

Engineered wood products and an introduction to timber structural systems

There are limitations on the maximum cross-sectional size and lengths of sawn timber that can be used as a structural component due to the availability of log sizes and the presence of naturally occurring defects in the timber (see Timber Engineering Notebook No. 1).

These defects can be cut out and the timber reconstituted using engineered wood techniques such as finger jointing (Figure 1) to create longer lengths of timber of an assured strength grade, or laminating to form a homogeneous timber section. Combinations of timber or laminated sections with different materials such as wood-based boards or metal elements are used to create 'engineered wood products' (EWPs) whose maximum size is limited only by manufacturing, handling and transportation constraints.

In addition to engineered wood products, there are reconstituted board products which comprise smaller wood-based strands and fibres re-formed into panel products. These have structural applications but are also used extensively in the furniture-making and packaging industries. Types of timber structural systems and their applications are also introduced in this Notebook.

Engineered wood products

EWPs including glued laminated timber, finger joints, plywood, stressed skin panels, mechanically and adhesive bonded web beams and connected and nail plated trusses, have been in existence for at least 40 years.

Recently, there have been significant developments in the range of EWPs for structural applications with materials such as laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), prefabricated I-beams, metal web joists and 'massive' or cross-laminated timber (CLT) becoming more widely available.

These EWPs are typically manufactured by adhesively laminating together smaller softwood sections or laminates (e.g. glulam and CLT) or veneers or strands of timber (e.g. LVL, LSL and PSL). The varying performance of EWPs is influenced by the size of wood component used in the product. At one end of the spectrum smaller sections of timber are laminated and finger jointed to form sections of glulam, whilst at the other end, reconstituted board products such as oriented strand boards (OSBs) and medium density fibre boards (MDFs) use small wood strands or fibres bonded together (Table 1).

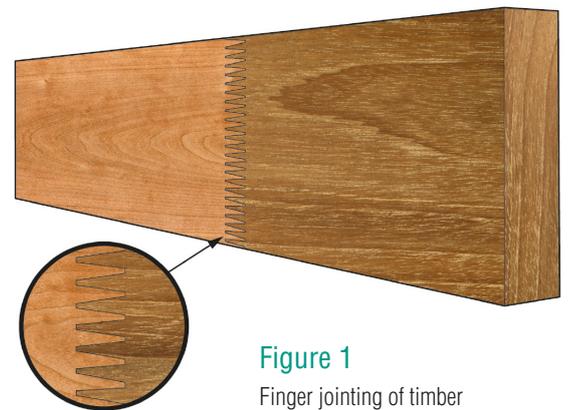


Figure 1
Finger jointing of timber

Table 1: Fibre size and beam types for timber products

Timber	Sawn timber sections As cut from the tree
Engineered wood products (EWPs)	<p>Finger jointed lengths of timber Fabricated from smaller lengths of timber to form a longer element length</p> <p>Glulam and CLT Small sections typically 25-45mm thick glued together to form a bigger beam or slab section</p> <p>Veneers e.g. LVL or plywood Typically 2-4mm thick wood glued together to form sections – both boards and beams</p>
Reconstituted board products	<p>Strands e.g. OSB wood slices Glued together to form sections – both boards and beams</p> <p>Wood fibres Bonded to form sections – more typically used for board products than beams e.g. particleboards and fibreboards</p>

