

Glued laminated timber - Production and strength classes

STEP lecture A8
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Objectives

To describe the production of glued laminated timber and to discuss its advantages in construction. To explain the strength determining factors and the background of the European regulations.

Prerequisites

A7 Solid timber - Strength classes
A12 Adhesives

Summary

The production of glued laminated timber is described and the performance and minimum production requirements are discussed. The resulting advantages compared to solid timber are demonstrated. The factors influencing the strength and stiffness properties of glulam beams and the background to the regulations in CEN-standards are explained.

Typical Production Process

The production process may vary slightly between different countries. A typical sequence of operations for the production of glued laminated timber (glulam) is shown in Figure 1.

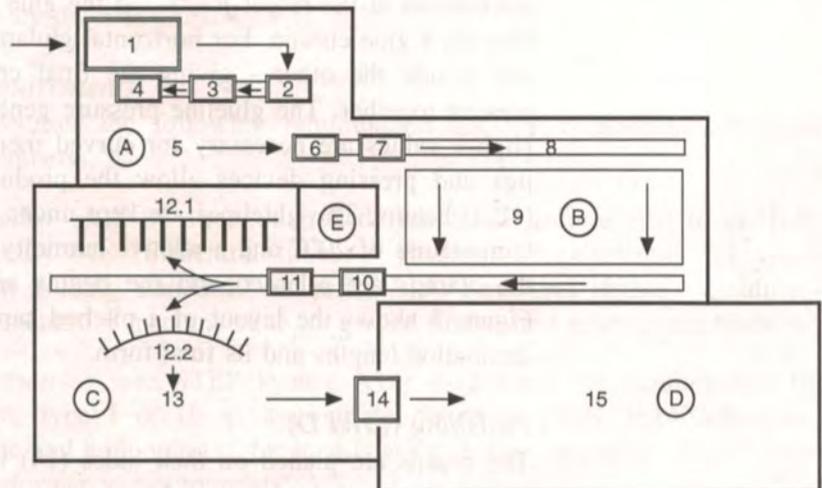


Figure 1 Typical production process for glulam.

Preparation of the planks (area A)

Planks with a maximum thickness of approximately 50 mm and lengths ranging from about 1,5 to 5,0 m are taken from an outdoor stockyard and kiln dried (1). One reason for this is that the adhesives used require the moisture content of the wood to be 15% maximum (see STEP lecture A12). After drying the planks are pre-planed (2) and strength graded (3). The moisture content is controlled, the ends of the planks are cut off in preparation for finger jointing (4) and the planks stock piled (5).

Finger jointing (area B)

The planks are joined lengthwise by means of finger joints to produce a continuous lamination. A typical finger joint is shown in Figure 2 with the notation given in prEN 385 "Finger jointed, structural timber".

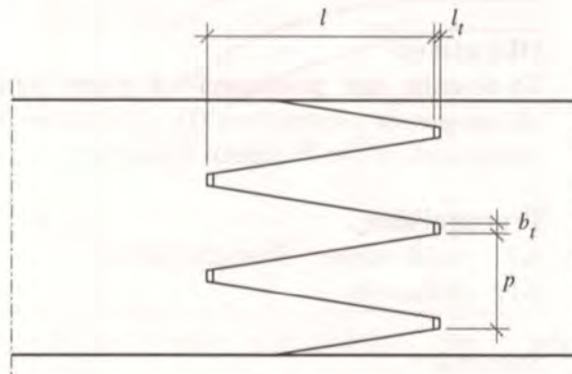


Figure 2 Finger joint (l = finger length, p = pitch, b_t = tip width, l_t = tip gap).

The joint profile is cut into the end-grain and the adhesive is applied (6). The planks are then pressed together for at least two seconds (7) such that the resulting friction between the fingers keeps the planks together during handling. The continuous section is then cut into laminations of the required lengths (8) and stored (9) for a minimum of eight hours to ensure the curing of the glue before the further handling of the laminations.

