WOODINFORMATION

Glued laminated timber

Figure 1 This striking glulam bridge, near Oslo in Norway, is based on a Leonardo da Vinci design dating from 1502.
Vision: Leonardo da Vinci, Vebjørn Sand Architects: Selberg Arkitektkontor Engineers: Reinertsen Engineering
Glulam fabricators: Moelven Limtre. Photograph: courtesy Terje Johansen
Further information:www vebjorn-sand.com /thebridge.htm

Aesthetically attractive structural timber components of large sizes and complex shapes can be fabricated from smaller sawn sections (laminates) by the process of glued lamination, known as glulam.

Glulam is manufactured from laminates of sawn timber, planed to a smooth surface, before being glued together with the grain in the laminates running essentially parallel. Laminated veneer lumber (LVL) and plywood, on the other hand, are produced from peeled veneers, which can run either parallel or parallel/perpendicular respectively.

Individual laminates can be end-jointed by the process of finger jointing to produce long lengths. Beams wider than the normal commercially available laminates can be manufactured by edge-gluing after finger jointing. The lay-up of these wide laminates is arranged so that both edge and finger joints are staggered.

Specialist manufacturers can produce laminated components in the size, section and profile required. Virtually any size of cross section and length of component can be produced from glulam. The constraints are those imposed by transportation and individual manufacturer's facilities. Spans of 40 metres and depths of 2 metres have been produced, but spans up to about 30 metres are more usual. In the USA, highly competitive domed structures spanning 150 metres have been built using glulam ribs.

Most manufacturing companies employ design engineers who will undertake any necessary detailed design calculations and advise on construction detail.

To provide immediate availability of straight laminated beams most manufacturers provide stockists with a range of standard beams in commonly used sizes. These provide convenient and economic alternatives to other materials.

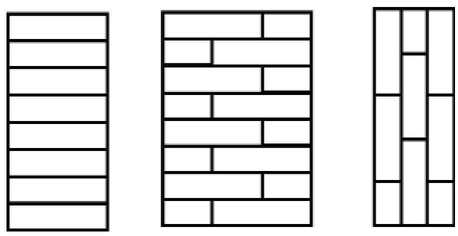

Figure 2 Horizontal glulam (left and centre) and Vertical glulam (right)

Structural forms

Glulam components can be manufactured to meet virtually any architectural or aesthetic structural requirement. Common basic structural forms include:

Straight:
eg purlins, beams, lintels, portals

Triangulated:
two dimensional eg A-frames, trusses, girders
three dimensional eg pyramids, space frames, cones

Curved:
two dimensional eg arches, portals
three dimensional eg domes (portals or geodesic).

Section depths may be varied along the length of the component to form tapered beams and columns, arches and portal frames. Strength to weight ratio is high and the comparatively low weight facilitates handling compared with components manufactured from other materials. The sizes of glulam normally available in the UK are shown in Table 1.

Other applications

Edge-glued slabs have been produced for bridge decks, trailer floors and heavy-duty floors in warehouses. Their full potential has not been exploited by the construction industry, although a double tongued and grooved decking system for ceilings and floors has been popular with specifiers for several decades. These slabs and decking systems have a high load-carrying capacity, combined with good heat and sound insulation. They produce an efficient structural solution, which ideally complements glulam components.

Performance

As a result of the low moisture content dictated by the bonding and the random laying-up of the laminates, the finished component will usually have better dimensional stability and suffer less from shrinkage and deformation than solid wood sections, which often complete their drying after installation. The low coefficient of thermal expansion of timber, compared with steel, is also an advantage as expansion joints may be omitted or simplified, even in large structures. Similarly, timber has better resistance to corrosive, industrial or marine atmospheres than either steel or concrete.