DECREASING SIZE OF ORIGINAL WOOD MATERIAL

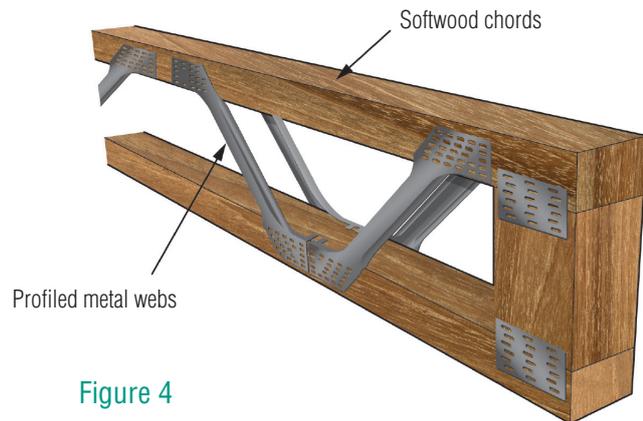
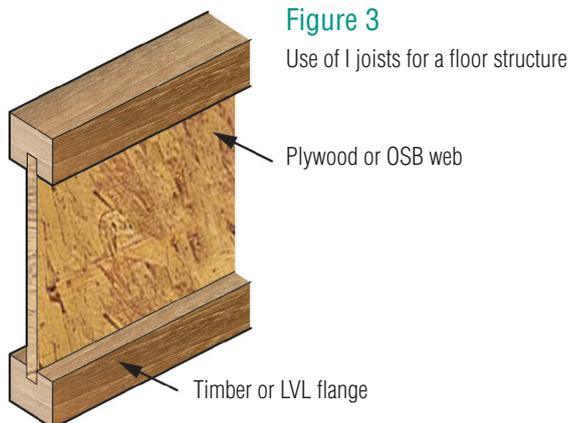


Figure 4
Open web joist



Thin webbed joists (I joists)

I joists (Figure 2) are an EWP manufactured with flanges made from softwood or LVL with glued thin webs generally made from OSB, fibreboard or plywood. I joists can be used to resist either flexural or axial loads or a combination of both (Figure 3).

Metal web or open web joist

Open web joists are shallow parallel-chord trusses manufactured using similar techniques to that used for trussed rafters comprising a member with flanges (or chords) usually made from softwood and with metal or timber strutting to form the webs (Figure 4).

The chords (and webs where timber webs are used) are generally planed softwood graded in accordance with BS EN 14081-1. The strength class of the timber is usually C27 in accordance with BS EN 338:2009 or TR26 (whose characteristic strength values are equal to that of C27 but whose characteristic stiffness values are taken from BS5268-2:2002). The depth of the chords is generally 47mm and their widths range from 72mm to 145mm. Metal webs are typically profiled, nominal 1mm galvanised light gauge steel with a zinc coating specification of Z275.

Open web joists are principally used as a roof or floor joist element. They are often preferred to I-joists as they allow a combined services and structural zone.

Plywood

Plywood is a flat panel made by bonding together, under pressure, a number of thin layers of veneers (or plies). Plywood was the first type of EWP to be widely available.

The structural properties and strength of plywood depend mainly on the number, thickness, species and orientation of the plies.

The structural grade plywoods that are commonly used in the UK construction industry are:

- American construction and industrial plywood
- Canadian softwood plywood
- Finnish birch-faced, birch and conifer plywoods. Birch plywood gives a good fair-faced finish and is readily persuaded into curved profiles
- Swedish softwood plywood

Plywoods are typically used for roof and floor decking applications and for wall sheathing boards.

Plywood for structural applications should be specified as "having exterior glue bond to BS EN 314-2 and veneers in compliance with BS EN 636:2003". This replaces the previous definition for the plywood of WBP exterior grade where 'WBP' describes the properties of the adhesive and 'exterior grade' describes the durability of the outer veneers.

The characteristic strength and stiffness values for plywood for use in structural design are contained in BS EN 12369-2:2004.

Laminated veneer lumber

Laminated veneer lumber (LVL) is a structural member manufactured by bonding together thin vertical softwood veneers with their grain parallel to the longitudinal axis of the section, under heat and pressure. In some cases cross grain veneers are incorporated to improve dimensional stability.

LVL is often used for high load applications to resist either flexural or axial loads or a combination of both. It can provide both panels and beam/column elements.

The requirements for LVL are contained in product standard BS EN 14374:2004.