Gluing (area C)

The laminations are planed (10) to remove the remaining rough surface and the unevenness at the finger joints and the glue is applied (11) usually by running it beneath a glue curtain. For horizontal glulam, the laminations are placed on edge one beside the other - giving the final cross-section lying on its side - and pressed together. The glueline pressure generally is between 0,4 and 1,2 N/mm^2 . Higher values are necessary for curved members or hardwood laminations. The jigs and pressing devices allow the production of straight (12.1) and curved (12.2) beams. The gluelines are kept under pressure in a controlled climate at a temperature of 20°C and a relative humidity of 65% for at least six hours before the clamps are released and the beams are stacked (13) ready for finishing. Figure 3 shows the layout of a pitched cambered beam with the corresponding lamination lengths and its final form.

Finishing (area D)

The beams are planed on their sides (14) in order to remove residual adhesive squeezed out of the joints and to ensure smooth surfaces. Finally the beams are finished (15). These operations include various treatments and preparation work which benefit from being carried out under controlled conditions (e.g. drilling of holes for connections, the application of coatings). Sometimes the glulam is wrapped to protect it against damage and dirt.

Preparation of the adhesives (area E)

Unless resin and hardener are pumped directly from storage tanks and mixed automatically during application, a separate room for the preparation of the adhesives (mixing of resin and hardener) is required. There should also be suitable resin and hardener storage facilities and an area with access to adhesive cleaning equipment.

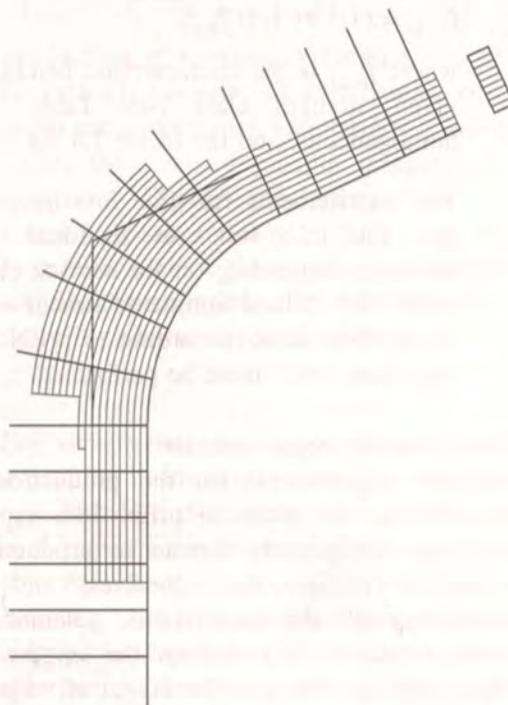


Figure 3 Layout of a pitched cambered beam with corresponding lamination lengths.

Performance and production requirements

In prEN 386 "Glued laminated timber - performance requirements and minimum production requirements" procedures are specified in order to obtain reliable and durable bonding, so that the glue lines in the laminated timber maintain their integrity throughout the intended life of the structure. The most important requirements are described below.

General Requirements

prEN 386 specifies the following requirements for the components of glued laminated members:

- The *timber* shall be strength graded (see STEP lecture A6) to conform with prEN 518 "Structural timber - grading - requirements for visual strength grading standards" or prEN 519 "Structural timber - grading - requirements for machine strength graded timber and grading machines".
- The *adhesives* (see STEP lecture A12) shall meet the requirements for adhesive type I or II, as appropriate, listed in prEN 301 "Adhesives, phenolic and aminoplastic, for load-bearing timber structures: classification and performance requirements".
- The characteristic bending strength $f_{m,j,k}$ of the end joints obtained from flatwise bending tests according to prEN 408 "Timber structures - Solid timber and glued laminated timber - Determination of some physical and mechanical properties for structural purposes" shall meet the following requirement:

$$f_{m,j,k} > f_{m,j,k,r} \quad (1)$$

where $f_{m,j,k,r}$ is a required characteristic bending strength. prEN 1194 "Timber structures - glued laminated timber - strength classes and determination of characteristic values" specifies

$$f_{m,j,k,r} = (1,3 \text{ or } 1,4) f_{m,g,k} \quad (2)$$

where $f_{m,g,k}$ is the characteristic bending strength of a glulam beam with a given strength class (see Table 2). The factor 1,3 is valid for homogeneous, and the factor 1,4 for combined, glulam.