The considerable savings in maintenance costs on exterior structures, such as bridges, make the use of glulam a very attractive proposition to specifiers and owners. The hazards of wet and exterior locations are met by using good detailing and durable hardwood or properly preservative-treated softwood components. The use of exterior microporous wood stains will provide surface protection, give a satisfactory appearance and are easy to maintain. If the top surfaces of horizontal or sloping laminated sections are not protected by roof overhangs, it is advisable to provide a ventilated metal capping. This reduces wetting of the upper laminates and will also prolong the life of any finishes.

When subject to fire, large timber sections have greater resistance to loss of structural integrity than steel or pre-stressed concrete. This resistance is provided by a layer of charcoal which forms around the surface of the section during exposure to fire. The rate of charring for different species of timber is known, therefore the performance and endurance of timber in fire is predictable. This means that the overall size of the section required to achieve the necessary fire resistance can be readily calculated. The method of calculation is included in BS 5268-4: *Fire resistance of timber structures Section 4.1 Method of calculating the fire resistance of timber members*. The performance of timber in fire is described in TRADA WI sheet *Timber and wood based sheet materials in fire.*

Table 1 Common sizes for softwood glulam in the UK. Typical stock sizes shown ***bold.***

Breadth mm	*Depth mm*																			
	180	225	270	315	360	405	450	495	540	585	630	675	720	765	810	855	900	945	990	1035
65	X	X	X	**X**																
90		X	X	**X**	X	**X**	X													
115				X	X	**X**	**X**	X	X											
140					X	X	X	X	X	X	X	X								
165								X	X	X	X	X	X	X	X					
190												X	X	X	X	X	X	X		
215														X	X	X	X	X	X	X

Manufacture

The manufacturing procedure for glulam components will depend upon the volume and nature of the work, together with the fabricator's production facilities. All stages of the process for the manufacture of glulam with finished lamination thicknesses of not more than 45 mm, should comply with the requirements of BS EN 386 *Glued laminated timber - Performance requirements and minimum production requirements*. A high standard of glulam production can be achieved with simple equipment, but the trend is towards large-scale production using complex machinery. BS EN 390 *Glued laminated timber - Sizes - Permissible deviations* gives allowable deviation from the target sizes of the finished components.

The BS EN 386 requirements apply to structural members used in Service Classes 1 and 2. For members used in Service Class 3, special precautions need to be taken, for example the use of weather-resistant adhesives. The Service Classes are defined in BS 5268-2 *The structural use of timber. Permissible stress design, materials and workmanship* and in DD ENV 1995-1-1 *Eurocode 5: Design of timber structures. General rules and rules for buildings (EC5)*. Typical environments for the service classes as shown in Table 2.

The general aim of BS EN 386 is to ensure that reliable and durable bonding is achieved consistently. To this end it lays down requirements relating to premises, staff expertise and equipment as well as technical aspects, such as the moisture content of the laminates at the time of gluing, the orientation and lay-up of the laminates, cramping pressures, curing time and temperature for the glues. Emphasis is laid on quality control, with routine daily testing of finger joints and laminate gluelines being required as part of the production process. The manufacturer is required to keep detailed records of every production run. External control through independent third party quality certification to oversee the quality of production is strongly recommended. Glulam produced to BS EN 386 should be marked with the following information:

- name or identity of the producer
- strength class or other strength identification
- adhesive type
- production week and year
- certificate number
- standard number ie EN 386.

Material preparation

Laminating stock is selected from commercial supplies by machine or visual grading, in accordance with BS EN 519 *Requirements for machine strength graded timber and grading machines* and BS 4978 *Specification for visual strength grading of softwood* respectively. The number of laminates in a component has a bearing on its strength. Generally, the greater the number of laminates for a given beam depth, the higher the strength. However, in the interests of economy, the number should be kept to a minimum, with each laminate not exceeding 45mm in thickness. This minimises splitting, distortion and problems associated with achieving adequate bond pressure. The geometric form of the glulam component determines the thickness of the laminates. The thicker laminates are used for straight and possibly very slightly curved components. Progressively thinner laminates will be used, as dictated by the radius of curvature, for arches, portal frames and similar profiles. For example, laminates down to a thickness of around 12mm will be required for small radius curves. Guidance for laminate thickness, compared with radius of curvature, is given in BS EN 386.

