber floors of all types of domestic buildings; see Figure 1.19a. There are two main reasons for which trimmer joists may be provided. First is to trim around an opening such as a stairwell or loft access (trimmer joists A), and to support incoming joists (trimmer joists B), and second is to reduce the span of floor joists over long open spans (trimmer joists C), as shown in Figure 1.19a.

Trimming around openings can usually be achieved by using two or more joists nailed together to form a trimmer beam, as shown in Figure 1.19c, or by using a single but larger timber section, if construction geometry permits. Alternatively, trimmers can be of hardwood or glued-laminated timber, boxed ply-webbed beams, or as shown in Figure 1.19d, composite timber and steel flitched beams.

All flooring systems are required to have fire resistance from the floor below and this is achieved by the ceiling linings, the joists and the floor boarding acting together as a composite construction. For example, floors in two-storey domestic buildings require modified 30-min fire resistance (30-min load-bearing, 15-min integrity and 15-min insulation). In general, a conventional suspended timber flooring system comprising 12.5 mm plasterboard taped and filled, T&G floor boarding with at least 16 mm thickness directly nailed/screwed to floor joists, meets this requirement provided that where joist hangers are used they are formed from at least 1-mm-thick steel of strap or shoe type. Further information on fire safety and resistance is given in 1.11.

1.9 ADHESIVE BONDING OF TIMBER

In recent years there has been a significant advance in adhesive technology achieving high strength, stiffness and durability. These adhesives are now being used with timber, in the production of EWPs and also in timber construction to manufacture adhesively bonded components and connections (glued joints).

Connections bonded by adhesives can result in a better appearance and are often stiffer, requiring less timber; if formed by thermosetting resins they can perform better in fire than mechanical connectors. Their main disadvantage is the high level of quality control that is required in their manufacture and they can also degrade in conditions of fluctuating moisture content, in particular where dissimilar materials are involved. Examples of uses of adhesives in structural timber connections include finger joints, scarf joints, splice and gusset plates (using high-quality structural plywood plates), in the manufacture of I-beams, box beams, stress skin panels and in composite (sandwich) constructions where OSB or plywood side panels are bonded to a core of polystyrene such as in the manufacture of SIPs.

Structural adhesives should be weather and boil proof to BS EN 301:2006 [28]. Acceptable strength and durability can be achieved by using phenolic and aminoplastic-type adhesives as defined in BS EN 301. The adhesives should meet the requirements for adhesives type I or II as follows:

- Type I adhesives, which will withstand full outdoor exposure and temperatures up to and above 50 °C.
- Type II adhesives, which may be used in heated and ventilated buildings and exterior protected from weather. They may not be able to withstand prolonged exposure to weather or to temperatures above 50 °C.

The following adhesives may be considered:

- Resorcinol formaldehyde and phenol resorcinol formaldehyde
  Type: phenolic thermoset resin – for exterior use.
  Uses: finger jointing, laminating, timber jointing, etc.
- Phenol-formaldehyde (PF) hot setting
  Type: phenolic thermoset resin – for exterior use.
  Uses: plywood, laminating, particleboard, etc.
- Melamine urea formaldehyde
  Type: aminoplastic thermoset resin – for semi-exterior and humid interior use.
  Uses: plywood, laminating, particleboard, timber jointing etc.
- Urea formaldehyde
  Type: aminoplastic thermoset resin – for interior use.
  Uses: plywood, laminating, particleboard, timber jointing etc.
- Casein adhesives
  Type: milk product – for interior use only.
  Uses: general purpose timber jointing.

It should be noted that not all adhesives are classified in accordance with BS EN 301. It is therefore important for the designer to ensure that the adhesives selected are suitable for the specified service class and comply with the relevant building regulations. It is also important that timber is conditioned to a moisture content corresponding to the average moisture content likely to be attained in service and that surfaces are properly prepared prior to gluing.

1.10 PRESERVATIVE TREATMENT FOR TIMBER

Under ideal conditions timber should not deteriorate, but when timber is used in exposed (outdoor) conditions, it becomes susceptible to degradation due to a variety of natural causes. It will suffer rot and insect attack unless it is naturally durable or is protected by a preservative. In general, timber with a moisture content of over 20% is susceptible to fungal decay; timber of any species kept in dry conditions will remain sound; however, dry timber may be subjected to insect attack. Timber can be protected from the attacks by fungi, harmful insects or marine borers by applying chemical preservatives. The degree of protection achieved depends on the preservative used and the proper penetration and retention of the chemicals, as treatability varies among the species and also between their heartwood and sapwood. Some preservatives are more effective than others, and some are more adaptable to specific use requirements.