- The requirements for *glue line integrity* are based on the testing of the glue line in a full cross-sectional specimen, cut from a manufactured member. Depending on the service class, delamination tests (according to prEN 391 "Glued laminated timber - delamination test of glue lines") or block shear tests (according to prEN 392 "Glued laminated timber - glue line shear test") must be performed.

Manufacturing requirements

Minimum requirements for the production of glued laminated members for structural use are given in prEN 386, especially those concerning production conditions (equipment, climate in production halls), the treatment, sizes and species of timber, the adhesives, and the manufacturing process itself (positioning of the laminations, tolerance limits, cramping). Examples of manufacturing requirements are the lengthways grooving of wide laminations to reduce cupping effects or the layout of wide cross-sections with layers consisting of two boards arranged parallel to each other.

Quality control

Quality control is of particular importance in glulam production due to the nature of its manufacture and end use. Since the quality of the glue lines cannot be appraised in the produced members, special attention has to be given to quality control during production. Generally, quality control consists of an internal part carried out by the producer and an external part by an independent third party. Quality control includes daily bending tests of finger joints and either delamination tests or block shear tests to check glue line integrity. Furthermore, records have to be kept giving the details of every production run including the date and the number of members produced, their species, timber quality, dimensions, moisture content of the timber, time for start of adhesive application, time for start and end of the cramping process, cramping pressure, type of resin and hardener, amount of adhesive per m^2 and calibration of the moisture meter as well as the temperature and relative humidity of the different production halls. Quality control also relates to the training of the personnel and the strength grading of the timber.

Large finger joints

If large finger joints are used to join entire glulam members (as, for example, in the case of frames), special performance and minimum production requirements have to be fulfilled. These requirements are given in prEN 387 "Glued laminated timber - Production requirements for large finger joints. Performance requirements and minimum production requirements". There may be additional national requirements.

Advantages of glued laminated timber in use

Glued laminated timber is a highly engineered building material, extending in many cases the traditional use of timber. The main reason for this is that the production process with integral quality control as described above, provides a number of advantages compared with solid timber. The most important are described below.

Beam sizes

Due to the production of continuous laminations, unlimited beam sections and lengths are theoretically possible. Glulam beams with depths of 2,0 m or lengths of 30 to 40 m are not exceptional. Limitations however, are imposed by the open time of the glue, the sizes of planing machines and production halls or for architectural reasons. During the transportation of glulam beams if the dimensions exceed 16 m in length, 2,5 m in width or 3,5 m in height, supplementary actions such as the application of blinker-signal equipment, police escorts or exceptional permissions may be necessary. Also the routes have to be checked carefully in order to avoid sharp bends and low bridges.

Beam shapes

The possibility of curving the single laminations before gluing allows the production of exciting beam shapes (see also STEP lecture B8). This also allows beams to be precambered to accommodate dead load deflection. The production of curved beams requires the adaption of jigs and pressing devices for every new beam geometry; thus the production time is higher in comparison with straight beams. The resulting cost difference depends on the number of similar members and is often negligible. Tapered members can be produced by simply varying the length of single laminations or by sawing two tapered members from a straight element.

Higher strength and stiffness

Because of the production process, knots are spread more evenly within the volume of the beam leading to a more homogeneous material. The influence of single potential failure areas due to knots is reduced, resulting in a lower variability and, in lower quality timber, a higher mean strength. A more detailed description of strength influencing factors is given below.

Combined glulam

The use of laminations makes it possible to match the lamination quality to the level of stress. In the case of a bending member for instance, laminations of a higher strength class are positioned in the outer highly stressed regions, whereas in the inner zones laminations of a lower quality may be used. This allows a more economical use of the available wood material.