Table 2 Service classes for glulam structures

Service Class	*Climatic conditions*	*Average equilibrium moisture content in softwood*	*Typical environment*
1	*20° C; humidity exceeding 65% for only a few weeks per year*	*12%*	*Timber in buildings with heating and protected from damp conditions eg internal walls, intermediate floors, warm roofs*
2	*20° C; humidity only exceeding 85% for a few weeks per year*	*20%*	*Timber in covered buildings, eg ground floors, cold roofs, inner leaf of cavity walls, external single leaf walls with external cladding*
3	*Conditions leading to higher moisture contents than Service Class 2*	*Above 20%*	*Timber exposed to the weather, eg exposed parts of open buildings, marine structures*

Figure 3 Winter gardens, Sheffield. This larch glulam structure forms part of the city's current regeneration process.
Architects: Pringle Richards Sharratt
Structural Engineers: Buro Happold

Figure 4 Lahti Sibelius Hall, Finland. An example of internal structural glulam. Composite glulam and LVL both in spruce.

End jointing, to obtain full-length laminates, is usually achieved using finger joints, which should conform to BS EN 385 *Finger jointed structural timber. Performance requirements and minimum production requirements*. BS EN 385 requires the strength of the joint to be compatible with the strength of the grade and species of timber being joined. BS 5268-2 gives joint efficiency ratings for some common profiles of finger joints manufactured in accordance with BS EN 385. Both BS 5268-2 and EC5 permit the use of 'large finger joints', ie through the whole section of a glulam member, providing the process is subject to third party quality assurance. The joints are covered in BS EN 387 *Glued laminated timber - Large finger joints - Performance requirements and minimum production requirements*.

Bonding

Adhesives used in the manufacture of glulam components are required to have sufficient strength to provide a bond between the laminates that is at least as strong as the timber. They must also be creep-free under load and have a durability suited to the component's service conditions. Refer to BS EN 301 *Adhesives, phenolic and amino-plastic, for load-bearing timber structures - Classification and performance requirements* for acceptable adhesives. Further information is given in TRADA WI sheet *Adhesives for wood and wood based products - BS EN Standards*. Glulam exposed to the weather, or subject to prolonged high temperatures (in roofs in summer, for example, temperatures can exceed 50°C), should incorporate Type I adhesives to BS EN 301. For other components under cover or in heated and ventilated buildings, Type II is suitable.

Adhesive spreading and clamping must be accurately carried out without interruption, since adhesives have finite pot life and assembly times. To achieve a controlled spread of adhesive, laminates are coated using double roller glue spreaders or applicator nozzles, which apply continuous beads of adhesive along the full length. Jigs are used to assemble the glued laminates. They are then clamped under controlled pressure to achieve a thin glue line, the clamping force being provided by hydraulic, pneumatic or mechanical means. Recommended cramping pressures for laminates of conifers are given in BS EN 386. The clamped laminates are held at a steady temperature until the adhesive is fully cured. Curing time will be dependent upon the type of adhesive and the temperature applied. Alternatively, very short curing times, of the order of minutes, may be achieved by the use of radio frequency heating. After curing is completed, the component is conditioned for a period at room temperature before it is further worked or put into service.

Finish

At the end of the conditioning period, and after any drilling or cutting is completed, the component is finished to the specified standard, generally by planing and sanding. Minor defects in appearance may be removed and holes plugged. Preservative or decorative treatment can be applied if specified.

