# JOINING TIMBER WITH GLASS FIBRE AND EPOXY.

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## Abstract

Wood-Glass-Epoxy joints are made by wetting glass fibre cloth with epoxy resin and bonding it to the sides of the timbers. They represent an economic alternative to punched metal plates or bolts in a variety of applications including those where high durability, waterproofing or an attractive appearance are required. They may also be used to enhance the properties of the timber members themselves. Previously published work has shown that these joints perform well in fatigue. This paper presents test results for strength and stiffness for a number of different joint configurations with the timbers parallel and at 30, 60 and 90 degrees to each other. The results indicated that uniaxial glass cloth performs better than biaxial glass cloth in all joints. Mis-aligning the glass with the direction of loading has a significant detrimental effect on performance. For the non-parallel joints the unavoidable effect of loading at an angle to the grain reduced both the failure loads and the stiffness.

## Introduction

Bonded glass fibre represents an attractive option for joining timber in some structural applications. The glass is thoroughly wetted with the liquid resin and sets to form a composite which is bonded to the timbers. Punched metal connectors give excellent performance for light to medium weight timber frames at very low cost but glass-epoxy could be competitive in the following circumstances:

- Site applications where access is limited. The epoxy does not need to be pressed or nailed into the timber.
- Situations where the timber members need to be reinforced. The glass-epoxy may be used to reinforce the tension face or wrap entire members to improve their performance.
- External applications which may require protection for the timber. An ultraviolet stabilised epoxy will provide good protection against all forms of rot.
- If there is a requirement to prevent water ingress a glass-epoxy coating can be used over an entire structure. This is the basis for its popularity for boat building.
- Applications where the structure requires a good appearance. The glass is a white cloth as supplied but when wetted with the resin it becomes transparent and the completed composite gives the appearance of a varnish.

The authors have previously published work in which glass-epoxy joints were compared to other jointing systems such as bolts and dowels (1) and also a study of the fatigue resistance of the joints (2). In both of these studies the glass-epoxy performed well but all of the samples were straight butt joints with the weave of the glass parallel to the grain of the timber. In this paper results are presented for the strength of joints with different configurations.

## Literature Review

Using glass fibre to reinforce wood materials began in the early 1960s (3,4). Wood-glass fibre composite beams were analysed in elastic deflection but also in the plastic region (4). Various species of wood were reinforced by applying unidirectional glass fibre strands impregnated with epoxy resin to the top and bottom surface.

Further studies were developed for laminated timber using different kind of adhesive (polyester, vinyl-ester and phenol-resorcinol resins) as described in the excellent review from reference (5). This also mentioned research for wood/glass fibre composites in other applications:

- Glass Fibre Reinforced Plastics (GFRP) were used to reinforce wood transmission poles in the early 1970s.
- Plywood was overlaid with glass fibre (an in-depth series of tests was performed by the American Plywood Association in 1972 and 1973). This reinforced board was used in the transportation industry and was extensively used in cargo shipping containers, railroad cars and vans.
- An extensive study was performed in Germany using solid wood, plywood and particleboard in 1974-1976. GFRP incorporating a polyester resin was bonded to the surfaces of the core material in a wet process. A considerable

improvement in the strength and the stiffness properties was obtained and a significant reduction in creep was reported.

A study (6) was carried out using glass fibre with phenol-resorcinol formaldehyde resin to increase the tension and bending strength of impression finger joints. Composite members were made of a core wood material (finger joint) with veneers on each side and glass fibre layers sandwiched between veneer and core. The strengths were increased from 10 to 40% over unreinforced joints, using only a glass fibre reinforcement level of 3.5% and 7% by volume. It was noticed that a maximum of 80% of the glass fibre strength capacity was effective in these tests.

The use of composite fabrics to reinforce wood crossties (sleepers) was investigated (7). The authors investigated the feasibility of hand wrapping for GFRC (Glass Fibre Reinforced Composites)/wood crosstie and experimentally evaluated their mechanical behaviour. Northern red oak wood and unidirectional E-glass/epoxy reinforcement were used. Results of the experimental tests indicated that only one layer of reinforcement provided noticeable enhancement to both strength and stiffness. Average increases in stiffness of 15 to 41% and strength of 14 to 31% were achieved.

The same year, the same team (8) produced a paper about accelerated ageing of wood-composites members. Using red oak wood as a core and two types of composite fabrics (glass and carbon) as external reinforcements, they undertook series of shear strength tests. Several adhesives for bonding were used. The results showed that phenolic-based resins had higher retention of shear strength after being subjected to ageing conditions. The ageing process was composed of six cycles of swelling and shrinkage effects. The best combinations were wood/glass/epoxy and wood/carbon/epoxy, which retained nearly 50% of their shear strength capacity after the ageing process.

The performance of fibre reinforced polymer composites used with wood has been reviewed (9). Strength, stiffness and accelerated ageing response of sawn and laminated wood beams wrapped with glass composites and bonded in place with polymeric resins were reported. The authors concluded that hybrid wood components exhibit increases in strength and stiffness of up to 40 and 70% respectively, over non-wrapped wood beams for a constant volume percent of fabric. These mechanical properties could be increased further with the addition of more layers of fabric.

