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SECTION 2/3 SHEET 31
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# Structural glued joints in timber

## ADHESIVES AND TIMBER CONSTRUCTION

Recent years have seen some astonishing developments in adhesive technology. Ships' hulls can be adhesively bonded together, underwater repairs have been made to oil rigs using adhesives which set in water and make joints that have a fatigue strength greater than welding, and concrete motorway bridges have been built incorporating adhesively bonded joints. It therefore seems likely that there is scope for many new developments in adhesive bonding in the field of timber construction too.

Adhesives are widely used in non structural applications such as furniture manufacture and joinery. They are also used in the manufacture of panel products such as plywood and particleboard, some of which are used structurally. TRADA Wood Information Sheet 2/3 - 23 'Introduction to wood based panel products' gives further information on this subject. Laminated components such as glulam and more modern developments such as laminated veneer lumber and parallel strand lumber also rely on adhesive bonding.

This Wood Information Sheet is concerned only with the use of adhesives in structural joints. For these applications adhesive bonds are used in two main ways:

- to form structural joints such as scarf joints, finger joints, glued gusset joints and glued dowel joints.
- to fabricate components such as I beams and stressed skin panels made of plywood or hardboard glued to solid timber

In many cases nails, bolts or other fasteners could be used - so why consider the use of adhesives? Adhesively-bonded joints are generally stiffer, require less timber, have a better appearance and are safer in fire. Their chief disadvantages are that stringent quality control is required in their manufacture, and for certain situations there is a lack of the necessary engineering design information.

## STRUCTURAL USES OF ADHESIVES

The principal uses of structural adhesively-bonded joints in timber are outlined below.

### *Scarf and finger joints*

Glued butt joints where the end grain is bonded are weak and are not suitable for structural joints. Three commonly used end joints are illustrated in Figure 1, the first two being used most often in glulam. Scarf joints with shallow slopes are the strongest, but they use up more timber than finger joints, so the latter are more common, in spite of the special cutters which are needed for their manufacture. The ratio of the strength of the jointed timber to the unjointed CLEAR timber, expressed as a percentage, is termed the efficiency of the joint, and the efficiency decreases as the slope of the scarf or fingers increases. However, most finger-joints manufactured in accordance with BS 5291 'Manufacture of finger joints in structural softwood' will not reduce the bending strength below that of the corresponding SS grade material.

### *Dowelled end joints*

Where it is necessary to join the ends of glulam sections, steel dowels bonded into the ends with epoxy resin can give the required shear strength, in conjunction with steel splice plates to take any tensile forces and bending moments. Threaded steel rods in combination with epoxy resin can resist withdrawal loads too, and they have been

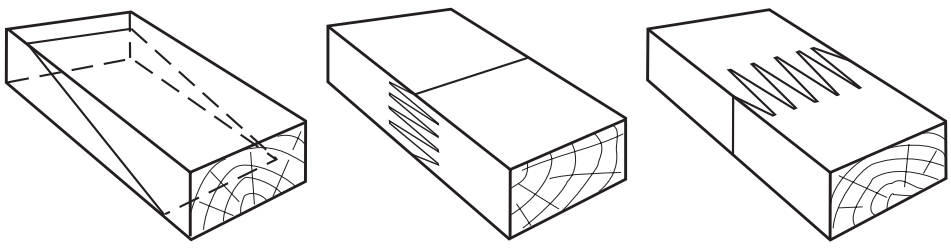

*Figure 1 End joints* *Scarf joint* *Horizontal finger joint* *Vertical finger joint*

used to attach the base of glulam columns to concrete. Such fixings are generally suitable only in glulam and in fairly constant climatic conditions.

***Splice plates and gusset plates.***

Solid timber members which meet in the same plane can be joined together in an efficient way by gluing them between side plates of plywood. In dry conditions tempered hardboard or structural grade chipboard could be used instead. When two members in line are joined end to end the side plates are called splice plates: in other configurations of joint, such as those shown in the roof truss in Figure 2, they are called gusset plates.