Laminated strand lumber

Laminated strand lumber (LSL) is a structural member made by cutting long thin strands approximately 300mm long and 0.8mm - 1.3mm thick directly from de-barked logs. The strands are blended, coated with adhesive and oriented so that they are essentially parallel to the longitudinal axis of the section before being reformed by steam-injection pressing into a solid section. LSL is used in similar applications to LVL.

Parallel strand lumber

Parallel strand lumber (PSL) is a structural member made by cutting long thin strands (typically 3.2mm thick, 20mm wide and up to 3.0m long) from timber veneers. The strands are oriented so that they are essentially parallel to the longitudinal axis of the section before being coated with adhesive and fed into a continuous press and microwave-cured. PSL is used in similar applications to LVL.

LSL and PSL have recently become less widely available in the UK due to a preference for LVL and supply chain considerations.

Glued laminated timber

Glued laminated timber (glulam) is a structural member made by gluing together a number of graded timber laminations with their grain parallel to the longitudinal axis of the section. Members can be straight or curved, horizontally or vertically laminated and can be used to create a variety of structural forms (Figure 5).

Laminations are typically 25mm or 45mm thick but smaller laminations may be necessary where tightly curved or vertically laminated sections are required.

The requirements for the manufacture of glulam are contained in product standard BS EN 14080: 2013.

Cross laminated timber

Cross laminated timber (CLT) is a structural timber product with a minimum of three cross-bonded layers of timber, of thickness 6mm to 45mm, strength graded to BS EN 14081-1:2005 and glued together in a press which applies pressure over the entire surface area of the panel.

CLT panels typically have an odd number of layers (3,5,7,9) which may be of differing thicknesses but which are arranged symmetrically around the middle layer with adjacent layers having their grain direction at right angles to one another (Figure 6).

The structural benefits of CLT over conventional softwood wall framing and joisted floor constructions, include:

- large axial and flexural load-bearing capacity when used as a wall or slab
- high in-plane shear strength when used as a shear wall
- fire resistance characteristics for exposed applications
- superior acoustic properties

Due to its arrangement as a panel rather than a framed construction comprising discrete loadbearing elements, CLT also distributes concentrated loads as line loads at foundation level. A variant of CLT developed in Germany in the 1970s is Brettstapel or 'massive timber', which is the term commonly used for solid timber construction that does not generally



Figure 5
Connections in curved, vertically laminated glulam



Figure 6
Cross laminated timber

Table 2: Characteristic strength, stiffness and density properties for some EWP's

Grade	Bending strength (N/mm ²)	Mean modulus of elasticity parallel to grain E _{0,mean} (N/mm ²)	Characteristic density (kg/m ³)
Versa-Lam LVL ¹	44	14600	580
Steico LVL ²	48	14000	550
Kerto S LVL ³	44	13800	480
LSL 1.55E ⁴	34.2	10600	430
GL28H ⁵	28	12600	410

¹Courtesy Boise Cascade ²www.steico.co.uk ³Metsa Wood Kerto VTT Certificate No184/03 October 2005 ⁴Louisiana Pacific ETA - 13/0038 ⁵Homogenous glulam to BS EN 1194:1999

use glue or nails. Fabricated from softwood timber posts connected with hardwood timber dowels, the system works by using dowels with a moisture content lower than that of the posts. Over time, the dowels expand to achieve moisture equilibrium, thus 'locking' the posts together and creating a structural load-bearing panel system. CLT should be designed using the principles given in BS EN 1995-1-1 and -1-2 together with data from the manufacturer of the product.

Table 2 illustrates the properties of a variety of EWP's.

Reconstituted wood-based board products

Reconstituted board products are typically manufactured by combining smaller wood strands or fibres with adhesive. There is a structural penalty when timber is modified from a sawn product to small strands and fibres used in board products, as the effects of creep increase as the amount of glue used to join the smaller wood elements increases.

The design of reconstituted timber board materials takes the resulting reduced performances into account by the use of relatively low values for the factor k_{mod} in BS EN 1995-1-1 Table 3.1 for OSB, particleboards and fibreboards.