No references have been found in the literature to work exactly similar to that presented in this paper.

## Sample fabrication.

The timber samples were European Spruce graded C16 to C24 to BS5268 Part 2 (10). The samples had a nominal cross section of 100mm by 50mm. Unidirectional glass fibre woven roving weighing 500g/m$^2$ (SP Systems product code UT-E500 (11)) was selected for some of the joints. In this cloth almost all of the fibres are uni-directional with just a very light weave across them to hold them in place during fabrication. For the other joints a Bi-Axial cloth weighing 450 g/m$^2$ (XE-450) with equal weights of glass in the warp and the weft was used. The epoxy was a clear coating/laminating resin (SP Systems product code Spabond 120 (11)) which was used with slow hardener at the recommended ratio of 100:44 by weight.

The wood/glass/epoxy samples were made of two pieces of timber with a length of glass fibre/epoxy on each side and were tested with the load applied axially to the grain direction of one of the timbers (12). For the load parallel to the grain tension tests and the 90 degrees grain/load angle, the length of composite was of 200 mm. It was 232 mm long for the 60 degrees and 400 mm long for the 30 degrees. The glass was only applied to the 100mm wide faces of the samples. The area of the joint was coated with wet resin, the glass was then positioned and resin stippled into it with a brush and then the completed joint was consolidated with a roller to expel any possible remaining air. Direct bond between the two pieces of timber was not required so no resin was introduced into the joint and foil was used to prevent any bond from forming. An example of a completed joint is shown in figure 1.

At the ends of the assembled samples two shear-plate connectors were held between two steel plates and connected with a 20 mm diameter bolt in order to apply the loads. This system was used in previous testing programmes for timber joints (1, 2, 12). The minimum distance from the connectors to the tested joint (i.e. glass fibre/epoxy layers) was 300 mm.

PVC and steel brackets were glued onto the timber in order to hold Linear Variable Differential Transformers (LVDTs) in position. The LVDTs measured displacements at the gap position between the brackets located on either piece of timber. On the parallel samples they were fixed in a symmetrical arrangement to check any misalignment of the sample. A typical arrangement for a non-parallel sample is shown in figure 2.

## Testing Programme

A total of 64 wood/glass/epoxy joints samples were tested. Details are given in table 1 and diagrams of the different configurations are given in figure 3. The samples coded P were parallel (straight) tests while those coded N were Non-parallel. Those coded U uses Uni-axial glass while those coded B used bi-axial glass.

Testing was carried out with a hydraulic jack on the strong-floor. Figure 4 shows the loading arrangement for the non-parallel samples which included a pinned joint in the loading box to ensure axial loading.

The rig was loaded until the sample was effectively held (i.e. a small load was applied to the sample). At this stage, the LVDTs were initialised through the data acquisition system as zero position. A testing sequence using a pre-load was used as specified in BS EN 26891 (figure 5). Using a loading rate of 6 kN/min, the load was constantly applied to the sample. The load and displacements were recorded at every 1.5 kN increment (every 15 sec.) and as the load came closer to the estimated failure load, they were recorded at every 0.6 kN increment (every 6 sec.).

A typical load-displacement curve is shown in figure 6. The joint stiffness was calculated over the elastic range of the sample. When the results were analysed some curves showed a change in slope (or stiffness) in the elastic range with a sudden increment of displacement. This was due to the failure in tension of some epoxy resin infiltrated accidentally between the timber piece butt ends (in the gap) and was excluded from the results for calculation of stiffness.

## Results

The results for strength and stiffness are shown in figures 8,9,12 and 13. The length of the error bars is one standard deviation.

The parallel samples with uniaxial glass failed by delamination of the composite layers from the timber surface on both sides. A typical failure is shown in figure 7. The TPU10 samples with the glass at $10^{o}$ had failure loads more than 15% lower and stiffness more than 25% lower than for the TPU00 test (figures 8 and 9). The slight mis-orientation of fibres weakened the system significantly. The same mode of failure by delamination occurred for TPU10 tests, revealing that the tension strength of the composite matrix was still higher than the bond strength. The maximum slip in the gap at failure did not exceed 0.75 mm for the TPU10 test, which is to be compared with the maximum slip of 1.1 mm for TPU00 test. The load-displacement data showed that the TPU10 samples did not reach a plastic behaviour and remained in an elastic/plastic stage until failure.

The modes of failure observed for TPB00 tests were both tension rupture of the fibres and delamination. This is consistent with the failure loads obtained from the TPB00 test being lower than for TPU00 tests due to the decrease in the amount of glass in the biaxial cloth carrying the load. The elongation of each fibre for the TPB00 samples in the load direction was significant, resulting in a high slip in the gap area, with a maximum of 1.2 mm, a similar value to TPU00 test. High slip but lower failure load gave the TPB00 tests a lower stiffness than the TPU00 test, as shown in figure 9.