With most types of North American plywood included in BS 5268 'Structural use of timber' Part 2 'Permissible stress design, materials and workmanship' the area of glued joint required to transmit a given load is little more than half the area required if nails are used instead, and with a hardwood plywood, such as Finnish birch it is little more than a quarter. In moment-resisting joints the area required by glued North American plywood gussets is about two-thirds of the area required by bolts and steel side plates, and with the hardwood birch plywood only about one third. The choice of glued plywood gussets will evidently allow savings in material. Furthermore when bolts are used the depth of the main members is sometimes determined by the minimum edge-distances required, and in these cases the substitution of glued plywood gussets will permit the use of smaller members. The greater stiffness of adhesively bonded gusset joints may also permit a reduction in the cross-sections of the members.

***Glued structural components***

The design of all the components described in this section should be undertaken in accordance with BS 5268 Part 2 which defines suitable materials and grades. They should be manufactured in accordance with BS 6446 'Manufacture of glued structural components of timber and wood based panel products' which covers the preparation of the materials, the production of the glued components, production control and testing.

When nails and thermo-setting resins are used together, the shear resistance of the nails may not

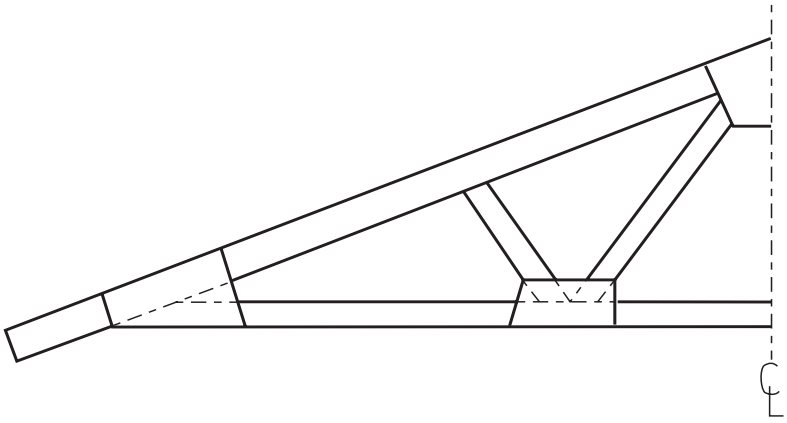

*Figure 2 Gusset plates*

be included in design calculations, because the greater rigidity of the adhesive causes it to take most of the load. However the addition of nails, improved nails or screws can reduce the often considerable tensile stresses perpendicular to the plane of a glued joint, thus significantly enhancing its strength, even though this may not be taken into account in standard design procedures.

In North America specially formulated elastomeric adhesives are used in conjunction with nails to fix board materials to timber in floors, timber- frame walls and roofs. On the basis that the stiffness of these adhesives and the nails are comparable, design procedures have been developed which allow both to contribute to the calculated strength and stiffness of these structures.

Beams

I-beams and box beams can be made by bonding plywood, tempered hardboard or structural grade chipboard webs to solid timber flanges, as illustrated in Figure 3 (a) and (b).

The flexural stiffness of the whitewood flanged I-beam illustrated in (a) is approximately equal to that of a standard size LB grade whitewood glulam beam, 115 x 540 mm in cross-section. A single beam of similar stiffness could not normally be obtained in solid whitewood because of the depth required.