Durability and preservation

The need for preservative treatment will depend upon the service conditions, the life required and the species of timber used. Reference should be made to the service classes in BS 5268-2 and in EC5 and also to BS EN 335 *Hazard classes of wood and wood based products against biological attack Parts 1 and 2*. The need for preservative treatment will depend upon the service conditions, the life required and the species of timber used. Generally, in environments where the moisture content of the glulam is less than 20% (Service Classes 1 and 2), it will not be necessary to treat the laminates, or the finished component, against fungal attack. The risk of insect attack for internal timbers will require separate assessment. In external locations, or other situations where the moisture content in service is likely to exceed 20% (Service Class 3 conditions), either the timber must be naturally resistant to decay, or preservative treatment will be required.

Where naturally durable species are used, only the heartwood of timber species in durability Class 2 (durable) or Class 1 (very durable) in relation to wood destroying fungi, should be chosen. This is in accordance with BS EN 350-2 *Durability of wood and wood-based products - Natural durability of solid wood. Guide to natural durability and treatability of selected wood species of importance in Europe*.

Currently, preservation should be in accordance with BS 5268-5, which refers to other British Standards for defining and specifying treatments. The BWPDA Manual (as amended, see References) includes additional preservative treatments which may be suitable but which have been developed since the BS Codes were last revised.

Future recommendations: European Standards follow a very different approach from the British Standards on preservation. Under the new system, the specifier defines the level of treatment which will give the required length of protection in a particular environment or hazard class. This is defined in terms of penetration requirements and preservative retention levels which are set out in BS EN 351-1 *Classification of preservative penetration and retention*. Nine penetration classes are identified. Guidance on the combination of penetration and preservative retention required to give a level of protection to meet the required service life of a component in a particular hazard class is not yet available in a definitive form as a British Standard. Preliminary recommendations are available in a Draft for Development, DD 239 (to be replaced by BS 8417). The European approach to the specification of preservative treatment will not be implemented in the UK until this guidance is available.

Advice on preservative specification is presented in general terms so that there is room for professional judgement in the light of special circumstances, design features, maintenance provisions etc. For instance, glulam timbers in a building classified as ‘high hazard’, might be less at risk from decay due to special design features, in which case a variation to the specification guidance might be appropriate.

Preservative treatment, preferably by vacuum pressure means, may be applied either to the manufactured glulam components or the individual laminates, prior to glulam manufacture. In the former case, the limitation on component size and shape, imposed by the size of the available treatment tanks, requires consideration. Where individual laminates are treated, the compatibility of the timber species, the treatment and the adhesive type should be checked before specification.

The past few years have seen a significant shift in the composition of many wood preservative formulations. Traditional light organic solvent preservatives are being replaced by micro-emulsion formulations with a significantly reduced organic solvent content. CCA (copper chromium arsenic) preservatives are being replaced with formulations that utilise an organic biocide in place of chromium and arsenic. These changes are being driven, at least in part, by the requirements of environmental regulations and are likely to continue for the next few years.

Certain precautions are necessary if water-borne treatments are used. The timber should always be re-dried after treatment for use in dry service conditions. When treating fabricated components, the adhesive manufacturer’s guidance should be sought, with regard to the time necessary after the adhesive has set, for it to cure and develop its full strength. Preservatives should be applied only after this period has expired, generally a week or so. The corrosion of metals can be accelerated by the presence of certain preservatives. The choice of metal for fittings will be determined by the general corrosion risk in service. Where necessary, advice should be sought from the preservative manufacturer.

It should be borne in mind that, notwithstanding the perceived need for preservative treatment, some form of surface protection will help maintain the appearance of glulam components and facilitate the removal of marks and blemishes occasioned during handling and erection. This is particularly relevant where a planed and sanded finish is specified. Information on coatings for outdoor use is given in the WI Sheet *Finishes for external timber.*

Design data

The two main reference documents which may be used for design guidance on glulam are Eurocode 5 and BS 5268-2. Although EC5 currently is a Draft for Development (DD ENV), it is equally acceptable to use either Code as the basis of design for glulam components and structures. The relevant supporting standards are referenced in both documents.