The modes of failure for the TPB30 samples were similar to the TPB00 test and were tension failure of the fibres and partial delamination. As a result, transverse rupture of the fibres was observed (due to the combined failure modes), following the orientation to the load direction (30 degrees). The failure load was generally 20% lower than for the TPB00 test. Once again, it seemed that premature failure was due to the fibre orientation, which weakened the joint significantly. The slip-load curves showed an elastic and plastic behaviour before failure. The maximum displacement did not exceed 0.8 mm, a much smaller value than for the TPB00 test. The stiffness based on elastic behaviour was only 10% less than for the TPB00 test. The fact that both strand directions of fibres were bonded to the timber with an angular orientation to the load (unlike TPB00 configuration where only one strand direction is loaded) improved the stiffness of the system.

For the non-parallel joints there were major differences between the TNU (uniaxial glass fibres) and the TNB (biaxial glass fibres) systems. The modes of failure observed for both systems were clearly different. The TNU tests always failed by delamination of the composite (figure 10), whereas the TNB tests failed by combination of delamination and tension rupture of the composite (figure 11). This observation was confirmed by the fact that failure loads for the TNB tests were lower than failure loads for the TNU tests, whatever angle configuration was considered (figure 12). For the TNU tests, all the fibres of the uniaxial glass were orientated in the load direction:  With fewer fibres available to transfer the loads, the TNB tests failed at lower loads, whether it was delamination failure or fibre rupture.

The increased bond area for the 30° and 60° samples would have been expected to give them a higher strength but this was not observed for the TNU and TNB tests.

For the TNU tests, where the joints were clearly unbalanced (the joints always failed by Delamination), the failure loads decreased as the grain/load angle reduced from 90 to 30 degrees. In this situation, the longer the composite layers, the lower the failure loads. The grain orientation was an important parameter to take into account. Failure by delamination always occurred on the timber members, where the composite was orientated with an angle to the grain. This indicated that the bond strength of the composite was reduced when the timber grain was not orientated in the same direction than the composite fibres and the loading. When the fibres were orientated perpendicular to the timber grain direction such as the TNU90 test, it is clear that this system was the strongest in terms of failure loads, as shown in figure 12. The average failure loads decrease as the angle to the grain reduces. But this reduction is not as significant as it could be, if the length of composite were equal for all the TNU tests.

The situation was rather different for the TNB tests. The modes of failure were less consistent and were generally combinations of various modes, such as fibre tension rupture, delamination and longitudinal shear failures. As a result, the failure loads did not decrease as the grain/load angle reduced from 90 to 30 degrees. The failure loads appeared to be fairly uniform for the TNB90 and TNB60 tests, and slightly higher for

TNB30. This inconsistency was probably due to the fact that only one half of the fibres were directly stressed in tension, then the tension capacity of the composite was lower than for the TNU tests. Furthermore, the biaxial fabric XE450 used for the TNB tests had two layers of fibres, skewed and stitched together, one on top of the other. Because the fibres were not woven, the bond between the composite and the timber only affected the layer of fibres in direct contact with the interface. This was certainly a reducing factor of the composite bond strength for the TNB tests. With lower bond and tension strengths, the length of composite became a major factor in the strength of the joint. Longer strands of fibres improved the bond strength significantly, but the grain orientation was still having a reducing effect on it.

The timber grain orientation has a direct effect on the joint stiffness. For the TNU90 and TNB90 tests, when the load was applied perpendicular to the grain, the elastic deformations were the largest. The timber properties are generally much lower in the radial or tangential directions than in the longitudinal direction of the grain.

It has been proposed (13) that approximate values of the moduli of elasticity may be found by taking $E_L$ (longitudinal modulus of elasticity) equal to 1.1 times the bending modulus, $E_T$ (tangential modulus of elasticity) equal to $0.05 \times E_L$ and $E_R$ (radial modulus of elasticity) equal to $0.10 \times E_L$. The stiffness of the joints would therefore be expected to decrease with increasing angles between the load and the grain. This was observed as a significant trend (figure 13)

Finite element analysis of the joints has been reported elsewhere (12). The complexities of the composite system made the analysis difficult but some agreement with the experiments was found. We are not aware of any use of these jointing systems in structures other than in some refurbishment work but we hope to carry out site trials.

## Conclusions

- Wood/glass/epoxy joints with uniaxial glass fibre tested in tension with load parallel to the grain were found the strongest in terms of failure loads and stiffness. Misalignment of glass fibres to the load and wood grain direction reduced significantly the strength and stiffness.

- Wood/glass/epoxy joints with biaxial glass fibre tested in tension with load parallel to the grain failed at lower loads because only half the amount of fibres was orientated in the load direction. However with the fibres orientated at 30 degrees to the load and the grain, the failure load was even lower but with higher stiffness.

- For the angled joints with uniaxial glass fibre, the samples tested in tension at 90 degrees to the grain were the strongest in terms of failure loads and stiffness. Failure loads decreased as the grain/load angle reduced from 90 to 30 degrees.

- For joints made of biaxial glass fibre and tested in tension with load not parallel to the grain, failure loads were similar at 90 and 60 degrees, and slightly higher at 30 degrees to the grain.

