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wood INFORMATION

Structural use of hardwoods

When compared with structural softwoods, hardwoods in the medium to high density ranges have

- greater strength and stiffness
- availability in longer lengths and larger sections
- higher density, giving superior fire resistance
- greater natural durability
- more varied aesthetic appeal as exposed members.

Oak trusses. Photo courtesy Cowley Structural Timberwork Ltd

Choosing hardwoods may allow a designer to use timber throughout a structure without the need to switch to other materials, such as steel or concrete, for long spans or heavy loadings. They can be used, for example for beams and joists, lintels and purlins and for parts of built-up components such as portals and webbed beams.

The hardwoods preferred for structural use generally have greater natural durability than the commonly used softwoods. They do not therefore normally require preservative treatment, provided that the vulnerable sapwood is excluded.

A recognition that Britain should be more self-sufficient in its use of building materials is creating renewed interest in the use of British-grown hardwoods. Oak, associated with buildings for centuries, is experiencing a large increase in demand. There is a large supply of British oak and its use as a renewable resource encourages improved woodland maintenance and development for commerce. Oak and similar timbers, such as sweet chestnut are also used for functions such as fencing, although low value uses like this are diminishing. Specialist carpentry based companies practising sustainable building technology no longer occupy a small niche market but are already significant and are growing rapidly.

The timber framing revival has led to renewed interest in additional sustainable temperate hardwoods and in a variety of modern as well as traditional architectural forms. The TRADA Technology publication *British-grown hardwoods - the designers' handbook*, sponsored by the Forestry Authority, gives information on timbers available.

Structural timber design in the UK has generally been carried out to BS 5268-2 *The structural use of timber. Permissible stress design, materials and workmanship*, which includes 13 hardwoods of both temperate and tropical origin. Increasing awareness of the structural Eurocodes series has already led to the adoption of documents such as Eurocode 5 by engineers embarking on the more individual and innovative hardwood designs that these permit. Both hardwood gridshells and engineering proof of some of the more complex aspects of traditional oak carpentry, benefit from the collective European knowledge combined in these and in support documents.

Structural hardwoods are strength graded in accordance with BS 5756: 1997 *Specification for visual strength grading of hardwood* and are allocated into strength classes defined in BS EN 338: 1995 *Structural timber. Strength classes*.

The density of many of the species used for structural purposes provides greater fire resistance than that of the lower density softwoods. This is acknowledged by the slower charring rates given in BS 5268-4 Section 4.1 *Recommendations for calculating fire resistance of timber members*.

Strength grading and strength classes

Strength grading

The strength of individual pieces of timber is assessed by strength grading. For hardwoods, this is undertaken to the rules laid down for visual grading in BS 5756. Five strength grades are defined at two moisture content levels; dry and wet:

- **HS** Tropical hardwoods
- **TH1** and **TH2** General structural temperate hardwood - for timber of a cross-sectional area less than 20,000mm^2 and a thickness less than 100mm. TH1 is a higher grade than TH2.
- **THA** and **THB** Heavy structural temperate hardwood - for timber of a cross-sectional area of 20,000mm^2 or more and a thickness of 100mm or more. THA is a higher grade than THB.

Dry graded timber is assessed when the batch of timber has an average moisture content of 20% or less, with no reading exceeding 24%. It is marked DRY or, if kiln dried may be marked KD.

Dry graded timber should be used in Service Classes 1 and 2 (see below). The exception to this rule is timber with a target thickness of 100mm or more which is difficult or slow to dry and is therefore graded and marked WET.

Wet graded timber is assessed at a moisture content higher than 20% and is marked WET. Wet graded timber should be specified for use in Service Class 3 or when the timber has a target thickness of 100m or more.

BS 5268 Part 2 defines three Service classes:

Service Class 1 - characterised by a moisture content in the materials corresponding to a temperature of 20° C and the relative humidity of the surrounding air only exceeding 65% for a few weeks each year. In such conditions most timber will attain an average moisture content not exceeding 12%.

Service Class 2 - characterised by a moisture content in the materials corresponding to a temperature of 20° C and the relative humidity of the surrounding air only exceeding 85% for a few weeks each year. In such conditions most timber will attain an average moisture content not exceeding 20%.