Dry wood

The planks are kiln dried to a moisture content of about 12% since the equilibrium moisture content of wood used indoors amounts to 9 to 12% approximately and hence the danger of damage caused by deformations (such as distortion) occurring during the drying process in the construction is almost excluded.

Dimensional accuracy

The drying of the laminations and the production process also allow the production of glulam beams with accurate dimensions. Since small tolerances are important for the use, and combination, of prefabricated members of different materials, the dimensional accuracy can determine the use of glulam even if sawn timber would have been sufficient in terms of strength and stiffness. With regard to the increased use of CAD and computer controlled finishing machines, dimensional accuracy is getting more important. If glulam is used in outer walls, wind tightness can be achieved more easily than if using sawn timber with moisture contents above the equilibrium moisture content.

Strength determining factors

Glulam is mainly used for bending members. Therefore the main emphasis in this section is put on the factors influencing the bending strength of glued laminated timber. Other strength properties are discussed in the next section.

Systematic studies (Colling, 1990a; Colling, 1990b) show that the strength of glulam beams is determined by the strength of the timber and the strength of the finger joints. A lamination consisting of planks connected with finger joints behaves to a certain extent like a series system. Depending on the strength ratio of the timber and the finger joints, respectively, failure will be initiated by either the failure of the timber or of the finger joint. To increase the strength of glulam beams, a balanced strength increase of both planks *and* finger joints is necessary.

The studies lead to the following conclusions:

- a more rigorous visual strength grading procedure is not likely significantly to increase the strength of glued laminated timber. Stricter visual strength grading decreases knot sizes and consequently leads to an increase of plank strength without affecting finger joint strength.
- Machine strength grading based on wood density and/or modulus of elasticity contributes to a strength increase of both planks *and* finger joints resulting in increased glulam strength values.
- Production related parameters such as sharpness of cutting tools, pressure applied or climate in the production halls also influence finger joint strength. Quality control of finger joints to produce reliable strength values is, therefore, essential.

Background to the regulations in CEN

prEN 1194 "Timber structures - Glued laminated timber - Strength classes and determination of characteristic values" (September 1993) provides equations for the calculation of the mechanical properties of glued laminated timber depending on lamination properties. The equations given in this version of prEN 1194 are shown in Table 1 for some of the more important properties.

Property		equation according to prEN 1194
Bending strength	(N/mm ²)	$f_{m,g,k} = 12 + f_{t,0,l,k}$
Tension strength	(N/mm ²)	$f_{t,90,g,k} = 9 + 0,75 f_{t,0,l,k}$
parallel to grain		$f_{t,90,g,k} = 1,15 f_{t,90,l,k}$
perpendicular to grain		
Compression strength	(N/mm ²)	$f_{c,0,g,k} = (1,5 - 0,01 f_{c,0,l,k}) f_{c,0,l,k}$
parallel to grain		
Density	(kg/m ³)	$\rho_{g,k} = 0,95 \rho_{l,mean}$

Table 1 Some mechanical properties of glued laminated timber.

The equations are valid for homogeneous cross-sections. For combined glulam the equations apply to the properties of the individual parts of the cross-section. As EC5 takes into account the decrease in strength of a material with increasing dimensions (see STEP lecture B1) the equations of Table 1 are related to members having a depth or width of 600 mm for bending and tension parallel to grain, and to a reference volume of 0,01 m³ for tension perpendicular to grain.

The *bending* strength of glulam beams is related to the tensile strength of the laminations by an empirical relationship, which is based on tests and analytical investigations. For standard lamination qualities this relationship indicates that the characteristic glulam bending strength is 40 to 90% higher than the characteristic tensile strength of the laminations. This may be explained by several effects (Colling and Falk, 1993). The most important are:

- a difference exists in the tension performance of single laminations as measured by standard test methods and their actual performance in a glulam beam. The test method in prEN 408 for determining the tensile strength provides no lateral restraint to the tension member. Contrary to the situation in a glulam member, off-centre defects such as edge knots consequently induce bending stresses thus reducing the tensile capacity.
- In glulam beams defects like knots are reinforced by adjacent laminations. The reinforcement provides alternative stress paths around the defect.