Oriented strand board

Oriented strand board (OSB) is a multilayer board made from strands of wood sliced from small diameter timber logs and bonded together with an exterior grade adhesive, under heat and pressure. OSB is manufactured in various grades with improving resistance to the effects of moisture. The minimum grade that should be used for

Table 3: Summary of timber, engineered wood and board products and their structural applications

Product	Application	Common sizes
Sawn timber	Small structural framing, studs and joists, general carcassing, door panels, joinery	Length: up to 5.4m Width: 25-75mm Depth: up to 250mm
Finger-jointed softwood	Floor and roof joists, ceilings, loadbearing studs, cladding support, prefabricated multi-span 'cassette floors', laminations for glulam members	Length: up to 20m Width: 38-75mm Depth: up to 250mm
Glulam	Large structural elements, beams, columns, trusses, bridges, portal frames, post and beam structures	No theoretical limits to size length or shape. Common size range: 60 to 250mm wide by 180mm to >1000mm deep
'Massive' or cross laminated timber (CLT)	Floor slabs, roofs, beams, columns, load bearing walls, shear walls	Length: up to 20m Thickness: 50-300mm Width: up to 4800mm
Laminated veneer lumber (LVL)	Beams, columns, trusses, portal frames, post and beam structures, structural decking, I-joint flanges, stressed skin panels	Length: up to 20m Width: 19-200mm Depth: 200mm up to 2500mm
Laminated strand lumber (LSL)	Beams, columns, post and beam structures	Length: up to 20m Width: 30-90mm Depth: 90mm to >1000mm
Parallel strand lumber (PSL)	Beams, columns, post and beam structures	Length: up to 20m Width: 45-200mm Depth: 200mm to >1000mm
Particleboards	Flooring, ceiling and panel infill	Board materials typically available in 1220mm x 2440mm sheets and thickness ranges from 9 to 25mm
Oriented strand board (OSB) & plywood	Structural sheathing and decking	
Metal web or open-web joists	Floor and roof joists, ceilings, prefabricated 'cassette floors'	Length: up to 20m Width: 72-147mm Depth: 200-400mm
I joists	Floor and roof joists, formwork, ceilings, loadbearing studs, cladding support, prefabricated 'cassette floors'	Length: up to 20m Width: 38-97mm Depth: 200-500mm
Box beams, thin flange beams e.g. stressed skin panels	Beams, roofs, columns	No theoretical limits to size length or component sizes

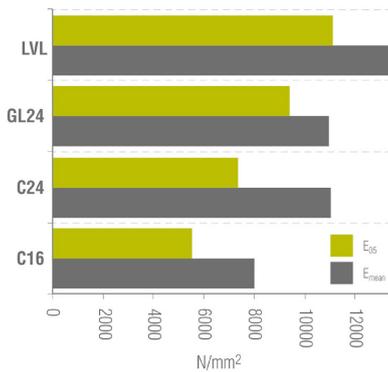


Figure 7
Comparison of modulus of elasticity (E) and associated variation with various timber grades and structural timber composites

structural applications is OSB/3 as given in BS EN 300:1997. OSB is commonly used as a structural sub deck material for floors and roofs and as a sheathing material for walls. It is also used for composite constructions such as I joist webs and structural insulated panels (SIPs).

Particleboard and fibre composites

There are a number of different board materials made from particle and fibre composites including fibreboards, tempered hardboard, cement-bonded particleboard and wood chipboard. The most common for structural applications is chipboard, which is made from small particles of wood and binder.

Chipboards are classified as grades P1-P7 in BS EN 312:2003 depending on their intended use. The minimum grade that should be used for structural applications is P5 which is a moisture-resistant grade.

The characteristic strength and stiffness values for OSB, particleboards and fibreboards for use in structural design are contained in BS EN 12369-1:2001.

Table 3 shows the range of timber and EWPs available, together with their typical applications.