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| Type of test | Glass type | Angle between glass fibre orientation and wood grain in upper section. | Angle between two timber sections in the joint | Total number of samples |
|---|---|---|---|---|
| TPU00 | Uniaxial | 0 | 0 | 8 |
| TPB00 | Biaxial | 0 | 0 | 8 |
| TPU10 | Uniaxial | 10 | 0 | 6 |
| TPB30 | Biaxial | 30 | 0 | 6 |
| TNU90 | Uniaxial | 0 | 90 | 6 |
| TNB90 | Biaxial | 0 | 90 | 6 |
| TNU60 | Uniaxial | 0 | 60 | 6 |
| TNB60 | Biaxial | 0 | 60 | 6 |
| TNU30 | Uniaxial | 0 | 30 | 6 |
| TNB30 | Biaxial | 0 | 30 | 6 |
| Total | | | | 64 |

*Table.1 Summary table of wood/glass/epoxy joints test programme.*

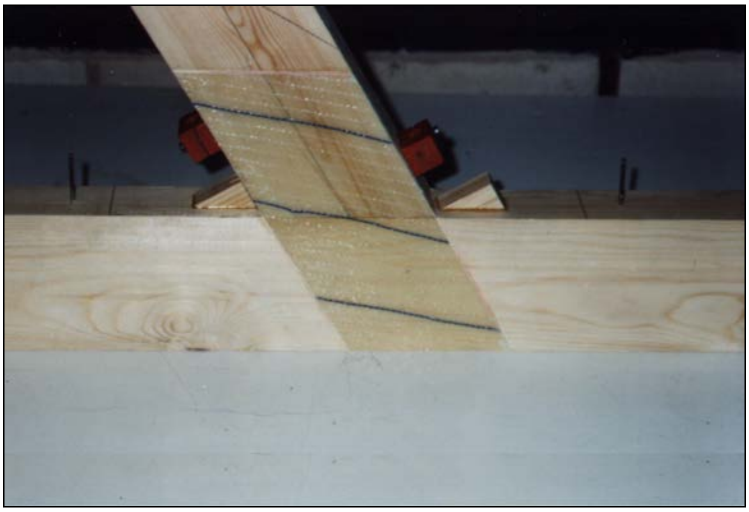


Figure 1. Completed joint for a sample TNB60. The dark lines are signal threads at $45^o$ to the fibres.