Service Class 3 - due to climatic conditions is characterised by higher moisture contents than Service Class 2.

Marking

Hardwoods strength graded in accordance with BS 5756 should be marked with:

- the species and grade
- the company responsible for the grading
- the Certification body and the BS number, BS 5756
- DRY, KD or WET as appropriate.

Strength classes

Timbers of similar strength properties are grouped together into strength classes. These are defined in BS EN 338 which includes six strength classes for hardwoods, D30 - D70, see Table 1.

Strength classes offer a number of advantages both to designers and suppliers. Note that poplar, which is a hardwood is included in the strength classes for softwoods (C14 - C40). The Wood Information Sheet 4 -21 *European strength classes and strength grading* gives more details.

BS EN 338 gives characteristic values for strength and stiffness properties for each strength class. These are used in the limit states design system laid down in Eurocode 5 and are derived directly from test values, taking no account of factors of safety or other significant factors which are applied as part of the design process. Table 2 shows the characteristic values for the hardwood strength classes.

BS 5268-2: 1996 is a permissible stress design code which gives grade stresses for the strength classes defined in BS EN 338 and also for the individual hardwood species included. Table 3 shows the BS 5268-2: 1996 grade stresses for the hardwood strength classes.

Table 1 Strength graded hardwoods assigned to BS EN 338 strength classes

Species	Strength class				
	D30	D40	D50	D60	D70
Balau					HS
Ekki				HS	
Greenheart					HS
Iroko		HS			
Jarrah		HS			
Kapur				HS	
Karri			HS		
Kempas				HS	
Keruing			HS		
Merbau			HS		
Oak *	TH1 THB	THA			
Opepe			HS		
Teak		HS			

* Note that the TH2 grade of oak does not meet the requirements for the D30 strength class. Designs using TH2 grade oak should be based on the grade stresses given in BS 5268-2 for the individual species and grade.

Table 2 Characteristic values for hardwood strength classes (BS EN 338)

Strength properties N/mm²	**D30**	**D40**	**D50**	**D60**	**D70**
Bending	30	40	50	60	70
Tension parallel to grain	18	24	30	36	42
Tension perpendicular to grain	0.6	0.6	0.6	0.7	0.9
Compression parallel to grain	23	26	29	32	34
Compression perpendicular to grain	8.0	8.8	9.7	10.5	13.5
Shear	3.0	3.8	4.6	5.3	6.0
Stiffness properties kN/mm²					
Mean MOE parallel to grain	10	11	14	17	20
5th percentile MOE parallel to grain	8.0	9.4	11.8	14.3	16.8
Mean MOE perpendicular to grain	0.64	0.75	0.93	1.13	1.33
Mean shear modulus	0.60	0.70	0.88	1.06	1.25
Characteristic density kg/m³	530	590	650	700	900

Table 3 Grade stresses and moduli of elasticity for hardwood strength classes for Service Classes 1 and 2 (BS 5268-2).

N/mm²	**D30**	**D40**	**D50**	**D60**	**D70**
Bending parallel to grain	9.0	12.5	16.0	18.0	23.0
Tension parallel to grain	5.4	7.5	9.6	10.8	13.8
Compression parallel to grain	8.1	12.6	15.2	18.0	23.0
Compression perpendicular to grain*	2.8 / 2.2	3.9 / 3.0	4.5 / 3.5	5.2 / 4.0	6.0 / 4.6
Shear parallel to grain	1.4	2.0	2.2	2.4	2.6
Modulus of elasticity Mean Minimum	 9500 6000	 10800 7500	 15000 12600	 18500 15600	 21000 18000
Average density kg/m³ at 20°C/65% RH	640	700	780	840	1080

* When specification excludes wane at bearing areas, the higher value of compression perpendicular to grain stress may be used, otherwise the lower values apply

Design to BS 5268 Part 2

Structural design using hardwoods to BS 5268-2 is no different from using softwoods. Some points to note are that the strength properties of individual hardwood species may be higher than those for the strength class to which the species belongs. Designers may wish to take advantage of this by basing their designs on an individual species and grade.

The grade stresses apply to long-term loading; modification factors are given in the Code for medium, short and very short term loading.

