Production of radiata glulam for Olympic facilities

G B Walford, Scientist, Forest Research Institute

Abstract

Glulam members for the construction of buildings to be used for the Olympics 2000 games in Sydney, were specified as F11 grade. This requires a characteristic bending strength in the outer laminations of 33 MPa and a modulus of elasticity of 10.5 GPa. Proof tests on the initial production showed it to be inadequate. This paper describes the material selection, proof testing, and other measures necessary to provide the required performance.

Introduction

The structure

Hunter Laminates Ltd in Nelson won a contract to supply nearly 1000 m^3 of glulam for the construction of Exhibition halls at the new Sydney Showgrounds. These buildings are to be used during the Olympic games in 2000. One building is rectangular in plan, 216 m long by 68 m wide, consisting of six identical halls, each 36 m wide. The roof shape is a simple barrel arch rising to 17 m and the structure supporting it is described as a lattice arch. The other hall is circular geodesic dome with a diameter of 70 m. Figure 1 shows the member configuration in plan for half of one of the rectangular halls. Figure 2 shows orthographic views of one of the rectangular halls, and the dome.

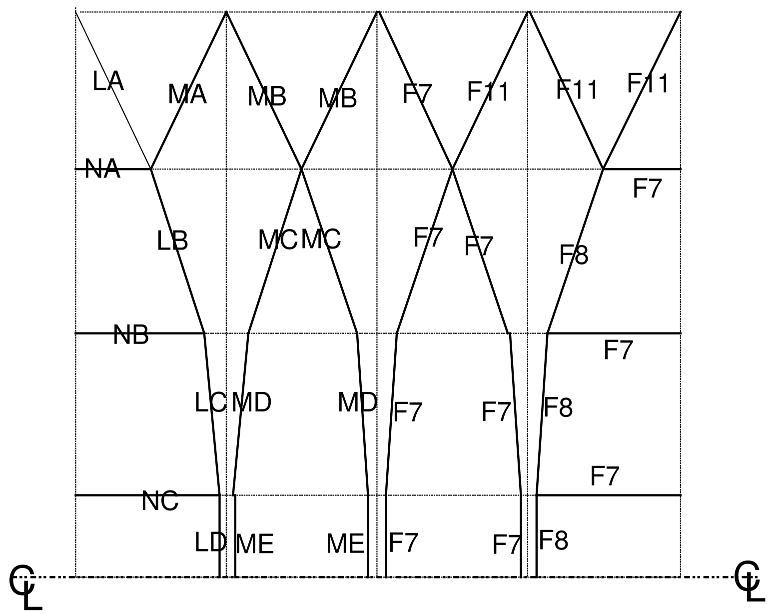

Figure 1. Part plan of the layout, labelling and grade of the glulam members in the rectangular halls

The glulam members

The timber members were straight glue-laminated radiata pine and predominantly 10 m long by 800 mm deep, with thicknesses of 180 or 280 mm. 180 mm is the preferred width ex 200 mm wide laminations, while 280 mm is the preferred width ex 300 mm wide laminations.