There are a number of widely used methods of application of preservative treatments. Pressure impregnation with a water-borne agent is appropriate for timber in ground contact or high hazard conditions. Double vacuum impregnation with a solvent-based organic preservative is a preferred method for treating joinery timbers. Micro-emulsion treatments, which are water borne, with new more environmentally acceptable products, are now available in the market. Preservatives should be applied under the controlled conditions of an authorised wood treatment plant.

British Standard BS 8417:2011 [29] provides guidance on the treatment of timber for use in the United Kingdom, and includes the requirements of key parts of other relevant BS and EN standards. Issues related to the requirement for preservative treatment include service life, in-service environment, species type and its natural durability as well as the type and form of the preservative treatment.

BS EN 335-1:2006 [30] provides a description of use classes and lists the potential biological organisms and insects that may challenge the timber in a particular service condition. A summary of use classes is given in Table 1.21.

Recommendations for the treatment of softwood timbers are given in BS 8417. Further information on the protection of timber and timber products may be found in the following:

- TRADA publication: Wood Information Sheet WIS 2/3-33 Wood preservation – Chemical and processes, 2005.
- Wood Protection Association (WPA): Industrial Wood Preservation, Specification and Practice, Derby, 2006. (www.wood-protection.org).

1.11 FIRE SAFETY AND RESISTANCE

Fire safety involves prevention, detection, containment and evacuation; requiring prevention of the ignition of combustible materials by controlling either the source of heat, reducing the combustibility of the materials or providing protective barriers. This involves proper design and detailing, insulation or construction and maintenance of the building and its components.

Timber and wood-based materials comprise mainly cellulose and lignin, which are combustible and will burn if exposed to an ignition source under suitable conditions. But this does not mean that due to its combustibility timber is an unacceptable material for construction use. Often the opposite is true. Due to its good thermal insulation properties, when timber burns a layer of char is created, which helps to protect and maintain the strength and structural integrity of the wood inside. This is why timber in

Table 1.21 Use classes and possible biological organisms*

Use classes	Definition of service situation (location of timber component)	Exposure to wetting during service life	Biological organisms			
			Fungi	Beetle[†]	Termite	Marine borers
1	Above ground, covered (dry)	None	No	Yes	Possible	No
2	Above ground, covered (risk of wetting)	Occasionally	Yes	Yes	Possible	No
3	(i) Above ground, exterior, protected	Occasionally	Yes	Yes	Possible	No
	(ii) Above ground, exterior, not covered	Frequently				
4	(i) In contact with ground, exterior and/or fresh water	Predominantly or permanently	Yes	Yes	Possible	No
	(ii) In contact with ground, severe exterior and/or fresh water	Permanently				
5	In salt water	Permanently	Yes	Yes	Possible	Yes

*In accordance with BS EN 335-1:2006.
[†]The risk of attack can be insignificant depending on specific service situations.

large sections can often be used in unprotected situations where non-combustible materials such as steel would require special fire protection.

The fire protection of timber depends on many factors including size, species type and moisture content. Smaller section sizes, low-density species and sections with cracks and fissures are more likely to ignite and burn more easily than larger and denser ones, and as such may require treatment with flame-retardant chemicals. This may also be a design requirement for situations that require the use of materials with better fire-resistance properties. The treatments used are based on formulations of water-soluble inorganic salts such as ammonium phosphate or water-soluble humidity-resistance formulations and organic resins.

The choice of fire-retardant treatment depends upon many different factors, including the standard of performance required and the conditions in which the treated timber or panel products are to be used. There is much literature available on the choice of fire-retardant treatment and information is also available from specialist organisations including the following:

- TRADA publication: Wood Information Sheet WIS 2/3-3, Flame Retardant Treatments for Timber, 2003.
- Wood Protection Association (WPA): Flame Retardant Specification Manual, 2nd Edition, Derby, 2011. (www.wood-protection.org).

The fire performance of all materials to be used in buildings (of various use), including wood and wood-based products, is given in the relevant Building Regulations operating in Scotland, England and Wales, and Northern Ireland.

The design of timber structures for the accidental situations of fire exposure should be carried out in accordance with the requirements of Eurocode BS EN 1995-1-2:2004 [31] in conjunction with BS EN 1995-1-1:2004+A1:2008 [12] and EN 1991-1-2:2002 [32]. This standard describes the principles, requirements and rules for the structural design of buildings exposed to fire, so that

- fire risks are limited with respect to the individual, neighbouring property, society, and where required, directly exposed property, in the case of fire, and
- a detailed structural fire design is carried out covering the behaviour of the structural system at elevated temperatures, the potential heat exposure and the beneficial effects of active fire protection systems, together with the uncertainties associated with these three features and the consequences of failure.

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