Advantages of EWPs as structural materials

Use of waste timber

Timber can be recycled and turned into strands and fibres and reconstituted into an engineered wood product.

Enhanced strength and stiffness

By building up a structural section from a number of smaller elements it is possible to reduce the variability inherent in natural timber, thereby improving the strength and stiffness of the composite section.

This is illustrated in Figure 7 which shows the mean and 5th percentile modulus of elasticity parallel to the grain associated with a range of softwoods, hardwoods and structural timber composites. The figure shows that composites have better stiffness properties than the natural sawn sections from which they are composed.

Increased size and scope of application

Engineered timber structures incorporate factory produced components where the constraints on length and section may be determined only by manufacturing, handling and transportation considerations rather than the constraints set by the size of log available. It is therefore possible to extend the range of timber engineering possibilities to large span and tall structures.



Figure 8
Scunthorpe Sports Academy: example of glulam gridshell roof

Reduced moisture content

The production requirements for certain EWPs may call for low moisture content e.g. gluing, which can result in lower movement upon drying out in service. However, in some cases (e.g. OSBs) the moisture content of the product following manufacture is lower than will be experienced during the construction phase, which can lead to problems due to dimensional changes of the product in humid environments.

Dimensional consistency

Engineered wood products disperse the natural defects inherent in solid timber and are manufactured to controlled tolerances. As a result, their dimensional consistency is significantly improved. This can be beneficial where tight tolerances may be required e.g. at connections. More regular joist depths also result in flatter floor structures than would be possible with sawn timber joists; thus avoiding some of the problems that can be associated with small variations in joist depth such as 'nail squeak'.

Ease of installing services and ease of handling

Service runs for mechanical and electrical infrastructure can easily be installed through open-web joists and, to a lesser extent, through I joists.

I joists and open web joists in particular are lighter in weight than equivalent solid timber sections and are therefore easier to handle.

Types of timber structures

Structural methods have been developed, incorporating EWPs, to provide timber structures which achieve a particular function with satisfying aesthetic form and performance e.g. timber gridshells and stressed skin panel roofs (Figure 8).

Portal frames and beam and post structures

Large open plan structures can be created by using portal frames and beam and post structures constructed from engineered wood products.

Platform frame construction

Methods of construction such as platform frame construction enable the construction of multi-storey timber frame structures for buildings which have a cellular arrangement of rooms and where internal loadbearing walls can be utilised.

Table 4: Types of timber structural systems and their applications

System	Application	Limitations
Platform frame construction (softwood construction)	Residential, care homes, hotels, student accommodation	Commonly used for cellular-plan buildings with internal load-bearing walls. Up to 7 storeys possible, however requirements for preventing building overturning may govern
Glulam or LVL beam and post frames	Schools, atria, commercial, supermarkets	Used to create 'open' framed areas but require separate bracing systems for stability. No theoretical limits on span or number of storeys
Glulam or LVL portal frames	Halls, industrial buildings, arenas, distribution centres	Usually single storey. Large open spaces with spans of more than 30m possible. The size of the portal frames is usually only limited by transportation
Cross laminated timber (CLT) or 'Brettstapel' (massive timber)	Multi-storey residential, schools, academies, auditoria, exhibition spaces, places of worship, sports halls, theatres where an exposed timber finish is beneficial	Platform and balloon-frame construction. Tall single storey wall panels possible and structures up to 10 storeys tall have been constructed. Large panels need careful consideration in terms of transportation and handling
Structural insulated panels (SIPs)	Residential, care homes, hotels, student accommodation; infill panels to steel and concrete frames; roof panels for 'room-in-the-roof' construction	External envelope wall panels within platform frame or frame infill construction. Up to 4 storeys possible for load-bearing applications. Good thermal performance. Roof spans may be limited by shear and creep deflections of core materials
Special structures	Gridshells, arches, domes, bridges	Project specific solutions which typically span 10-50m, though there are examples of 150m span gridshells
Engineered trusses	'Feature trusses' using glulam or oak, industrial, commercial and institutional	Spans between 10 to 50m
Trussed rafters	Roofs for residential buildings, care homes, hotels, masonry, steel and concrete structures	Typically up to 12m but for special designs spans of up to 30m are practicable
Stressed skin panel roofs and floors	Swimming pools, infill panels to steel frames, civic buildings	Roof spans up to 20m; floor spans up to 12m