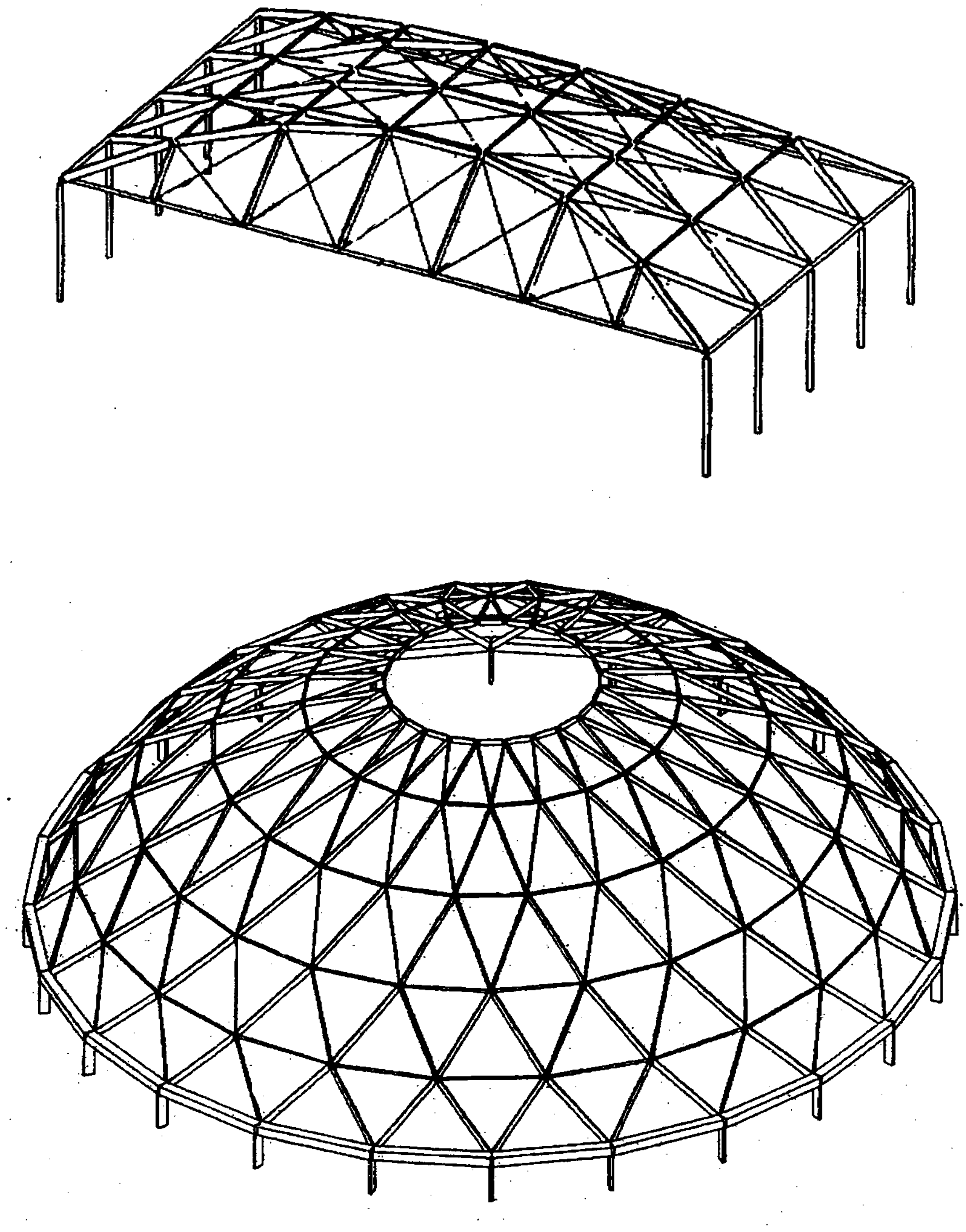

Figure 2. Orthographic views of the rectangular halls and the dome.

The members are connected to fabricated steel components at the joints through threaded steel bars which are epoxy-grouted into their ends. The 180 mm wide members contain 8 bars at each end, while the 280 mm wide members contain 10. The testing to verify the capacity of these joints is described by Gaunt (1998). The member identification, dimensions, and grade are given in table 1 while the location of the members is given in figure 1. Initially, all members were specified as F11 but this was later reviewed.

Table 1. Glulam member identification, dimension and grade.

Member Id	LA	LB	LC	LD	
Length, mm	9578	9689	9060	8859	
Width, mm	280	280	280	280	
Grade	F11	F8	F8	F8	
Member Id	MA	MB	MC	MD	ME
Length, mm	10096	10096	9889	9060	8859
Width, mm	180	180	180	180	180
Grade	F11	F11	F7	F7	F8
Member Id	NA	NB	NC		
Length, mm	4499	8597	10580		
Width, mm	180	180	180		
Grade	F7	F7	F7		

Full length reinforcement

A further requirement for the outer MA members was that they have full length reinforcing bars, two near each edge, because they are permanently under tension from gravity loads. The bars also had to connect to the steel joint components so there was a fabrication problem in that the glulam member had to be trimmed accurately to length. This trimming could not be done if the members contained reinforcing bars. The solution was to make the members without the reinforcing bars but with the outermost laminations (one each edge), temporarily nailed in place. After the members were finished to size the outermost laminations were removed, grooves routed in the member, the reinforcing put in place and the outermost laminations glued on with epoxy adhesive. Figure 4 shows the positions of the end anchorages. The reinforcement is connected to the outermost anchorages.