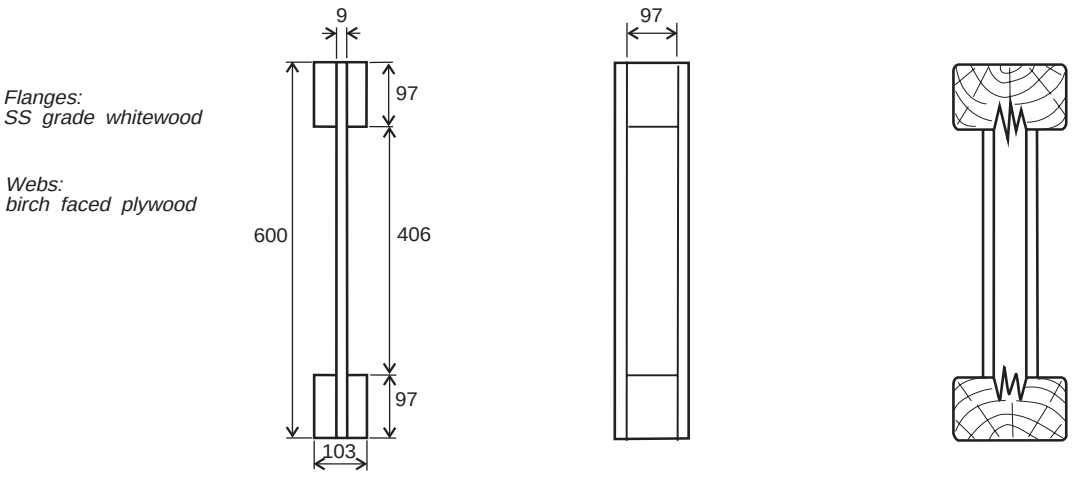


*Figure 3 Glued beam types (a) I-beam (b) box beam (c) formwork beam*

In some European countries I-section formwork beams, made with plywood webs or solid timber lattice webs which are finger-jointed into solid timber flanges, are used extensively for temporary construction works. The beams, including their adhesively bonded joints, last for seven to ten years on building sites, retaining good dimensional stability and surviving frequent handling.

### *Stressed skin panels*

Glued stressed-skin panels are normally made of plywood bonded to one or both sides of a series of solid timber joists or studs. Floors may be upgraded by this means, provided that the surfaces to be joined can be properly prepared and that adequate pressure is applied, normally by nailing at spacings specified in BS 6446, during curing. As an example, the addition of 17 mm sanded Douglas fir plywood to one side of 50 x 150 mm SC3 joists spaced at 400 mm centres will halve the deflection of the floor under load, and the addition of a second skin will halve it again.

### *Resin-bonded repairs*

Epoxy resin is regularly used by specialist companies for in-situ renovation work, where sections of existing beams or columns must be strengthened or replaced. Strengthening is effected by cutting out a channel and replacing the lost material by steel rods grouted in with epoxy resin. New member sections can be end-jointed to old by means of steel rods and resin to replace decayed or insect-damaged sections. The technique produces an invisible joint, which, if properly designed, has excellent fire resistance.

## *TYPES OF ADHESIVE*

Table 1 shows the types of adhesives described below, together with an indication of their uses. The adhesives most commonly used in timber construction can be placed in one of three groups, though they are not all suitable for load bearing joints.

### *1 Thermo-setting resins*

These consist of a synthetic resin and hardener, and they are most commonly supplied as two liquids or a liquid and a powder which must be mixed before use. The resins, either phenolic or aminoplastic, are derived from the reactions of various compounds with formaldehyde: the phenolic resins are particularly resistant to moisture. In the correct environment and in properly made joints thermo-setting resins make a bond which will remain stronger than all but the densest species of timber.

BS 1204 'Synthetic resin adhesives (phenolic and aminoplastic) for wood' is published in two parts: those covered in Part 1 'Gap filling adhesives' are suitable for load-bearing purposes and provide satisfactory bond strengths in bond lines up to 1.3 mm thick. The adhesives covered in Part 2 'Specification for close contact adhesives' are suitable only in joints where the surfaces to be joined can be brought into close contact so that the thickness of the bond lines does not exceed 0.15 mm.

*Table 1 Types of adhesive and their uses*

| Adhesive | Abbreviation | Type | Uses | Suitable conditions |
|---|---|---|---|---|
| Resorcinol formaldehyde | RF | Phenolic thermoset resin | Laminating, finger jointing, wood jointing. (Rarely used alone because of high cost) | Fully exterior, load-bearing |
| Phenol-resorcinol formaldehyde | PRF or PF/RF | | Laminating, finger jointing, wood jointing, including boats | |
| Phenol-formaldehyde | PF | | Plywood, some particleboard | |
| Melamine formaldehyde | MF | Aminoplastic thermoset resin | Plywood, particleboard, formwork panels. (Not often used alone in the UK) | Semi-exterior and moist interior, load-bearing |
| Melamine urea formaldehyde | MUF | | Laminating, finger jointing, particleboard, medium density fibreboard, plywood | |
| Epoxy resin | | Multi-component thermoset resin | Structural repairs, timber to steel, glass fibre etc, boats, glulam rivets, end jointing | |
| Cross-linking polyvinyl acetate | cPVA | | Wood jointing, site gluing, laminates to woods | Non load-bearing |
| Urea formaldehyde | UF | Aminoplastic thermoset resin | Plywood, particleboard, medium density fibreboard, panel surfacing, wood jointing | Interior, load-bearing |
| Casein | | Milk product | Laminating, finger jointing, wood jointing | |
| Polyvinyl acetate | PVA | Thermo-plastic emulsion | Wood jointing, small-scale gluing operations | Interior, non load-bearing |
| Elastomeric adhesives | | Elastomeric solution | Site gluing, nailed and glued joints, laminates to woods | |