Species and strength classes of timber

Much of the glulam produced in Europe is softwood; BS EN 386 notes that the species suitable for glulam production and available in most European countries are European whitewood, European redwood and Douglas fir. It lists other softwoods and poplar as also having been used for glulam, but does not mention hardwoods, although many glued laminated bridge structures are manufactured using naturally durable hardwood species. Both EC5 and BS 5268-2 require that the timber used to manufacture glulam is strength graded either visually or mechanically to BS 4978 and BS EN 519 respectively. BS 5268-2 includes tables which relate visual grades for solid timber to their appropriate European strength classes. Machine grading to BS EN 519 is direct to strength classes. Grade stresses can be calculated for glulam from the strength classes of the laminates.

Eurocode 5 is based on the limit states approach to design, which uses characteristic values for materials properties. Characteristic values for glulam properties for design to EC5 are given in BS EN 1194 *Timber structures - Glued laminated timber - Strength classes and determination of characteristic values*. This standard lists four glulam strength classes GL24, GL28, GL32 and GL 36. In the European strength class system, the numbers refer to the characteristic bending strength of each class. Thus GL 28 glulam has a characteristic bending strength of 28 N/mm^2.

Glulam can be either homogenous, where all the laminates are the same strength class of timber, or combined, where the outer laminates (one-sixth of the depth on both sides) are a higher strength class than the inner ones. Tests indicate that in the lower and mid-range strength classes, laminated timber has a higher characteristic bending strength than the timber from which it is made because defects are eliminated or spread through the glulam section. Conversely, in the higher strength classes, the finger joints in the outer tension laminates are not 100% efficient, and thus the glulam strength class may be lower than the material from which it is made. BS EN 1194 gives the minimum required strength properties for strength classes GL24, GL28, GL32 and GL36 and also suggests homogenous and combined beam lay-ups that fulfil the strength and stiffness requirements for GL24, GL28 and GL32 (see Table 3).

The EC5 design procedure for simple glulam members, such as beams and columns, is generally no different from that for solid timber and may therefore be considered simpler than the procedure in BS 5268-2, where the number of laminates in the section has to be taken into account.

In both BS 5268-2 and EC5, special treatment is required for the design of curved and pitched cambered glulam beams. EC5 also gives guidance on the design of straight tapered beams. For mechanically fastened joints in glulam, as in solid timber, the formulae in EC5 require the characteristic density of the material rather than its strength class. Lamination averages out this value, so the load-carrying capacity of mechanically fastened joints, calculated from EC5, will, in many cases, be increased by laminating the timber. EC5 also gives advantageous rules for plain dowelled joints, which are useful in glulam structures.

General information on EC5 is included in the TRADA WI Sheet *Eurocode 5 – An introduction* and detailed guidance for engineers is given in TRADA Eurocode 5 Design Guidance, which includes Guidance Documents, Interim Technical Data

Table 3 Examples of beam lay-ups (lamination strength classes in accordance with BS EN 338) from BS EN 1194:

Glulam strength class	*GL24*	*GL28*	*GL32*
Homogenous glulam	C24	C30	C40
Combined glulam: outer / inner laminations	C24 / C18	C30 / C24	C40 / C30

Sheets, calculated Design Examples ranging from single components to whole buildings, plus a selection of Design Aids. The calculations include examples of glulam structures.

Further information

Most national builders-merchants stock, or have immediate access to, the common range of beam sizes and will advise on the total range available. The Glued Laminated Timber Association (GLTA), www.glulam.co.uk, will advise on available sizes and stockists.

References

Standards

BS 4978: 1996 Specification for visual strength grading of softwood.

BS 5268-2: 2002 The structural use of timber. Permissible stress design, materials and workmanship.
BS 5268-4.1:1978 Structural use of timber – Part 4: Fire resistance of timber structures – Section 4.1: Recommendations for calculating fire resistance of timber members.