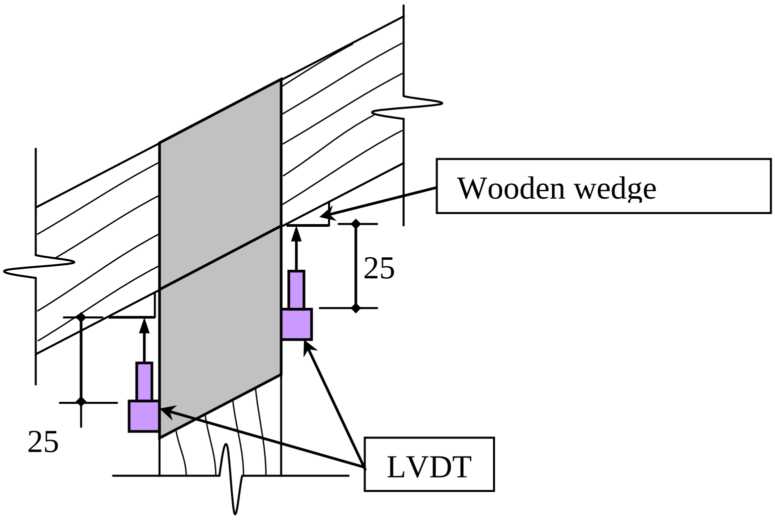


Figure 2. Typical configuration for LVDTs

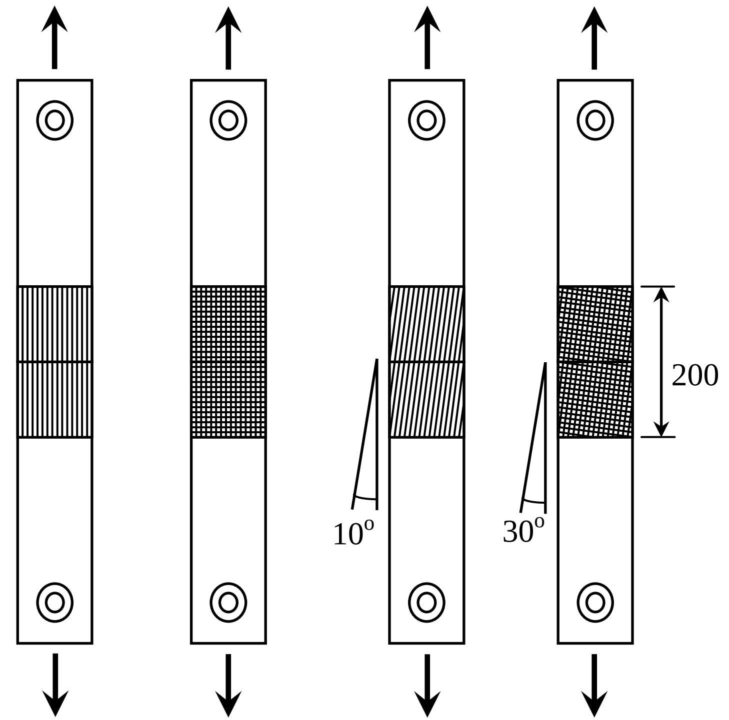


Figure 3a

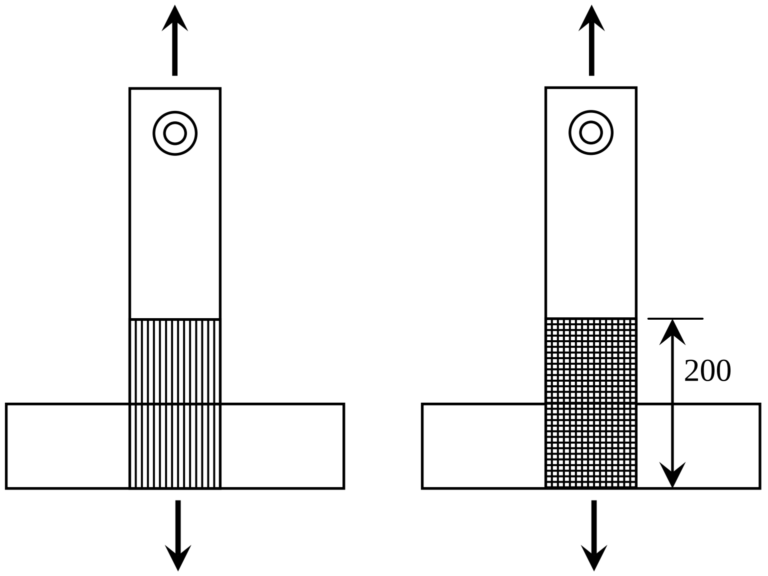
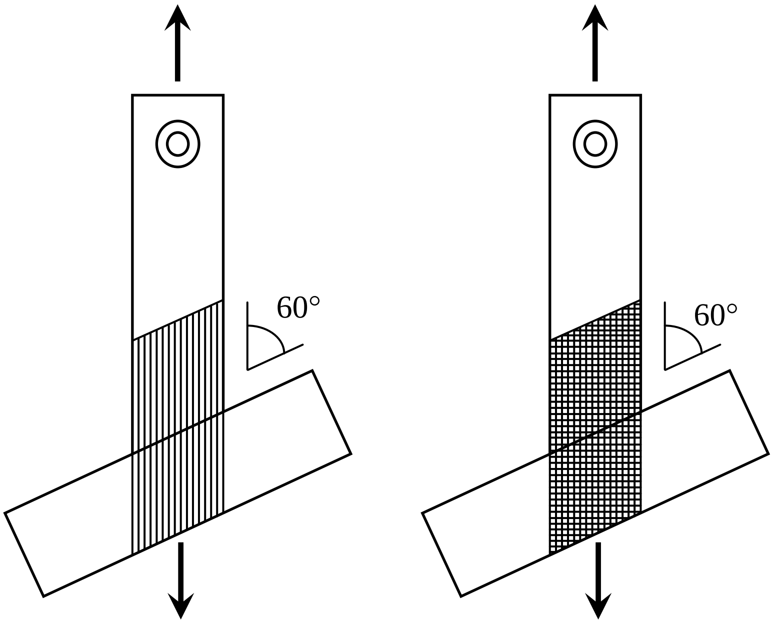
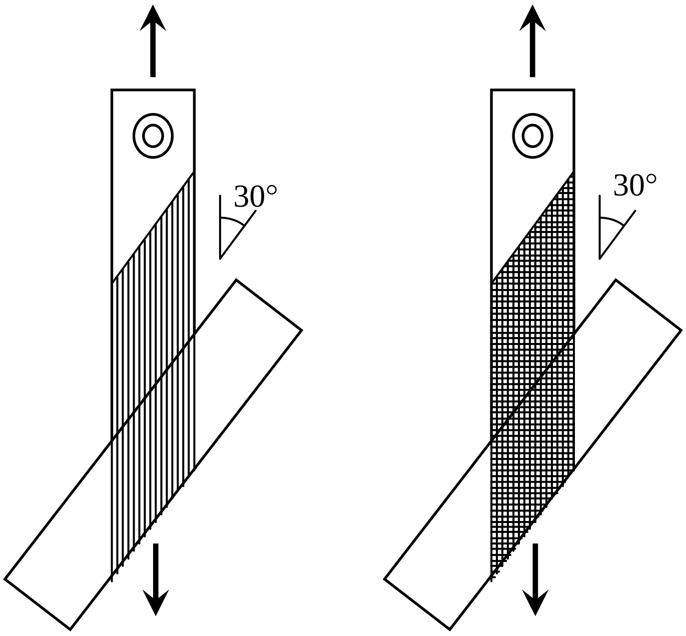


