WOODINFORMATION

Section 1 Sheet 45

August 2001

CI/SfB
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Uniclass L6617+L6618:N311+N312
UDC 691.11

Structural use of wood-based panels

Structural wood-based panel products have a long and continuing history of use in applications that exploit their in-plane strength and stiffness, such as stressed skin panels and webs of box and I-beams, see Figures 1 to 3. Additionally, they have been used where their perpendicular-to-plane mechanical properties are most important, in structures such as floors and formwork.

Post-war developments of proprietary webbed beam and joist systems peaked in the 1950's and '60s. More recently, a new generation of proprietary I-joist systems has made a significant impact upon the construction industry. This resurgence has been accelerated by the growth of automated, fast factory production systems and the development of low-cost structural wood-based panels produced from sustainable forestry resources.

There is potential for still further increasing the use of structural wood-based panels in housing, light office accommodation and other similar fast track construction projects. Their long history of use, complemented by industrial modernisation, supports the drive towards greater building prefabrication. Their origins, from small-diameter material taken from well-managed forests, supports sustainable construction, waste reduction and carbon emission reductions.

Based on the findings of an EU-supported TRADA Technology research project, this Sheet explores ways in which structural wood-based panels may best be exploited, in situations where in-plane properties are the predominant engineering consideration. In-plane shear strength, shear modulus, allied design coefficients and property modifiers are discussed.

Figure 1 Stressed skin panels, 24 m long; clear span 21m
Photo: Cowley Structural Timberwork Ltd

Figure 2 Ply-box portal frames

Figure 3 Large vertical diaphragm

Key properties

The properties of structural wood-based panels are a direct function of their constituent materials and the way in which they are manufactured. The physical and mechanical properties of panel types can be tailored to meet the requirements of specific end-uses. For structural applications, most of the key design properties are related to bending, tension, compression and shear.

Bending

Bending strength and modulus of elasticity values for panels commonly refer to out-of-plane, or flatwise, bending. These conditions arise in floors and formwork, for example. In some cases however, such as the web of an I-beam or I-joist, edgewise bending values may be required.

For flatwise bending, panels such as plywood and OSB have significantly different strength values along and across the panel. Thus, it is important that they are installed in the correct direction. These directions are usually referred to as the "major" and "minor" axes of the panel or sometimes as "parallel" and "perpendicular" to the long direction of the board. Associated properties are indicated by 0 and 90 degree subscripts. For other panel types, such as particleboard, the properties are assumed, for design purposes, to be the same in both directions.

Where edgewise bending properties (as well as in-plane shear, see below) are necessary for design, orientation in relation to sheet direction may also be significant. This therefore needs to be stipulated as part of the component manufacturing specification.

Tension and compression

The tension and compression strength, and their associated elastic moduli, normally refer to in-plane properties. As with bending properties, these can vary significantly, in relation to the major and minor panel axes. Hence, design details and specifications need to clarify what is required, to comply with the assumptions made in the calculations.

Values may also be quoted for tension perpendicular to the plane of the board, also sometimes known as internal bond strength. This is a property chiefly intended to give a measure of the quality of the bond between the particles, strands or veneers of the panel and is generally used as a part of the quality control process.

Shear properties

Panel shear:

Panel shear strength reflects the ability of a panel material to resist in-plane forces such as those shown in Figure 4. These act in the plane of the panel, causing it to deform into a lozenge shape. For engineering calculations involving these types of effect, both a strength property and a shear modulus value may be required. These properties are appropriate to applications such as I-beams and joists, where the web resists significant shear forces. Shear diaphragms within structures, such as stressed skin panels, also entail design calculations that rely on these types of property.

Planar shear:

In situations where perpendicular-to-face, or out-of-plane bending occurs, significant planar shear effects are set up in the plane of the panel. These are in the orthogonally opposite direction to the bending itself, and hence are in the reverse sense to panel shear. That is to say, the in-plane layers of the board tend to slide over one another at or close to shear failure. Planar shear often occurs where stresses have to be transferred between components through an adhesive joint, such as between the web and flange of an I beam.

In plywood, this property was also traditionally termed rolling shear, since at failure, the fibres have the tendency to roll over one another, as indicated schematically in Figure 5. This failure condition can also occur in solid wood and in materials such as LVL when critical shear strains are transverse to the fibres. When used in association with structural panels, this may also be an effect that requires calculation checks.