The grade stresses quoted in BS 5268-2: 1996 are for dry graded timber for use in Service Classes 1 and 2, ie for a moisture content of 20% or below. Wet graded timber, ie over 100 mm thick or for use in Service Class 3, should be designed using the modification factors given in the Code to convert the grade stresses to those appropriate for Service Class 3. Timber over 100 mm thick which is graded and supplied wet, but which is used in Service Class 1 or 2 situations will dry out in service. In this case, the initial design should be based on the grade stresses appropriate for Service Class 3 with checks made on the calculations for the timber after it has dried out. However, the strength properties of timber generally increase as the moisture content reduces so the grade stresses for Service Classes 1 and 2 are higher than those calculated for Service Class 3. The design detailing should take account of the shrinkage which will occur in the timber members as they dry down to their equilibrium level.

BS 5268 -2: 1996 includes a table giving likely in-service moisture contents and moisture contents which should not be exceeded at the time of erection. However, TRADA research has shown that these moisture contents are higher than those found in practice, see Table 4. Wood Information Sheet 4 -27 *Moisture content standards for timber* gives more details of this research.

To avoid shrinkage and the possibility of splits occurring, timber ideally should be installed at the moisture content which it will attain in use. For heated buildings this means that the timber should be kiln dried. The specifier must therefore balance the cost implications against the consequences of timber shrinkage after installation and ensure that the design detailing is appropriate.

Even dry graded timber, installed at 20% moisture content will shrink as it dries to an equilibrium of around 10 - 12 % or below. Shrinkage may be accompanied by the development of fissures and distortion, eg twist.

Hardwood composites

Hardwoods in glulam can be straight sections or curved beams, arches and portals. Curved hardwood glulam beams are often favoured in the design of footbridges. BS 5268-2 gives methods for determining the relevant design stresses. Hardwood laminations are strength graded and the BS EN 338 strength class of the laminates is used to assign the glulam strength class. Grade stresses

Table 4 Moisture content

Service Class	**Examples of use in building**	**Average moisture content likely in service - BS 5268 Part 2 %**	**Average moisture content found in TRADA research %**	**Maximum moisture content of individual pieces at time of erection - BS 5268 recommendation %**
1	Internal in continuously heated building	12	10 - 12 or lower (individual readings down to 6)	20
2	Covered and generally heated Covered and generally unheated	15 18	11 - 12 15 - 17	20 24
3	External, exposed	20 or more	-	-

for glulam can be calculated from the strength class of the laminates. Further information is given in the Wood Information Sheets 1 -6 *Glued laminated timber - An introduction* and 1 - 38 *Glued laminated timber – European Standards*.

The ability of conventional adhesives for glulam to produce satisfactory gluelines must be considered more carefully than for most softwoods. Some hardwoods have acquired a good reputation for gluing, such as iroko for bridge beams and similar exterior uses, and others, such as jarrah, keruing and kapur. Others, such as teak are difficult to glue satisfactorily.

Laminated oak has been used in continental Europe and a TRADA Technology research project has examined the potential of producing structural timber composites, including glulam from British-grown hardwoods. BS EN 386: 1995 *Glued laminated timber. Performance requirements and minimum production requirements* is aimed at ensuring that reliable and durable bonding is achieved consistently.

TRADA Technology research has also examined the use of poplar for producing laminated veneer lumber but commercial supplies of structural timber composites (LVL, parallel strand lumber and laminated strand lumber) in the UK at present are all produced from softwoods.

Some structural hardwoods, such as greenheart and ekki, are so dense that their shear resistance is higher than the shear strength of conventional gluelines. In addition, extractives and oils in some timbers make gluing a highly specialised operation. Advice should be sought from timber technologists and adhesive suppliers before specifying glulam from hardwood species.

Mechanical laminating using steel dowels is used for long span bridges, built using ekki. The dowels, often stainless steel, are driven through pre-drilled holes, designed for an interference fit. Design rules for this method are included in BS 5268- 2 and in Eurocode 5.

Design to Eurocode 5

DD ENV 1995-1-1: 1994 Eurocode 5: *Design of timber structures. General rules and rules for buildings* can be used as an alternative to BS 5268 Part 2. The definitive version is not likely to be published until sometime after 2000. It is a limit states design code and as such represents a radically different design method from the permissible stress method traditionally used in the UK.