Thermo-setting resins are divided into four categories in BS 1204, based on their resistance to the environment:

WBP: Weather-proof and boil-proof

These are adhesives which have been proved to make joints which are highly resistant to weather, micro-organisms, cold and boiling water, steam and dry heat.

BR: Boil-resistant

These adhesives make joints which have good resistance to weather, cold water and the boiling water test, and are highly resistant to micro-organisms, but they fail under prolonged exposure to the weather.

MR: Moisture-resistant and moderately weather-resistant

Such adhesives make joints which survive full exposure to the weather for only a few years, cold water and micro-organisms for a long period, and hot water for a limited time, but fail in the boiling water test. They are not normally recommended for structural joints.

INT: Interior

Adhesives which make joints resistant to cold water but which are not required to withstand attack by micro-organisms. Adhesives in this category are not recommended for structural joints.

### *2 Polyvinyl acetate thermo-plastic adhesives*

These are based on an aqueous emulsion of a polyvinyl acetate polymer, and they may also contain fillers and plasticizers. One-part PVA emulsions have long been used for furniture and indoor joinery, but they creep under load, particularly at elevated temperatures and in moist conditions. More recently the addition of a separate hardener has produced chemically cross-linking types which are vastly stronger and more durable. Nevertheless they are still not recommended in the UK for load-bearing applications or for use in chemically polluted atmospheres.

### *3 Other types of adhesive*

Casein adhesives are made from milk. In most low- and medium-density timbers they make strong joints which are exceptionally durable indoors or if well-protected from the weather. Although still quoted in BS 5268 : Part 2 as suitable for interior, low hazard situations, BS 1444, which was the standard specification for these adhesives, has now been withdrawn. However a new European standard for the specification and testing of casein adhesives for structural use in wood is in preparation.

Epoxy resins for wood are two-component systems based on a resin and a hardener, both of which may contain fillers. Although relatively expensive, they are used in boat building and structural repair work, where their ability to bond wood to other materials such as glass-fibre and steel is valuable. Epoxy resins are also used in conjunction with dowels and rivets to form end joints in glulam.

Elastomeric adhesives are mostly based on a solution of a natural or synthetic rubber in an organic solvent. They are suitable for on-site application to relatively large surface areas. In the USA elastomerics with added fillers are known as construction adhesives, and they are widely used in conjunction with nails to stiffen and strengthen floors and wall panels. Some types appear to have adequate strength and creep resistance for structural work, but in the UK it is felt that the data available are insufficient to confirm this.

Other adhesives which are less commonly used in structural timber work are described in a TRADA Research Report 'Structural glued joints in wood: the state of the science' and in the TRADA publication 'Adhesives for wood'.

## *SELECTION OF ADHESIVES*

The choice of a suitable adhesive will depend on both technical and manufacturing considerations.

### *Exposure categories*

An important factor which affects the performance and selection of adhesives is the amount of moisture to which they will be subject in service, in particular variations in atmospheric humidity and temperature. BS 5268 : Part 2 defines four exposure categories, which are shown in Table 2.

Eurocode 5 `Design of timber structures' Part 1 defines three service classes which correspond to equilibrium moisture contents in solid timber of:

12% or less - Service Class 1 ($20^{o}C$; 65% relative humidity)

18% or less - Service Class 2 ($20^{o}C$; 85% relative humidity)

> 18% - Service Class 3

The European standard, BS EN 301 `Adhesives for load-bearing timber structures', defines only two categories: 'high hazard' and 'low hazard'. 'High hazard' is similar to the two high hazard categories defined in Table 2, and 'low hazard' is similar to the other two.