Dependent upon the panel type, planar shear strength properties may vary between major and minor sheet axes. Where this is the case, considerations in design and specification are similar to those referred to under bending.

Calculations involving planar shear strength are required in situations where forces have to be transferred between a flange or other adjacent timber or wood-based material, into the structural panel through an adhesive joint. All types of adhesively bonded, thin-webbed beams and thin-flanged panels experience the effect, see Figure 6. In the manufacture of such components, attachment is normally achieved by adhesive bonding, with pressure applied through press or clamping arrangements. An alternative technique also uses adhesive, but employs mechanical fasteners, such as small nails or staples, to maintain the bonding pressure whilst the adhesive cures. In this case, the connection should not be assumed to be mechanically fastened for strength verification purposes. Because of the substantial difference in stiffness between mechanical and adhesive connections, the fasteners cannot be relied upon to prevent planar shear failures within the installed component.

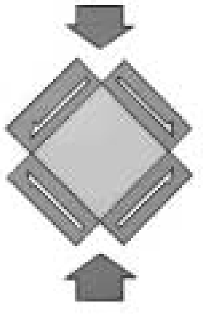

Figure 4 Panel shear schematic based on a test arrangement to create pure tension and pure compression across the diagonals to obtain the shear modulus and ultimate shear strength

Figure 5 Schematic of planar shear

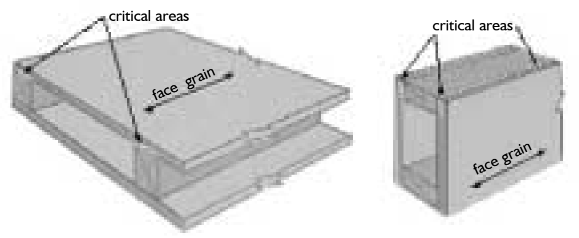

Figure 6 Planar shear - critical regions in ply-webbed beam and stressed skin panel

As noted above, planar shear strength verifications may be necessary in both the structural panel and in the connected flanges, stringers or other timber elements. Design calculations seldom need to consider planar shear moduli. This is convenient because it is not easily measured, since the strain deformations concerned are very small.

Time dependency in structural wood-based panel properties

In timber structures, the ambient air humidity and temperature, its cyclical changes, and the duration of time under which load is sustained, all have a considerable and interacting influence on performance. Both ultimate strength and deformation behaviour are affected. In general terms, highly variable moisture and temperature conditions, and long load durations, have the worst effects.

In structural wood-based panels, the effects of load duration and of moisture are both experienced, and must be taken into account in design. As a general guide, the more highly comminuted the panel type, and the lower the grade of its constituent materials, the more pronounced the time dependency effects, see Table 1.

Table 1 Time dependent effects on panel types

Product type	Wood form	Relative particle/ fibre size	Propensity for time dependency
Solid timber	Undisturbed	larger	lesser
Plywood	Peeled veneers	↑	↓
OSB	Wood strands		
Particleboard	Wood chips		
Fibre boards -	Individual wood fibres		
		smaller	greater

The term "creep" is often used to describe the tendency for deflection to increase with time under a sustained load. "Duration of load" is used to describe the relationship between the maximum sustainable short term stress and the lower stress that can safely be sustained for longer durations.
In design calculations, duration of load modification factors are required for ultimate strength conditions and deformation modification factors are necessary for serviceability verifications. For components, deformation modifiers are also required as part of the strength check calculations.

The time dependency effects are taken into account in design, by assigning the structure, or its components, to classes. Three service classes represent ambient conditions whilst five load duration classes are stipulated. In Eurocode 5, the design coefficients for strength and for deformation are termed k_{mod} and k_{def} respectively. BS 5268 has used a slightly different format for these modifiers, but in the forthcoming 2001 edition, it will be brought fully into line with the European approach.

Design properties

In the UK, structural design with timber can be carried out in accordance with BS 5268-2 *Structural use of timber. Code of practice for permissible design, materials and workmanship* or with DD ENV 1995-1-1 *Eurocode 5: Design of timber structures. General rules and rules for buildings*.