Guidance on design to Eurocode 5 is given in a series of documents available from TRADA. These range from introductory Wood Information Sheets to specialist guidance for engineers - see Further information.

Specialist hardwood design

For many structural applications of hardwoods, particularly European and British species, modern design methods and standards may not always be appropriate. Also, designers may wish to use timbers which are not included in BS 5268-2. Reclaimed timber may be used but specialist guidance should be sought on grading and moisture content.

Restoration and repairs to historic buildings and structures may demand very careful selection of high grade oak or other hardwood. Special forms of drying, available from specialist suppliers can be called upon where complex laminated or carved sections are needed. In such cases there is close liaison between the specifier, the timber supplier and the fabricator. The supplier can thus 'fine tune' his proposed solutions and select material to meet the special needs of the designer and fabricator. Structural timber repairs often employ a range of techniques. TRADA Technology publications '*Resin repairs to timber structures*' give guidance to professionals involved in the design and execution of such repairs.

In other projects using traditional timbers, such as oak or chestnut, a 'carpentry' style of architecture and design using large, 'squareish' cross-sections with mortise, tenoned and dovetailed joints may be adopted. Member sizes then are often dictated by stiffness rather than strength and may be governed by the thicknesses required to form the joints. In such cases specifying high strength grades is expensive and wasteful. Qualities available from 'carpentry quality' oak may be perfectly adequate and make more efficient use of the woodland resource than unnecessary over-specification.

BS 5268-2: 1996 contains grade stresses for only a limited number of hardwoods, mostly tropical species. Information on oak has been included in the 1996 edition having been in its forerunner, CP112. It was excluded from the early editions of BS 5268 because of the need to develop a general purpose strength grading system for temperate hardwoods (now in BS 5756). The now superseded

CP 112 grading system of 'numbered visual grades' required the grader to know the end use of the piece, ie whether it was to be a beam or column. The numbered grades, 75, 65, 50 and 40 were 'strength ratios' - they expressed percentage strengths of a notionally perfect piece of timber – the basic stress or 100 grade.

Demonstrating compliance with British Standards and recognised design codes, such as BS 5268-2 and Eurocode 5, is a rapid and convenient method of gaining Building Regulations approval. However, it is not the only route and conformity with other reliable, independent and well-established recommendations is often equally acceptable to Approving Authorities.

A Design Guide, *Hardwoods in Construction*, published by TRADA in 1991 contains information on basic and grade stresses for European-grown hardwoods, graded in accordance with principles laid down in the document and based on the old 'numbered grades'. It also contains a section on 'Designing with hardwoods not in BS 5268 Part 2' and explains how such timbers can be assigned to strength classes. The Design Guide was written before the introduction of BS EN 338 Strength classes but much of the information is still relevant to specialist designers wishing to broaden the range and application of hardwoods used in structural design. The 'numbered' grading system, explained in the book, can also be employed in the in situ assessment of existing structures. Its use may avoid unnecessary intervention in historic structures and may allow the structural engineer to justify the load carrying capacity of an existing structure and its components.

Further information

British-grown hardwoods - The designers' handbook. TRADA Technology. 1995.

Hardwoods in construction by C J Mettem and A J Richens. TRADA TBL 62. 1991. 112 pages. (see final paragraph above)

TRADA Red Booklets Timbers of the World:
RB 1 Timbers of Africa. 1978 (Reprinted 2000)
RB 2 Timbers of South America. 1978
RB 3 Timbers of Southern Asia. 1978
RB 4 Timbers of South East Asia. 1978
B 5 Timbers of Philippines and Japan. 1978
RB 6 Timbers of Europe. 1978
RB 7 Timbers of North America. 1978
RB 8 Timbers of Australasia. 1978
RB 9 Timbers of Central America and the Caribbean. 1979

Resin repairs to timber structures: guidance and selection. Volume 1 TRADA Technology Report 3/2000

Eurocode 5 – An introduction. Wood Information Sheet 1 - 37. 2000

Guidance for engineers on structural design to Eurocode 5 has been published by TRADA: details available as below

British Standards

BS 5268-2: 1996 The structural use of timber. Permissible stress design, materials and workmanship

BS 5756: 1997 Specification for visual strength grading of hardwood

BS EN 338: 1995 Structural timber. Strength classes

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

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