### *Permitted and recommended adhesives*

BS 5268 : Part 2 specifies the adhesives which are permitted for load- bearing purposes in each exposure category, as shown in Table 2. Eurocode 5 refers simply to `Type 1' and `Type 2' adhesives for structural use. The performance specification for both of these are given in BS EN 301 and 302. Type 1 adhesives are suitable in all EC5 service classes; Type 2 only in service classes 1 and 2 and not under prolonged exposure to temperatures in excess of $50^{o}C$.

Timbers which have a resinous or greasy surface, or a case- hardened surface (usually caused by hot-pressing or drying operations on veneers of plywood), are probably best glued with RPF or PF adhesives.

*TABLE 2 Use categories for adhesives*

| Category | Conditions | Examples | Permitted for load bearing use | Type (from BS 1204 Part 1) |
|---|---|---|---|---|
| Exterior high hazard | Full exposure to the weather | Marine and other exterior structures, exterior components or assemlies when the glue-line is exposed to the elements | RF<br>PRF<br>PF | WBP |
| Exterior low hazard | Exposed to the weather but protected from sun and rain | Inside the roofs of open sheds and porches, concrete formwork | RF<br>PRF<br>PF | WBP |
| | | | MUF [1] | BR |
| Interior high hazard | In closed buildings with warm and damp conditions where a moisture content of 18% is exceeded and the glue-line temperature can exceed 50°C | Laundries, unventilated roof spaces | RF<br>PRF<br>PF | |
| | Chemically polluted atmospheres | Chemical works, swimming baths | RF<br>PRF<br>PF | WBP |
| Interior low hazard | Heated and ventilated buildings where the moisture content of the wood will not exceed 18% and the glue line temperature will remain below 50°C | Inside heated buildings | RF<br>PRF<br>PF | WBP |
| | | | MUF [1] | BR |
| | | | UF<br>Casein [2] | MR |

Notes to Table 2

1 Other modified UF adhesives of the BR type may also be used
2 Casein should comply with the former BS 1444 or the forthcoming European standard for casein adhesives for structural use

Limitations

This table refers only to laterally loaded joints made with softwoods, plywoods, tempered hardboard or structural chipboard. For bonding hardwoods, and particularly resinous softwoods or other wood products, the advice of an adhesive manufacturer should be sought.

Glued structures other than laminated members should not be used in the `exterior high hazard' exposure category. The thickness of the glued members should not exceed the limitations set out in BS 5268 Part 2.

### *Manufacturing considerations*

The manufacturing considerations which need to be taken into account in choosing an adhesive relate to the method of application, whether heating is needed and available, the required speed of curing, and the cost. This in turn depends on the cost of the adhesive itself, its rate of spread, the equipment required to apply it, and the labour and time involved.

Further considerations may be the adhesive's *storage life* or *shelf life* (the time that it may be stored within a stated temperature and remain usable), its *pot life* or (for plywood) its *open assembly time* (the time following the opening of the container or the mixing of the adhesive during which it may be applied to the face or faces of the joints before they are brought together under pressure), and its *closed assembly time* (the time during which pressure must be maintained at a specified temperature in order for the joint to become strong enough for careful handling without the maintenance of pressure and without being stressed). Manufacturing considerations are set out more fully in the Research Report 'Structural glued joints in timber'. When there is any doubt about the best type of adhesive to use, the advice of a manufacturer should always be sought.

### *LIMITATIONS ON USE*

**General**
Structural glued joints should be designed in accordance with BS 5268 Part 2. They should not be employed unless every aspect of the manufacturing process can be properly monitored and controlled to ensure that it is undertaken in accordance with the relevant production standard.

BS 6446 covers such components as box beams, single web beams, stressed skin panels and glued gussets. BS 5291 covers finger joints in structural softwood.

The adhesive must be suitable for structural use and the service environment. Glued joints cannot be relied upon in materials or exposure conditions for which the adhesive is considered unsuitable. If hardwoods or excessively resinous softwoods are to be glued, or if there is any doubt about the suitability of an adhesive for its service environment, the adhesive manufacturer's advice should be sought.