Under the European standards system, characteristic values for wood-based panels for use in design must be derived in accordance with *EN 1058 Wood-based panels. Determination of characteristic values of mechanical properties and density* and *EN 789 Timber structures. Test methods. Determination of mechanical properties of wood-based panels*. For strength properties, the characteristic value is defined as the lower fifth percentile value ie with only a five percent probability of an individual panel having a lower value. For moduli, the characteristic value is usually the mean value. Characteristic values are given in *BS EN 12369-1 Wood-based panels. Characteristic values for structural design. OSB, particleboards and fibreboards*. These vary with panel type, grade and thickness, but some typical density and strength values, are extracted in Table 2. Some typical moduli values are given in Table 3. These are for example only and for a complete design would need to be modified for service class and duration of load. Values for plywood and other types of panel will follow in other parts of BS EN 12369, but in the meantime, advice should be sought from the manufacturer.

The proposed 2001 revision of BS 5268-2 will include design stresses for certain types of plywoods. For other panel types, factors will be given to enable the use of characteristic values derived in accordance with EN 1058 and EN 789 and those in BS EN 12369, will then be able to be used in conjunction with BS 5268-2.

Table 2 Examples of characteristic density and strength values for wood-based panels

from BS EN 12369-1. (Note: Values only for use with Eurocode 5, BS 5268-2: 2001, or other appropriate national standards)

Panel type	Thickness (mm)	Characteristic density (kg/m^3) and strength (N/mm^2) values Density	Bending		Tension		Compression		Panel shear	Planar shear
		ρ_k	f_m		f_t		f_c		f_v	f_r
			0°	90°	0°	90°	0°	90°		
OSB/3	6-10	550	18.0	9.0	9.9	7.2	15.9	12.9	6.8	1.0
	10-18	550	16.4	8.2	9.4	7.0	15.4	12.7	6.8	1.0
	18-25	550	14.8	7.4	9.0	6.8	14.8	12.4	6.8	1.0
P5 Particleboard	6-13	650	15.0		9.4		12.7		7.0	1.9
	13-20	600	13.3		8.5		11.8		6.5	1.7
	20-25	550	11.7		7.4		10.3		5.9	1.5
HB.HLA2 Hardboard	<3.5	900	37		27		28		19	3
	3.5-5.5	850	35		26		27		18	3
	>5.5	800	32		23		24		16	2.5

Table 3 Examples of characteristic moduli values for wood-based panels

from BS EN 12369-1. (Note: Values only for use with Eurocode 5, BS 5268-2: 2001, or other appropriate national standards)

Panel type	Thickness (mm)	Mean modulus (N/mm^2) values Bending		Tension		Compression		Panel shear	Planar shear
		E_m		E_t		E_c		G_v	G_r
		0°	90°	0°	90°	0°	90°		
OSB/3	6 - 10	4930	1980	3800	3000	3800	3000	1080	50
	10 - 18	4930	1980	3800	3000	3800	3000	1080	50
	18 - 25	4930	1980	3800	3000	3800	3000	1080	50
P5 Particleboard	6 - 13	3500		2000				960	-
	13 - 20	3300		1900				930	-
	20 - 25	3000		1800				860	-
HB.HLA2 Hardboard	<3.5	5000		5000				2100	-
	3.5 - 5.5	4800		4800				2000	-
	>5.5	4600		4600				1900	-

Applications and design approach

Potential end uses of panel products in permanent structural applications include:

- Web material for "thin" webbed I joists or box beams, for floor and roof applications
- Roof frames and portals, from I and box beams
- Floor or roof decking over joists and rafters.
- Thin flange material for stressed skin panels
- Shear panels in timber frame construction.

Panel selection is affected by many factors including strength and stiffness properties, weight and moisture resistance. The likely suitability of certain types of wood-based panels in structural applications is summarised in Table 4. It is important that not only the generic type, but also the grade of panel selected is appropriate to the end use service class.

Table 4 Uses of panel products in structural components

Panel materials	Box beams	I-beams	Floor/roof decking	Shear walls	Stressed skin panels
Plywood	Typical	Typical	Typical	Typical	Typical
OSB	Typical	Typical	Typical	Typical	Typical
Particleboard	Unlikely, due to self weight		Typical	Possible	Possible
Hardboard	Typical	Typical	Unlikely (restricted thickness range)	Typical	Possible
Medium board	Unlikely	Unlikely	Possible	Typical	Possible
Softboard	Unlikely	Unlikely	Unlikely	Typical	Unlikely
MDF	Unlikely, due to self weight		Possible	Unlikely	Unlikely
Cement bonded particleboard	Unlikely, due to self weight		Typical	Possible	Unlikely

Thin webbed joists and beams

Table 5 shows typical span ranges, proportions, and material constituents for thin-webbed joists and beams. Nowadays, for the applications shown, I-joists and I-beams would normally be used with frame spacings in the order of 2.4 to 4.8m. Small purlins or secondary joists of solid softwood would span in the cross frame direction to carry the roof, wall or floor surfaces.