Glulam specification

The specification for the glulam called for F11, F8 and F7 stress grades where these are classifications used in the Australian Timber Structures code, AS 1720. Thus the laminations were required to have the design properties listed in table 2. The particular members with those stress grades are shown in figure 1.

Table 2. Characteristic stresses for some Australian stress grades (MPa)

	Bending	Tension	Shear	Compression	MoE
	F'_b	F'_t	F'_s	F'_c	E
F11	33	17	3.1	25	10500
F8	25	13	2.5	20	9100
F7	20	10	2.1	15	7900

Meeting the glulam specification

To meet F11 grade by following the relevant Australian standards, it is required that radiata of SD6 strength group, (as it is categorised in AS 2878), is visually graded to Structural grade 2 (according to AS 2858). This grade is practically identical to Engineering grade as defined in the New Zealand timber grading rules, NZS 3631. To achieve the Structural grade 2 requirements and meet the overall appearance requirements for the glulam, practically all knots were docked out and replaced with fingerjoints. An in-grade evaluation to AS/NZS 4063 was done on a sample of 30 pieces of the 200x50 mm lamination stock, with 15 pieces coming from lengths sorted as "inner" laminations and 15 as "outer' laminations. The distinction between inner and outer was made on the basis of the curvature of the growth rings as seen on the ends of the boards. Those with above average ring curvatures (i.e. further from the log centre), were classified as outers. Those with below average ring curvature as inners. This recognises that the stiffer, stronger timber comes from the outer part of the log in pines. Table 3 gives the results obtained.

Table 3. Results of in-grade tests on 200x50 mm lamination stock.

	Bending		Tension	Compression
	strength	stiffness	strength	strength
	MPa	GPa	MPa	MPa
(a) Inner laminations				
no.	15	15	15	15
mean	56.5	7.80	25.4	34.1
c.o.v.	0.23	0.19	0.40	0.14
5%ile	36.9	6.11	12.7	28.3
F grade	F11	F5	F5	F14
(b) Outer laminations				
no.	15	15	15	15
mean	52.7	7.59	35.1	32.6
c.o.v.	0.26	0.18	0.22	0.21
5%ile	33.5	5.6	22.6	24.2
F grade	F11	F5	F14	F8
(c) All laminations				
no.	30	30	30	30
mean	54.6	4.69	30.3	33.3
c.o.v.	0.24	0.18	0.33	0.17
5%ile	33.6	5.74	12.6	25.9
Characteristic	**34.1**	**7.05**	**11.6**	**28.2**
F grade	**F11**	**F5**	**F7**	**F11**

The results show that the stock achieves an F5 grade for stiffness. The inner laminations were slightly stiffer than the outer ones, showing that visual grading cannot effectively sort timber for stiffness. The outer laminations were satisfactory for strength.

Laminated beam testing

The branching characteristics of radiata pine produces timber with large knots but relatively clear timber between them, in lengths of 0.6 to 2.0 m. Docking out the knots meant that it was difficult to meet the specified requirement that fingerjoints be not closer than 1.8 m in the outer laminations. The manufacturer requested that this requirement be waived so the specifier asked for strength tests be done to prove the adequacy of the glulam with shorter distances between fingerjoints. Beams were tested in opposing pairs, using a pair of hydraulically coupled jacks placed 3100 mm from the beam ends. Reaction ties were placed 100 mm from the beam ends. Deflections at midspan were measured by observing the relative movement between scales attached to the beams at midspan and taut strings running between nails driven at mid depth on the beams and in line with the end reaction ties. Load was measured using a calibrated load cell under one of the jacks. The testing regime was as follows:

a) Four beams of initial production, tested to failure.
b) Fortyeight beams of modified production, tested to 17.5 MPa
c) Sixtyfour beams of modified production, tested to 15 MPa
d) Thirtysix beams of machine graded and proof tested laminations, tested to 15 MPa