DD ENV 1995-1-1: 1994 Eurocode 5: Design of timber structures. Part 1-1 General rules and rules for buildings.

BS EN 301: 1992 Adhesives, phenolic and aminoplastic, for load-bearing timber structures: classification and performance requirements.

BS EN 335-1: 1992 Hazard classes of wood and wood-based products against biological attack. Classification of hazard classes.
BS EN 335-2: 1992 Hazard classes of wood and wood-based products against biological attack. Guide to the application of hazard classes to solid wood.

BS EN 338: 1995 Structural timber - Strength classes.

BS EN 350-1: 1994 Durability of wood and wood-based products - Natural durability of solid wood. Guide to the principles of testing and classification of the natural durability of wood.
BS EN 350-2: 1994 Durability of wood and wood-based products - Natural durability of solid wood. Guide to natural durability and treatability of selected wood species of importance in Europe.

BS EN 351-1: 1996 Durability of wood and wood-based products - Preservative-treated solid wood. Classification of preservative penetration and retention.

BS EN 385: 2001 Finger jointed structural timber - Performance requirements and minimum production requirements.

BS EN 386: 2001 Glued laminated timber - Performance requirements and minimum production requirements.

BS EN 387: 2001 Glued laminated timber - Large finger joints -Performance requirements and minimum production requirements.

BS EN 390: 1995 Glued laminated timber - Sizes - Permissible deviations.

BS EN 391: 2002 Glued laminated timber - Delamination test of glue lines.

BS EN 392: 1995 Glued laminated timber - Shear test of glue lines.

BS EN 408: 1995 Timber structures - Test methods - Solid timber and glued laminated timber - Determination of some physical and mechanical properties.

BS EN 519: 1995 Requirements for machine strength graded timber and grading machines.

BS EN 1193: 1998 Timber structures - Test methods - Structural and glued laminated timber - Determination of shear strength and mechanical properties perpendicular to the grain.

BS EN 1194: 1999 Timber structures - Glued laminated timber - Strength classes and determination of characteristic values.

TRADA and TRADA Technology

WIS 1 - 17 Structural use of hardwoods
WIS 1 - 25 Structural use of timber: An introduction to BS 5268-2:2002
WIS 1 - 37 Eurocode 5 - An introduction
WIS 2/3-1 Finishes for exterior timber
WIS 2/3 - 35 Adhesives for wood and wood products - BS EN Standards
WIS 4 - 7 Guide to strength graded softwood
WIS 4 - 19 European Standards on timber

Eurocode 5 Guidance Documents

GD1: 1994 Introduction to EC5: Design of timber structures
GD2: 1994 How to calculate design values for loads
GD3: 1994 How to calculate the design values of material properties
GD4: 1994 How to calculate deformations using Eurocode 5
GD5: 1998 How to calculation deformations in timber structures using Eurocode1
GD7: 1999 Multiple fastener joints to BS 5268-2 and Eurocode 5

Eurocode 5 Interim Technical Data Sheets:

ITD 3: 1994 Design data for timber connectors for use with EC5

Eurocode 5 Calculated Design Examples

Introduction to Design Examples. 1994
DE F Flexural members. 1994
DE C Compression members. 1994
DE J1-4 Joints. 1994
DE J5-8 Multiple fastener joints to BS 5268-2 and Eurocode 5. 1999
DE W1 Timber frame domestic building.1994
DE W2 Glulam sports hall. 1994

Eurocode 5 Design Aids

EDA 2 Fastener load tables. Revised 1998
EDA 3 Beam and column modification factors. Revised 1998

TRADA and TRADA Technology publications are available via the website www.trada.co.uk

British Wood Preserving and Damp-Proofing Association

BWPDA Manual. 1999. Derby.
List of wood preservative for which the supplier declares compliance with EN599. 1999. Derby.
Note: we understand revised editions will be published during 2003.

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