**Durability**
After long periods, some deterioration in the strength of the adhesive bond as well as of the timber will occur, particularly if the moisture content of the timber fluctuates, producing dimensional

changes. Unloaded softwood test joints made with the various adhesives which are recommended for load-bearing purposes, in the exposure environments for which the use of these adhesives is recommended, have retained from 80% to 95% of their original shear strength after 25 years. However the long-term durability of loaded glued joints which are exposed to the weather is not known with real certainty, and particular caution should be exercised when glued hardwood joints are subjected to conditions of fluctuating moisture content.

### *Gluing preservative-treated timber*

The use of preservatives can affect the bonding process. Three kinds of preservative are available: waterborne inorganic salts, solvent-based organic insecticides and fungicides, and creosotes.

Satisfactory bonds can be made with preservative-treated timber, unless the treatments (usually solvent-based types) contain water-repellants, since the latter prevent the adhesive from wetting the surface. Some adhesives contain wetting agents which help to counter this problem, but for the manufacture of glulam the use of timber treated with preservatives which contain water-repellants is not permitted.

Whichever kind of preservative is used, the timber should be lightly planed or sanded not more than 12 hours before gluing. The shavings should be handled and disposed of with care.

#### Waterborne preservatives

Wood treated with these must first be dried to a moisture content which conforms to BS 6446 - generally below 20% and within 5% of its expected level in service, and this will probably necessitate kiln-drying. However RF and PRF resins can be used if necessary with timber which has a moisture content as high as 25%. When measuring the moisture content it is preferable to use the oven-drying method, since the preservative salts may affect the accuracy of electrical resistance meters.

#### Solvent-based preservatives

The solvents must be allowed to evaporate before gluing, and this may take several days.

#### Creosotes

Although dry creosoted timber can be glued satisfactorily with RF, PRF or PF resins, this is not recommended.

### *Preservative treatment of glued joints*

Fully-cured structural glued joints may be treated with preservatives at ambient temperatures after manufacture without any loss in strength.

### *Flame retardants*

BS 5291 and BS 6446 prohibit the manufacture of glued joints in timber which has been previously treated with inorganic salts, and BS 5291 adds that even following their manufacture finger-joints may be treated with such salts only after seven days have elapsed. Timber treated with other types of flame retardent can be glued successfully, but advice should be sought from the adhesive manufacturer.

### *Site gluing*

Site gluing of structural joints is not recommended, unless the following conditions can be met:

- the measured moisture content of the components at the time of gluing is within the limits specified in the relevant standard
- the surfaces are plane and have been accurately machined with sharp tools or lightly sanded and brushed not more than 12 hours before bonding, and have been kept clean and dry until the joints are made
- during bonding and the specified curing period the minimum temperature specified by the adhesive manufacturer is maintained in the glueline - this will be at least $10^{o}$C and in many cases $15^{o}$C
- adequate pressure is maintained without relative movement between the components throughout the period of curing
- proper supervision of the entire process is maintained.

Note: BS 6446 recommends that the production area is enclosed and maintained at a minimum temperature of $15^{o}$ C.

### *CHECK LIST - HOW TO GLUE WOOD SUCCESSFULLY*

The main points to observe are listed below:

1 Follow carefully the directions of the appropriate British Standards and the instructions supplied by the adhesive manufacturer.

2 Do not attempt to manufacture structural glued joints unless you are satisfied that you have the necessary knowledge, equipment and environment.

3 Select an adhesive which is suitable for the exposure conditions in service and for load-bearing.

4 Confirm that the adhesive's storage life has not been exceeded, and that any equipment required to apply it is clean.

5 The wood should be dry (below 20% moisture content), and if possible in equilibrium with its expected service conditions.

6 For timber members use sharp cutters to obtain a flat, clean surface on each face which is to be bonded. Alternatively, if the surfaces are flat already (eg plywood), they may be lightly sanded. (Sanding can create more crushed wood cells than knife planing and so yield weaker fibres which make weaker joints.) Sanding dust should be completely removed.