The modifications to the production made after the series (a) tests were changes in the layup procedure to reduce open assembly times, to improve glue spread, and a change to ICI R15 glue in the fingerjoints but continuing to use ICI R25 between the laminations. Series (a), (b) and (c) were all made with ex 200x50 or 300x50 mm lamination stock whereas series (d) had laminations of 100x50 mm machine graded timber that was edge-glued to make up the finished beam widths of 180 and 280 mm. See figure 4 for the resulting arrangement. The change from 17.5 to 15 MPa between series (b) and (c) was done on the advice of the designing engineer.

Beam test results

Some beams broke and most were well below the MoE value required of F11 grade beams. Table 4 summarises the results of the beam bending tests.

Table 4. Summary of beam testing results

Series	No. tested	Average MoE	CoV of MoE	5%ile MoR	Failure stresses							
		GPa	%	MPa	MPa							
(a)	4	(1)	-	-	23.4	33.6						
(b)	48	7.81	7.64	10.9	10.2	10.9	10.9	14.1	14.1	14.1	16.4	16.4
(c)	64	7.63	11.2	15.0	11.5	14.1	14.5					
(d)	36	10.38	8.33	>15.0	>15.0							

Note (1) Doubtful MoE measurements - value not quoted.

As is to be expected, the MoE values from the beams agreed closely with the MoE values from the in-grade tests on the laminations. The strength values, however, bear little relation since the laminated beam strength depends on the strength of the fingerjoints and the specimens that were in-grade tested contained no fingerjoints.

Investigations

Strength and stiffness problems

An investigation showed that the deficiency in stiffness was due to the origin of the timber. Small clear specimens were tested and gave average properties as follows:

Density at test	481 kg/m^3
Bending strength	73.6 MPa
Bending stiffness	8.12 GPa
Compression strength	31.8 MPa

These results classify the timber as SD8, not SD6, principally on the basis of stiffness.

The timber had come from the West Coast of the South Island of New Zealand which has a low density site classification for radiata pine (Cown and McConchie, 1982). The measured MoE values met the F7 requirements and confirmed the results for glulam reported by Fairweather (1992). The deficiency in strength was primarily due to faults in the fingerjointing although there were other factors in the choice of adhesive, machining, glue spreading, and lay up procedures which probably contributed. Fingerjoint strength is compared in figure 3 to that of joints produced by other manufacturers. It can be seen that the strength of Hunter's joints were some 30 to 40% below that obtained by other manufacturers.