Figure 3b



TNU60 TNB60

Figure 3c



TNU30 TNB30

Figure 3d

Figure 3 Sample configurations

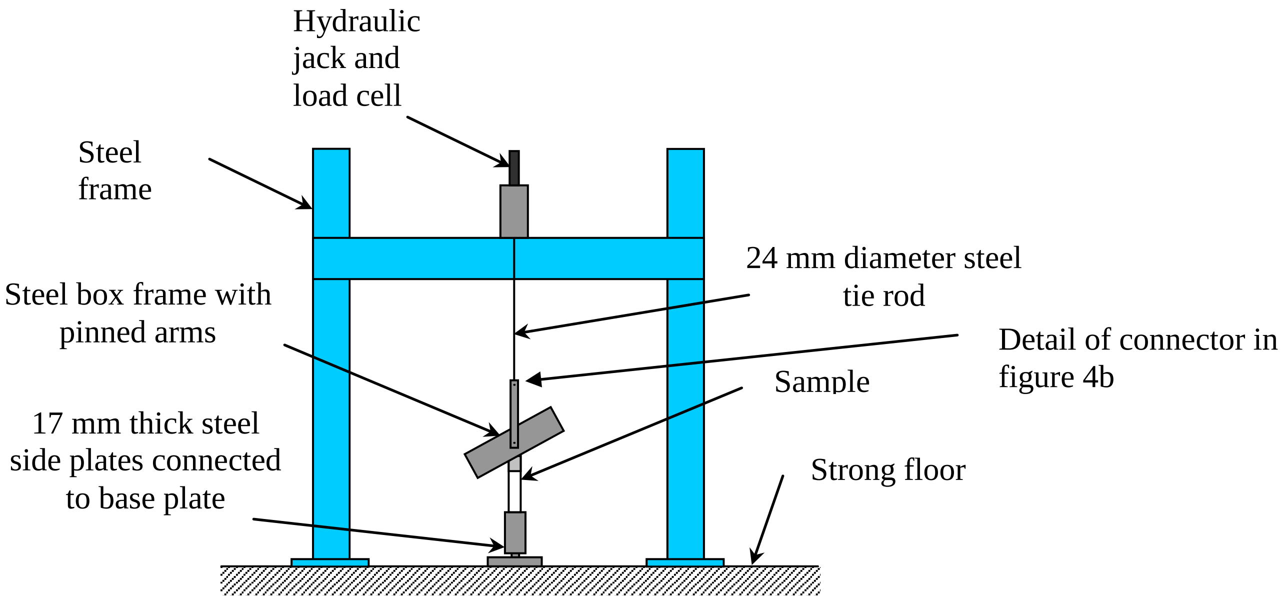


Figure 4a. Typical loading arrangement

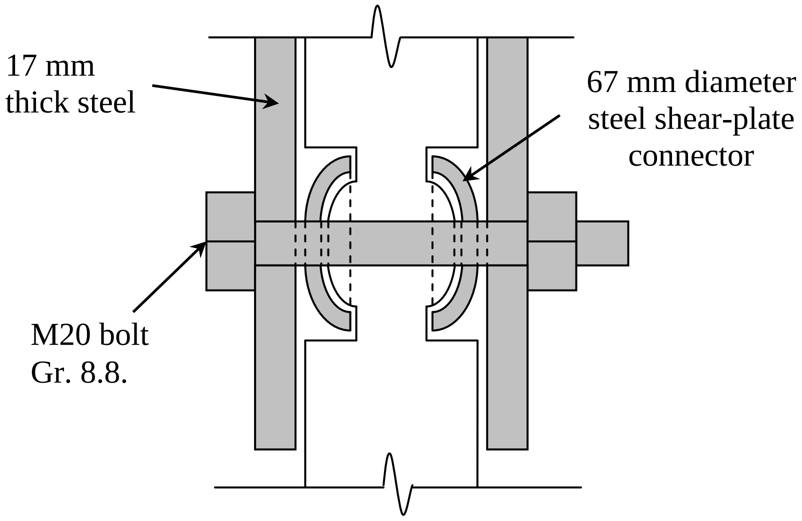


Figure 4b. Detail of clamping arrangement to the upper timber sample in figure 4a

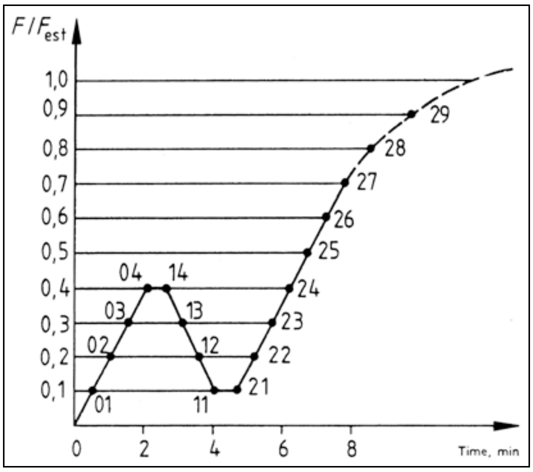


Figure 5 Loading procedures in accordance with BS EN 26891.