7 Commence gluing as soon as possible after planing or sanding and within the period specified in the appropriate standard. This will limit surface pollution from resins in the wood and contaminants from the air, and avoid the possibility of distortion resulting from changes in the moisture content of the components.

Steel plates, the smooth surface of hardboard, and timbers with resinous or greasy sufaces, should be wiped prior to bonding with any approved industrial degreasing agent, except

water-soluble ones, since these can leave a protective film which inhibits bonding (see Safety precautions). Acidic timbers may be neutralized with a weak alkaline solution such as 1% sodium carbonate.

8 Use clean vessels to mix the constituents of the adhesive, and follow the manufacturer's instructions for mixing and applying them. Make sure that the temperature at the glueline is within the specified range, and that the open assembly time is not exceeded.

When gluing timbers which have a very absorbent surface, use a viscous glue, possibly with extenders, or increase the spread, or apply a second coat after the first has cured. When gluing timbers which have a dense, close-textured surface, apply adhesive to both surfaces and allow partial drying of water-based and solvent-based types before applying reduced pressure. In any cases of doubt, seek the advice of the adhesive manufacturer.

9 BS 6446 gives instructions for applying pressure by nailing, but it is preferable to use mechanical clamps, with springs, which can be tightened after half an hour to maintain the pressure, or better still hydraulic clamps or airbags which are self-adjusting. For very small joints, weights may be adequate. The pressure should be sufficient to make as thin a glue-line as possible without squeezing out all the adhesive, that is between 0.35 and 2.0 $N/mm^2$ depending on the thickness of the members. 0.7 $N/mm^2$ is a good general value, but with members more than 30 mm thick it may not be possible to achieve this pressure with nails.

10 The temperatures specified by the manufacturer must be maintained throughout the curing period, and the joints should not be disturbed until curing is complete.

The curing times quoted by manufacturers are generally the times required for joints to acquire 50% of their ultimate strength. Joints which are stressed as soon as their restraining clamps are removed, such as curved glued laminated members, should be clamped for at least twice as long as this.

11 Before they are installed in their working environment, ensure that the completed joints are not exposed to conditions for which they are not designed.

***SAFETY PRECAUTIONS***

There are important health and safety matters to be considered when glued joints are manufactured:

- ventilation
- protection for the skin, eyes and lungs
- the risk of fire when using flammable materials
- the disposal of toxic waste
- some chemicals which are used to degrease steel parts are highly flammable and toxic.

## *REFERENCES*

### *British Standards*

**BS 1204** Synthetic resin adhesives (phenolic and aminoplastic) for wood.
Part 1 : 1979 (1991) Specification for gap-filling adhesives.
Part 2 : 1979 (1991) Specification for close-contact adhesives.

**BS 4169** : 1988 Specification for manufacture of glued-laminated timber structural members.

**BS 5268** Structural use of timber
Part 2 : 1991 Code of practice for permissible stress design, materials and workmanship

**BS 5291** : 1984 (1990) Specification for manufacture of finger joints in structural softwood.

**BS 5669** Particleboard.
Parts 1-5 : 1989

**BS 6446** : 1984 Specification for manufacture of glued structural components of timber and wood-based panel products.

**BS 6566** Plywood.
Parts 1-8 : 1985 (1991)

### *European Standards*

**Eurocode 5** Design of Timber Structures. General Rules and Rules for Buildings. This will be published by BSI as DD ENV 1995-1-1 in 1993 or 1994.
Part 1

**BS EN 301** : 1992 Adhesives for load-bearing timber structures -Polycondensation adhesives of the phenolic and aminoplastic types - Classification and performance requirements.

**BS EN 302** : 1992 Adhesives for load-bearing timber structures -Polycondensation adhesives of the phenolic and aminoplastic types - Test Methods
Parts 1 - 4

### *Other useful references*

Prices and a full list of TRADA publications are available on request.

"Structural glued joints in wood: the state of the science",
A V Page, TRADA Research Report RR 1/90, 1990.

"Adhesives for wood,"
O P Hansom, TRADA, 1987 (includes list of adhesive manufacturers).

"Gluing wood successfully", BRE Digest 314, 1986.

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