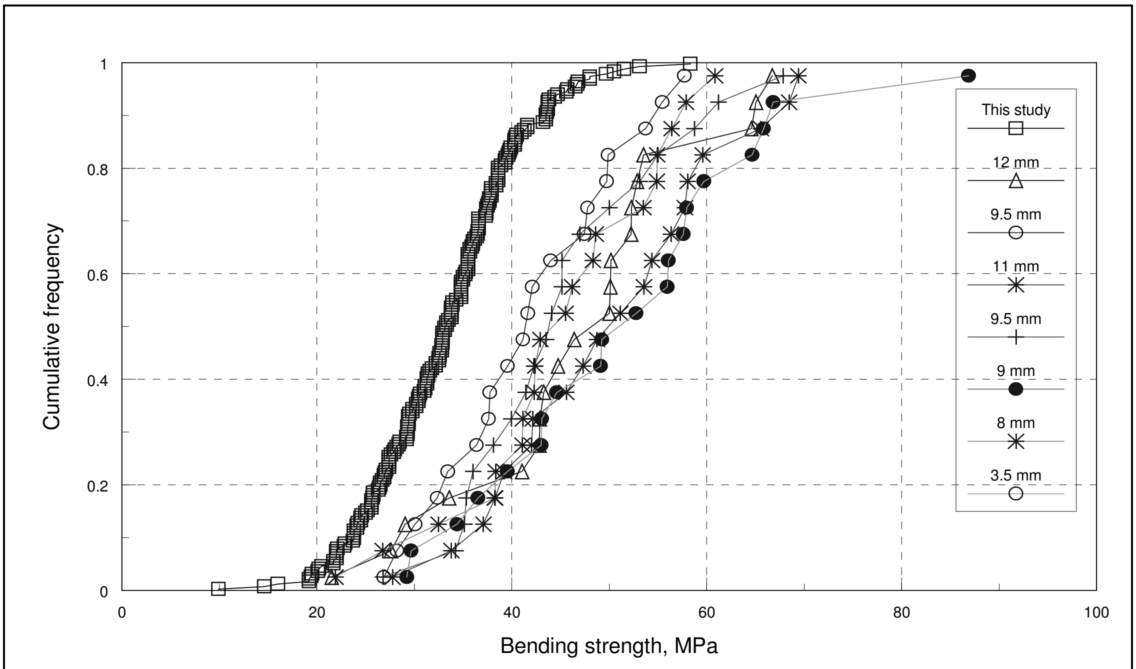

Figure 3. Comparison with strength of fingerjoints from other manufacturers.

Remedial measures

Stiffness
Machine grading provides timber of guaranteed stiffness since stiffness is measured by the machine. The characteristic strengths assigned to machine graded timber are given in table 5.

Table 5. Characteristic properties for MGP grades of timber

MGP grade	Characteristic strength, MPa				Modulus of elasticity	Modulus of rigidity
	Bending f'_b	Tension f'_t	Shear f'_s	Compression f'_c	E	G
MGP 15	41	23	9.1	35	15,200	1,010
MGP 12	28	15	6.5	29	12,700	850
MGP 10	16	8.9	5.0	24	10,000	670

Comparing the data in table 5 with that in table 2, it is seen that timber with stiffness equal to visually graded F11 (10,500 MPa) is achieved with a mixture of MGP 10 with a little MGP 12.

However, timber of sufficient width was not available so it was necessary to edge-laminate laminations. The resulting beam cross section is shown in figure 4. The data in table 4 for the series (d) beams shows that they had an average MoE of 10.38 GPa which was close to the required 10.5 GPa. The edge-laminating process in itself would improve strength.

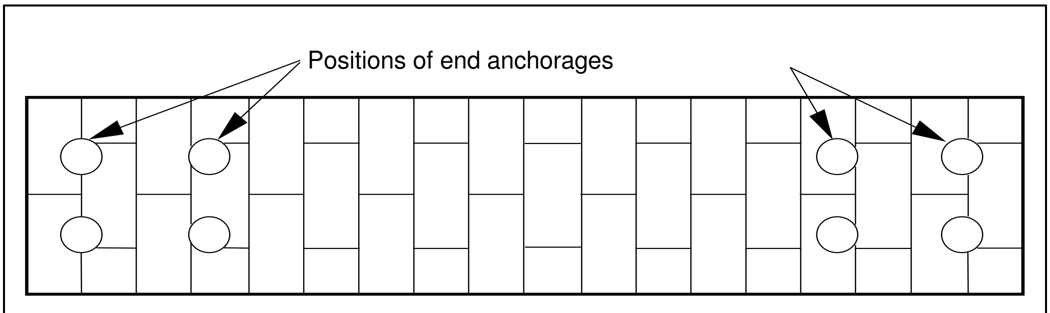

Figure 4. Beam cross section

Strength
Deficiencies in the fingerjointing machine were rectified. The samples of joints that were taken from daily production and tested gave the strengths shown in figure 5. It can be seen that the change of glue type had a small effect. R15 adhesive has a higher viscosity than does R25 and is thus more suitable for use on the end-grain of timber as occurs in fingerjoints.