Figure 7 I beams and columns fabricated from Kerto-S LVL for a tied portal frame structure. Warehouse in Freising, Germany. Photo: STEP

Table 5 Typical thin-webbed joist and beam span ranges, proportions, and materials constituents

Component description	Span range (m)	Pitch °	Approx proportions	Web thickness mm	Flange sections mm
Straight beam	4.2 – 18	0 - 12	h = l/14	6 - 24	50 x 100 to 4 no. 35 x 150***
Tapered beam	4.2 – 18	0 - 12	h = l/14	6 - 24	50 x 100 to 4 no. 35 x 150***
Pitched tapered beam	4.2 – 18	0 - 12	h = l/14	6 - 24	50 x 100 to 4 no. 35 x 150***
Simple pitched roof frame*	6.0 – 21	5 - 30	h = l/12 to l/15	6 - 24	50 x 125 to 4 no. 35 x 175***
Portal, optionally with tapered columns and rafters**	8.0 - 24	5 - 30	h = l/10 to l/15	9 - 29	50 x 125 to 6 no. 35 x 200***

* requires structural arrangement to resist horizontal thrust at eaves.

** requires suitable detailing at eaves haunch to transmit moments. *** or equivalents in e.g. LVL

Thin-webbed beams for joisted floors

I beams comprise pairs of flanges, separated by a web. Both multiple flanges and multiple webs are possible, see Figure 8. Typically the web is a wood-based panel product, although versions using other materials including steel-timber composite beams are known. Typical web materials are oriented strand board (OSB) and plywood, although structural hardboard and particleboard may occasionally be used. The webs are attached to the flanges either by an adhesive, or by mechanical fasteners. The flange material may be solid timber or a structural timber composite, such as LVL.

Structurally, the I-beam employs the familiar principle that the greatest stresses in a flexural member are close to the outer fibres. Hence, strong tensile and compressive flange material is used, permitting the central zone to be reduced in width and hence weight. The web is designed to resist the majority of the shear forces.

I-joists are effectively small I-beams used as joists and in similar applications. They are nearly always proprietary and provide reliable, quality controlled,

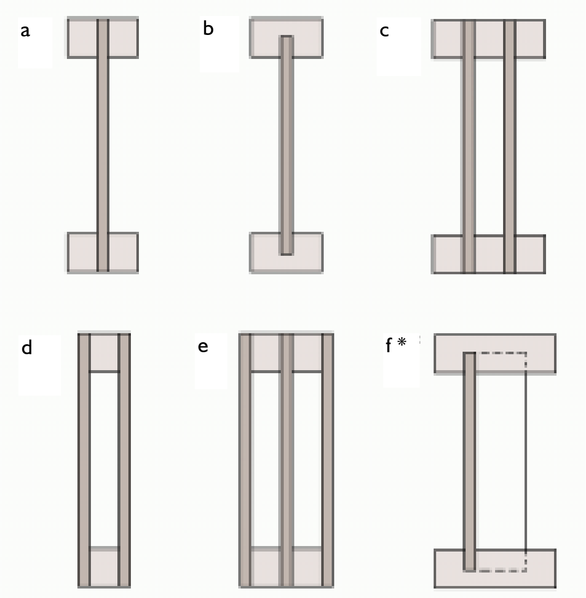

Figure 8 Generic built-up beam sections

- a I-beam: 2 part flanges
- b I beam -1 part flanges
- c Double I beam -3 part flanges
- d Box beam
- e Double box beam
- f Corply beam * (web sinusoidally curved for stability)

(* = proprietary type)

structural products. Their high strength and stiffness to weight ratio means that solutions are available giving lightweight, moderately long spans. Factory controlled moisture content avoids in-service shrinkage and movements.

More information is provided in WIS 1/42 *Timber I-joists: applications and design*. However, designers and those supervising construction need to be aware of the following:

- Stability of I-joists during construction.
- Services - there are restrictions on location of holes in the webs. No notching or cutting of the flanges is permitted.
- Correct joist hangers are required - matched to the I-joist width, with proper fixing methods.
- Attachments to flanges - there are some restrictions on these.
- Protection – essential during and after delivery.
- Cold bridging – good details are available to avoid this risk.
- Strutting – good practice details are available.
- Beam end support details – for some applications, additional end bearing support may be needed.