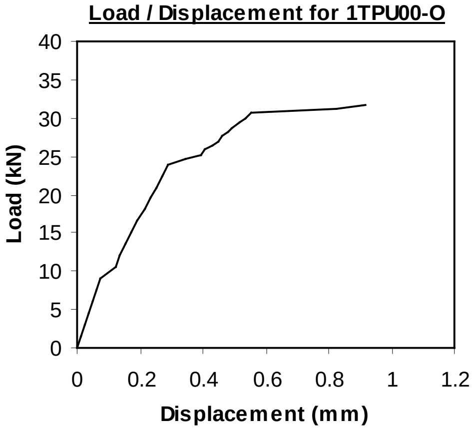


Figure 6.  Typical load-displacement graph

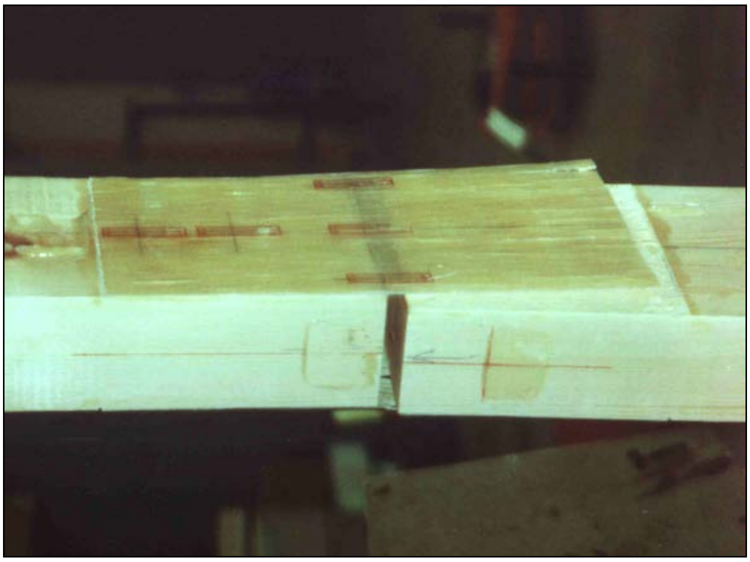


Figure 7. Failure of TPU00 sample by delamination on both sides.

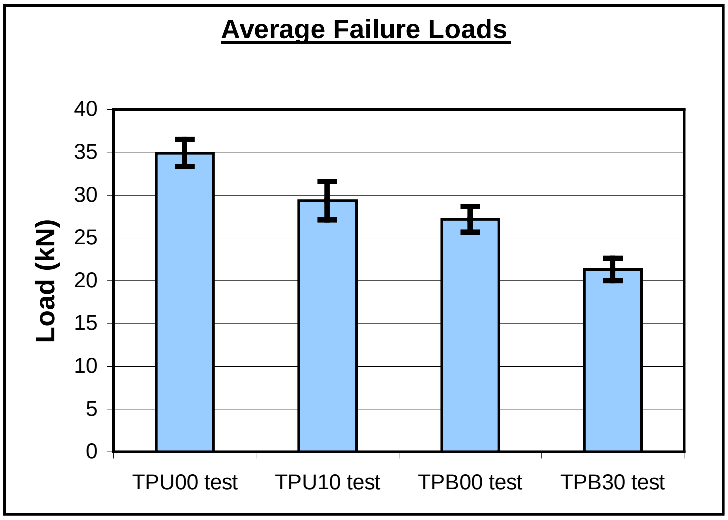


Figure 8 Average failure loads for all load parallel to the grain tension tests. The length of the error bars is one standard deviation

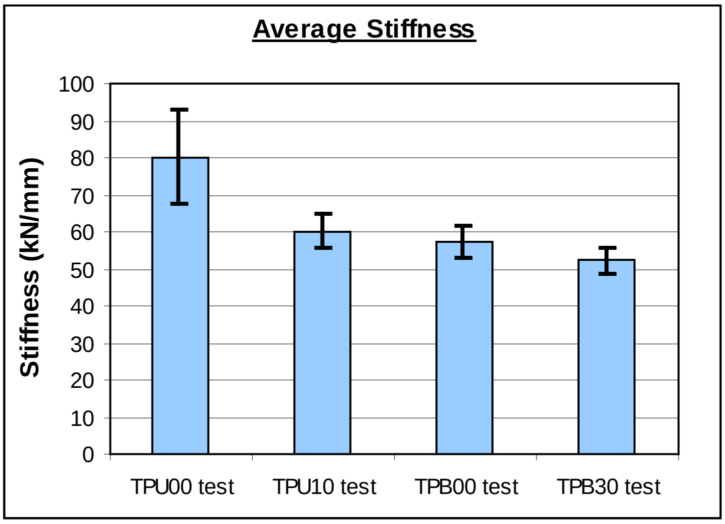


Figure 9 Average stiffness for all load parallel to the grain tension tests. The length of the error bars is one standard deviation