Trussed rafters

The modern trussed rafter roof is an engineered timber structure that has evolved in form over the past 40 years, but most commonly adopts the use of softwood timber tension and compression members connected in a single plane by punched metal plate fasteners, manufactured from galvanised mild steel.

Structural insulated panels

Other structural systems such as structural insulated panels (SIPs) are composite members which use a core of rigid insulation, not only to provide a u-value for a building's thermal envelope, but also to form a longitudinal shear connection between plywood or OSB face layers; thus enabling it to act as a structural panel.

Table 4 provides a brief description of the types and scope of engineered timber structures that can be designed to provide structurally efficient and aesthetically appealing structures for a wide variety of building uses. These and other structural methods will be investigated in more depth in subsequent articles in this series.

Design

Eurocode 5 has provided opportunities for UK designers to use timber for new applications that should give economic solutions, particularly as the code makes provision for the use of new materials, such as engineered wood products and new efficient jointing techniques. The code encourages engineers to gain a greater understanding of timber which will lead to more efficient and innovative designs for engineered timber structures.

Structural forms and detailing, together with examples of calculations for structural timber to Eurocode 5, will be discussed in future articles.

Limitations

In addition to the structural strength and stiffness aspects of timber engineering there are other considerations which affect 'wholebuilding' performance and must be considered. These include:

- Timber shrinkage and differential movement
- Design for robustness
- Architectural detailing including detailing for durability
- Fire during construction and service
- Workmanship and maintenance

As with structural form/detailing etc., these topics will be explored in more depth, later in the series.

RELEVANT CODES OF PRACTISE

BS 5268-2:2002 Structural use of timber – Part 2: Code of practice for permissible stress design, materials and workmanship

BS EN 300:1997 Oriented Strand Boards (OSB) – Definitions, classification and specifications

BS EN 312:2003 Particleboards - Specifications

BS EN 338:2009 Structural timber - Strength classes

BS EN 636:2003 Plywood – Specifications

BS EN 1995-1-1 Eurocode 5: Design of Timber Structures – Part 1-1: General – Common rules and rules for buildings

UK National Annex to Eurocode 5: BS EN 1995-1-1: Design of Timber Structures – Part 1-1: General – Common rules and rules for buildings

PD 6693-1:2012 UK Non-Contradictory Complementary Information (NCCI) to Eurocode 5: Design of timber structures

BS EN 12369-1:2001 Wood-based panels – Characteristic values for Structural Design: Part 1: OSB, Particleboards and Fibreboards

BS EN 12369-2:2004 Wood-based panels – Characteristic values for Structural Design: Part 2: Plywood

BS EN 14080:2013 Timber structures – Glued laminated timber – Requirements

BS EN 14081-1:2005 Timber Structures – Strength graded structural timber with rectangular cross-section. General requirements

BS EN 14374:2004 Timber structures. Structural laminated veneer lumber. Requirements

DEFINITIONS

Engineered wood products - reconstituted wood-based products which may be formed from homogenous wood-based material; for example glulam or non-homogenous products to form a composite material e.g. I joists.

Composites - an assembly of engineered or naturally occurring materials made from more than one constituent part, which work together structurally.

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The Structural Timber Association represents over 85% of the UK's timber structural frame supply industry and is a trade organisation that provides business and technical support to the industry. The Association provides peer reviewed outputs on subjects related to the timber industry such as health and safety, fabric and technical performance, fire safety, promotion and training. These documents and other information are available at www.structuraltimber.co.uk/information-centre/technical-library