Also in the case of *tension* and *compression* parallel to grain, the characteristic strength values of glulam beams are higher than those of the individual laminations. This may again be explained by load sharing effects as described above. The characteristic tensile strength has been assumed to amount to 75% of the characteristic bending strength. For compression see also STEP lecture B6.

In the case of curved and cambered beams, radial stresses occur (see STEP lecture B8). Due to smaller cracks in glulam beams, the characteristic *tensile strength perpendicular* to the grain is higher than for the laminations acting alone. The same applies to *compression perpendicular* to the grain where the characteristic values for glulam are higher due to the smaller variation in density compared with the single laminations.

The gluing of an increasing number of laminations leads to a more homogeneous material with low variation of *density*. Therefore, the characteristic density of glued laminated timber is close to the mean value of the density of the single laminations.

Strength classes

In prEN 1194 (September 1993) five strength classes for glulam are defined (see Table 2). The lamination qualities needed to comply with the required properties may be determined on the basis of the above mentioned equations (see Table 1).

Strength class		GL 20	GL 24	GL 28	GL 32	GL 36
$f_{m,g,k}$	(N/mm ²)	20	24	28	32	36
$f_{t,0,g,k}$	(N/mm ²)	15	18	21	24	27
$f_{t,90,g,k}$	(N/mm ²)	0,35	0,35	0,45	0,45	0,45
$f_{c,0,g,k}$	(N/mm ²)	21	24	27	29	31
$f_{c,90,g,k}$	(N/mm ²)	5,0	5,5	6,0	6,0	6,3
$f_{v,g,k}$	(N/mm ²)	2,8	2,8	3,0	3,5	3,5
$E_{0,mean,g}$	(N/mm ²)	10 000	11 000	12 000	13 500	14 500
$E_{0,05,g}$	(N/mm ²)	8 000	8 800	9 600	10 800	11 600
$\rho_{g,k}$	(kg/m ³)	360	380	410	440	480

Table 2 Strength classes for glued laminated timber.

For homogeneous glulam the design calculations may be carried out by the methods described in EC5.

In the case of combined glulam, however, the stress analysis may be carried out using the transformed section method and strength checks shall be made at all relevant points of the cross-section. This means that the different lamination qualities (characteristic strength and stiffness values) have to be taken into account.

The design of composite cross-sections therefore requires additional calculations. Table 3 shows the layup of timbers in accordance with prEN 338 "Structural timber - Strength classes" for homogeneous and combined glulam for the standard glulam classes. For those beams the design calculations may be carried out as for homogeneous cross-sections.

If other beam lay-ups are used, they must be checked to show that the behaviour of the composite beams is at least equivalent to an homogeneous beam with a target strength class based on Table 2. In the case of shear stresses and stresses perpendicular to the grain - which are normally critical in the core of the beam - the applied stress should be checked against the strength of the inner lamination material.

Strength class		GL 20	GL 24	GL 28	GL 32	GL 36
Homogeneous glulam	<i>all laminations</i>	C 18	C 22	C 27	C 35	C 40
combined glulam ¹	<i>outer laminations</i>	C 22	C 24	C 30	C 35	C 40
	<i>inner laminations</i>	C 16	C 18	C 22	C 27	C 35

¹ The requirements for the outer laminations apply to the extreme 1/6 of the depth on both sides

Table 3 Examples of beam lay-ups.

Concluding summary

- Glued laminated timber is a highly engineered building material, providing many advantages over solid timber.
- Special attention must be given to the strength grading of the laminations, the quality of finger joints, glue line integrity and quality control.
- Machine strength grading based on wood density and modulus of elasticity is the key to high strength glulam.

References

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