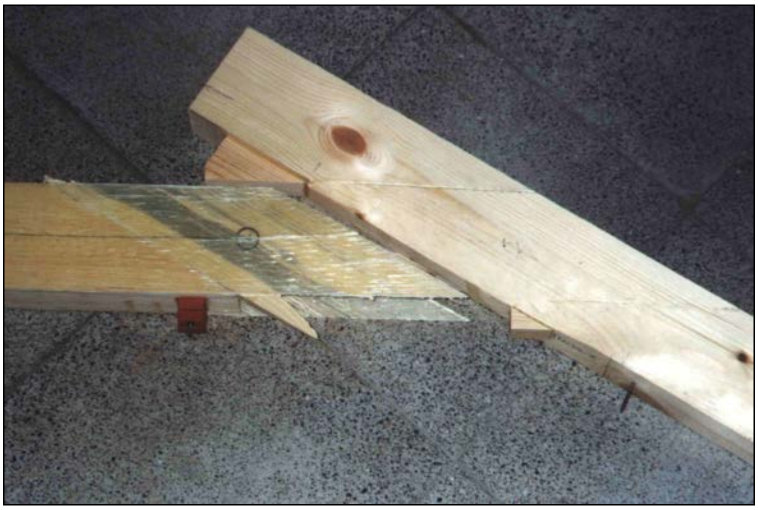


Figure 10. Top delamination on both sides at failure of TNU30 sample

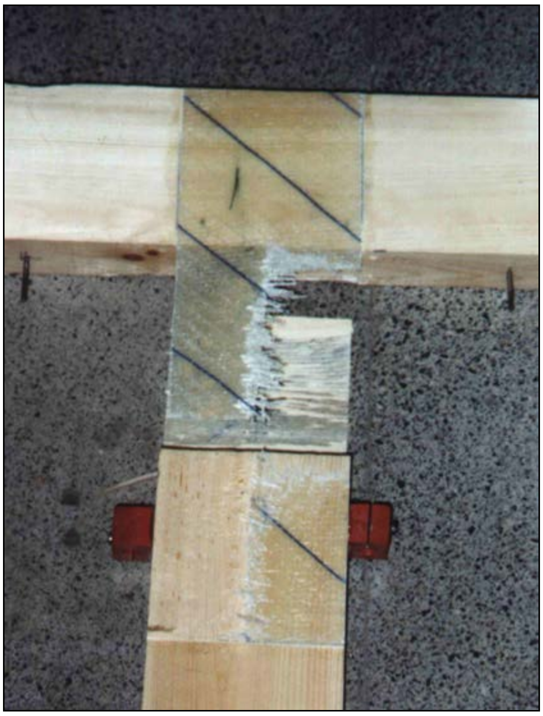


Figure 11.  Combined failure mode of TNB90 sample.  The dark lines are signal threads at 45° to the fibres.

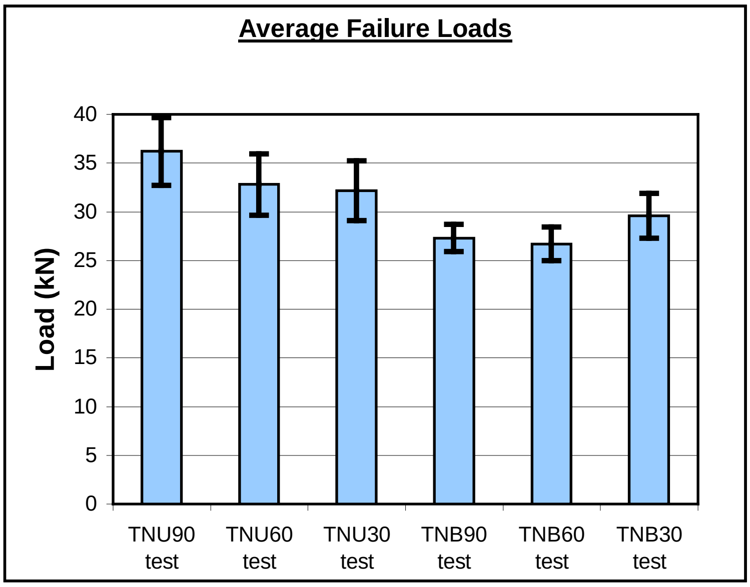


Figure 12 Average failure loads for all tension tests with the load not parallel to the grain. The length of the error bars is one standard deviation

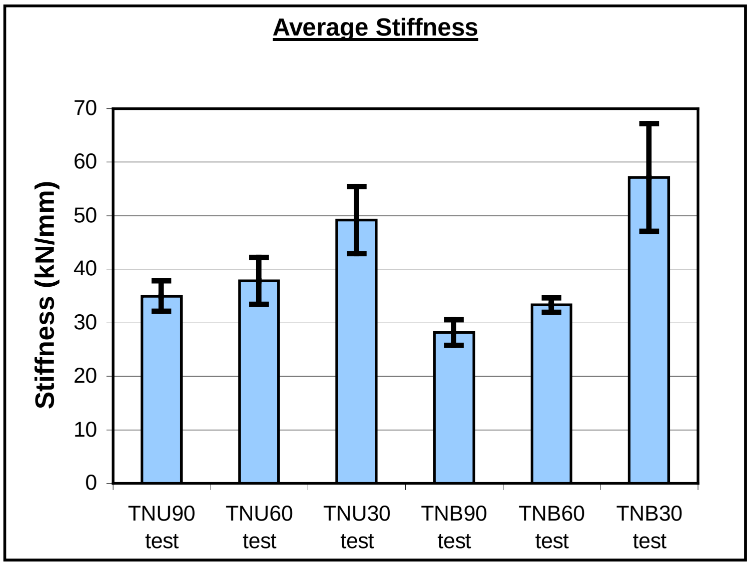


Figure 13 Average stiffness for all tension tests with the load not parallel to the grain. The length of the error bars is one standard deviation