Panel products for floor sheathing

There is a long-established record of use of timber as flooring. Structural plywood, and structural or flooring grades of particleboard have been the norm for decking in suspended ground floors and in intermediate and compartment floors. More recently, OSB has also taken on an important role in such applications.

The most common design route for such timber floors relies on standard details and construction forms, designed from span tables for designated load levels and joist spacings, based on the material properties. However, enhanced performance may be obtained through the use of calculated designs or by component testing. This is more likely to be undertaken in non-standard dwellings, or in other building purpose types, where the structures are more keenly examined.

Typical decking thickness values stipulated in the UK, for a range of building/floor use categories, are shown in Table 6. These apply where the floor is of a 'common' type ie is considered to be acting non-compositely. The effects of point loads, as well as the capability of resisting normal distributed loads, have been taken into account in deriving the values. The spans are appropriate to joisted floors where either solid timber or I-joists are used as the main structural members. In special circumstances, where horizontal diaphragms or thin flanged beam calculations are made, the skin thickness is normally determined by strength and stiffness calculation verifications.

Table 6 Typical decking types for a range of building/floor use categories.

Typical building/ floor use category	Sheathing types, with indicative dimensions Particleboard EN312 grade	Joist c/c (mm)	Thickness (mm)	OSB EN300 grade	Joist c/c (mm)	Thickness (mm)	Plywood grade	Joist c/c (mm)	Thickness (mm)
Self contained Dwellings	P5	600	22	OSB2 OSB3	400 600	18 18	*	600	15 or 18
Bedrooms in hotels and motels	P5, P7	400	22	OSB3	400	18			
Bedrooms and dormitories (not in hotels and motels	P5 P7	400 600	22 22	OSB3	400	18	In these applications, plywood thicknesses are normally derived from calculations		
Offices for general use	P5, P7	400	22	OSB3	400	18			
Public, institutional and communal dining rooms, cafes and restaurants	P5, P7	400	22	OSB3	400	18			
Bars	P4, P5, P7	300	22						
Classrooms	P5, P7	400	22	OSB3	400	22			
Gymnasia, Dance Halls	P4, P5, P7	300	22						

* only applicable to certain plywood types listed in BS5268 Part 2

Wall structures

Structural wood-based panels have for many years commonly been used in the construction of timber framed wall panels with OSB now frequently supplementing or replacing plywood. The main structural role of the panels is to provide the frame with its in-plane resistance to wind loads, or "racking resistance", as shown in Figure 10. At the same time, the frame is carrying vertical mass and variable (live) loadings. These are also supported in part by the stiffness and bracing effects provided by the structural sheathing.

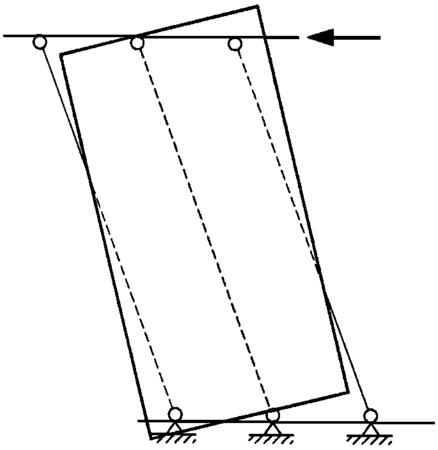

Figure 10 The concept of racking resistance. One or more panels tend to prevent the frame from lozenging.

The panel material is functioning principally to provide in-plane resistance. For this, it is depending upon properties such as panel shear strength, and in-plane bending strength, as discussed earlier. The panels are normally attached to the framing using mechanical fasteners, such as nails and staples. In these cases, planar shear is rarely a critical factor. The performance is usually dictated by the resistance and stiffness of the mechanical fasteners at the sheet edge. Occasionally however, consideration may be given to sheathings attached to the framing by adhesive-bonding methods. In these cases, the planar shear should be taken into account in design verifications. The consequent construction would be much stiffer, but the extra performance would be weighed against the costs of special calculations or prototype tests. The interactions between adjacent panels, might also require investigation in these cases.