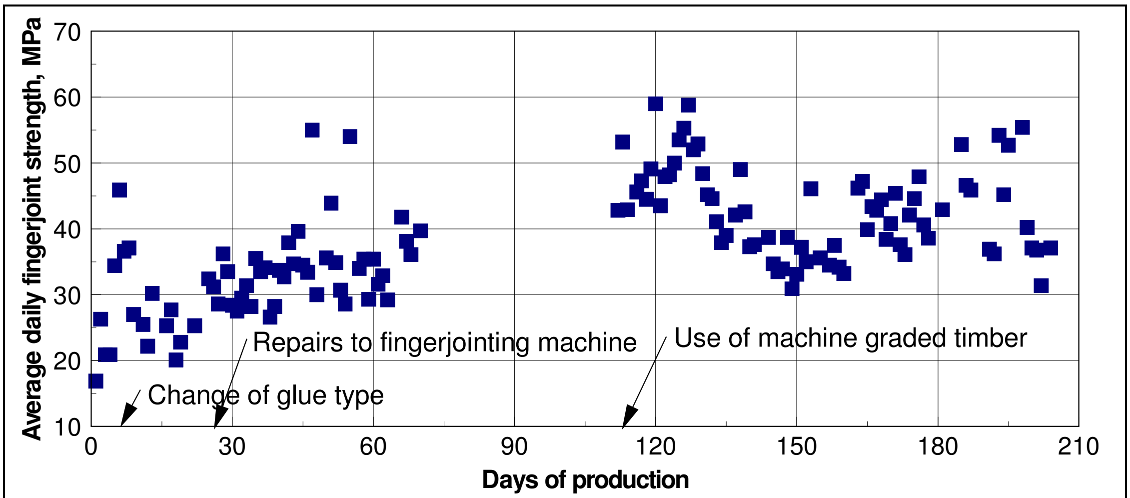

Figure 5. Time history of average daily fingerjoint strengths.

The testing of fingerjoint samples provides a measure of their overall strength and is useful for detecting changes in strength due, perhaps, to cutter wear, timber properties or other factors. It does not, however, provide assurance that every fingerjoint has the required strength. This can be provided only by proof testing. Laminations were proof tested by passing them through a machine which imposed a bending stress of 24 MPa in one direction. A double pass, loading the timber on alternate faces at a lower stress, was considered but not used. Any laminations that broke were simply rejointed and retested.

An in-grade evaluation was done on the machine-graded and edge-jointed laminations. The results obtained are given in table 6.

Table 6. Results of in-grade tests on machine-graded, edge-jointed laminations.

	Bending		Tension	Compression
	strength MPa	stiffness GPa	strength MPa	strength MPa
no.	30	30	30	30
mean	67.6	11.94	45.5	36.82
c.o.v.	0.203	0.180	0.243	0.126
5%ile	44.7	8.77	26.3	30.3
Characteristic	47.0	11.6	26.5	34.5
F grade	**F14**	**F11**	**F14**	**F14**

These results show that the desired lamination strength and stiffness was obtained. The actual strength of the beams made with these laminations was not determined but the ones that were proof tested all survived a stress of 15 MPa.

Comment on economics

A simple alternative to going to all the extra effort and expense of achieving beams with the high strength and stiffness required would have been to design the members for the lower properties, i.e. make them larger. Some members were already satisfactory since they were required to have an F7 rating. It is estimated that an increase in volume of 15 to 20% would have produced members that had a performance equal to the F11 rating required. By contrast the extra effort meant that the members cost 40 to 50% more and contributed to the manufacturer going into receivership.

Conclusions

- While visual grading can differentiate between timber pieces of different stiffness, it does provide an absolute measure of stiffness.
- Machine grading can provide timber of reliable stiffness.
- Proof testing provides a guarantee of timber strength and is particularly suitable for a glue lamination operation because laminations that beak under proof testing can be rejointed to provide reliable glulam.
- The branching characteristics of radiata pine mean that the strength of most glulam made from it will be determined by the strength of the fingerjoints in the laminations.
- Designers should be careful not to specify timber strength and stiffnesses above values which can be readily provided.
- Nevertheless, the painful exercise reported herein has resulted in Hunter Laminates Ltd being able to make some of the stiffest, strongest and most reliable glulam in New Zealand.

References

Cown, D.J. and McConchie, D.L., 1982; Wood density prediction for radiata pine logs. Forest Research Institute Bulletin No. 9.

Fairweather, R.H., 1992; Beam-column connections for multi-storey timber buildings. Research Report 92/5, Dept of Civil Engineering, University of Canterbury.

Gaunt, D., 1998; Joints in glulam using groups of epoxy grouted steel bars. IPENZ Annual conference, Auckland.