The type of behaviour that the commonly employed timber frame panels experience, is known in the UK as "racking". Elsewhere, the terms "shear wall" and "vertical diaphragm" are also found. In the former case, the situation may entail resistance to seismic, as well as wind actions, which is of course an extremely rare necessity in the UK.

Loadbearing, external wall structures are designed for racking and combined vertical loadings, using one or more of the following methods:

Using the laws of structural mechanics, together with data and broad design principles from BS 5268-2, Eurocode 5-1-1, and their supporting standards.

In accordance with BS 5268- 6.1 *Code of practice for timber frame walls. Dwellings not exceeding four storeys*. Basic racking resistance values (kN/m) are tabulated for the most common sheathing and lining board materials. .

Using racking values derived from load testing of full-size wall units, in accordance with *EN 594 Timber structures. Test methods. Racking strength and stiffness of timber frame wall panels*. Interpretation is then required, using either of the structural codes indicated above. Currently, interpretation procedures are not fully standardised.

Using a combination of these methods.

The most common design approach in the UK is to use BS 5268-6.1. Basic racking resistances of a range of board materials (divided into three categories) are presented in this code. and a selection is reproduced in Table 7. Note the different thicknesses of various material types required to obtain similar levels of performance. These values should only be used when carrying out all parts of the design in accordance with BS 5268. Product-specific values have also been derived from testing, for a number of proprietary product combinations. In some instances, design values having a similar basis are given in independent third party approval documents.

Table 7 Typical racking wall design performance
based on BS 5268-6.1

Sheathing materials	Basic racking (horizontal shear) resistance
Category 1: Plywood 9.5mm * OSB 9mm Chipboard 12mm Medium-board (e.g. "PanelVent") 9mm Cement bonded particleboard 12mm Special cellulose/gypsum types eg "Fermacell" 12.5mm	1.68 kN/m
Category 2: ** Bitumen impregnated insulation board 12.5mm 30mm plasterboard separating wall (2 layers, 19 + 12.5)	0.90 kN/m

* designated grades and sources only
** there are restrictions on the properties of the total structure that may depend on these forms of sheathing

Using the BS 5268-6.1 method, the basic racking values are modified when different materials, fixing or wall conditions exist. To support the calculations, a series of modification factors is provided. These cover aspects such as:

- Nail spacing
- Board thickness
- Wall height
- Wall length
- Wall openings
- Vertical load on the wall
- Masonry veneer contribution

A limit states version of the BS 5268-6.1 method, that is compatible with Eurocode 5 has also been developed, see References.

The future

The development of the UK Forest Products Industry is likely to become increasingly dependent upon initiatives such as a recently-installed I-joist production facility in Scotland, as well as the longer-established plant for home-produced OSB. Throughout the UK, there is an increasing and sustainable quantity of softwood timber, resulting from continuous replanting strategies dating back more than eighty years. The current sawn softwood supply from such sources is slightly more than 2 million m^3, and the projected increase for the next twenty years is in the order of 50%. Compared with uses such as cellulose for pulp, timber for construction represents a high value outlet.

The UK supply chain has already demonstrated the use of sawn softwood products, particularly spruce, in the C14 - C18 structural categories. However, limitations of further rapid growth in conventional applications are recognised since the strength and stiffness range of UK-produced softwood is relatively low, compared with supplies from the Nordic and Baltic regions. In addition, plain sawn timber, such as joists, studs and rafters cannot absorb all of the forecast increases in supply of UK material.

I-joists on the other hand, typically require quite small volumes of softwood, to produce large production runs of beam that are an extremely efficient structural item. Hence, they are seen by the UK forest products industry as a rewarding entry point to a number of higher performance markets, without competing against their own, better established products.

Globally, timber engineering is seeing rapid growth in the use of components such as thin-webbed beams, stressed skin panels, and innovative wall diaphragms. Elements acting as full structural composites include timber and steel, timber and ceramics, timber and fibre reinforced polymers, and even timber and glass.

References

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Acknowledgements

The information contained in this publication was produced and compiled as part of a research project carried out with financial support from the Commission of the European Communities, Agriculture and Fisheries (FAIR) specific RTD programme, ref FAIR-CT96-1638 “Extending Markets for Wood-Based Panels by Developing a Better Understanding of Shear Test Methods and Board Shear Properties”. The information does not necessarily reflect the views of the Commission and in no way anticipates its future policy in this area.

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