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Glulam design based on lamination grades and the use of mill shorts

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www.fwpa.com.au
FWPA Level 4, 10-16 Queen Street,
Melbourne VIC 3000, Australia
T +61 (0)3 9927 3200 F +61 (0)3 9927 3288
E info@fwpa.com.au W www.fwpa.com.au

Glulam design based on lamination grades and the use of mill shorts

Prepared for

Forest & Wood Products Australia

by

Dr Constantine Adam and Dr H R Milner

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Researcher/s:
Dr Constantine Adam and Dr H R Milner
Monash University
Clayton Campus
Wellington Road
CLAYTON, VIC. 3800

Forest & Wood Products Australia Limited
Level 4, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

Executive Summary

Australian Standard AS/NZS 1328.1:1998 is used for evaluating the bending and tension strengths of Australian glulam. The glulam bending strengths are given by a formula making them directly proportional to the characteristic finger joint bending strengths but modified by adjustment factor that depends on the finger joint spacing. The value is limited by an overriding provision that the glulam bending strength cannot exceed that of the bending strength of the laminating stock used in the outer tension zones. The method was based on a test report by Falk, et al (1992) that showed that, for Norwegian spruce, glulam bending strength was approximately 0.75 times the bending strength of finger joints, 1.50 times the finger joint tension strength and 1.1 times the bending strength of laminating stock. This resulted in a set of rules whereby glulam bending strengths were given as 0.75(1 + 0.05Smin) where S_{min} was the shortest shook in the outer laminations. The factor (1 + 0.05Smin) was introduced as an artifice because of a tendency by Australian and NZ manufacturers to use short laminating lengths (called shooks in this report) and was meant to encourage the use of longer lengths. It was also at this time that the GL grade system was introduced.

Over time it has become the view of some glulam producers that the shook length factor was a penalty that affected the competitiveness of structural glulam. It was asked that, if the finger joint strengths were known and met the requirements needed to meet specific GL grade requirements, then "what was wrong with having any number of finger joints". While manufacturers could no doubt establish that their strengths were adequate in "qualification testing" to justify claiming GL grade properties there was a problem of finger joint reliability. With finger joints, the manufacturing conditions can change quite rapidly due to factors such as glue feeders running dry, incorrect batch mixing, blunt cutters etc. so that the concern remained and this was the basic motive for undertaking the project. Thus the more finger joints the greater the risk. It will be seen from the results that, even though manufacturers supplying test specimens to this project were aware they were involved in research, finger joint unreliability became an issue with some participants. More recently at a GLTAA meeting some manufacturers exacerbated the problem by using shooks down to sixty (60) mm in length.

At the time when the project commenced there was tacit agreement that future glulam standards should be structured such that bending strengths would be better based on lamination tension strengths given that the outer laminations are loaded predominantly in tension. Attention has been drawn to a paper by Colling and Falk (1993) where it is stated that isolated laminations tested in tension differ in behaviour from outer laminations within a glulam beam. A major point made is that knots, in particular, are reinforced within a beam. Given the large size of knots, relative to timbers such as spruce, a concept has developed in which lamination strengths for Australian softwoods would be better assessed by tension testing in one and two sided form. When, used as a qualification procedure, this would allow a manufacturer to use whatever shook length, knot docking practices and other manufacturing practices they wish with the penalties built into the qualification test procedures. Laminating factors would then be based on the reinforced lamination strengths allowing for any other laminating effects such as dispersion of defects.

[1] By artifice is meant a device included to encourage particular practices. In this case it is the use of short laminating lengths combined with a poor knot docking practices.
[2] GLTAA is the acronym for the Glued Laminated Timber Association of Australia

The project objectives were to:

1. To investigate the relationship between shook length and tension strength for a range of species at the upper end of the density range in each case. Adhesive type will not be considered to be a variable.
2. To determine if the coefficient of variation of the lamination strengths can be introduced into the shook length formula so that good finger operations are rewarded and poor are penalized.
3. To develop design methodology that allows glulam bending strengths determined using individual finger joint tension.

The project examined this issue and the relationship between glulam bending and tension strengths and the tension strength of finger joints. Four manufacturers were involved in the project labelled anonymously A (A17 hardwood), B (MGP15 radiata pine), C (MGP15 slash pine), D (MGP10 radiata pine).

The project outcomes were:

The effect of finger joint spacing on lamination tension strengths has been examined (objective 1) but the results remain uncertain. The tension tests were conducted over a fixed length so that it was expected that as the number of finger joints increased there would be a progressive lowering of lamination tension strengths. Manufacturers were expected to follow good manufacturing practice by avoiding finger joints close to defects and by producing all finger joints in a single production run. This did not happen. The results are summarised in Tables A and B immediately below. All lamination data and glulam beams based on 35 mm deep laminations.

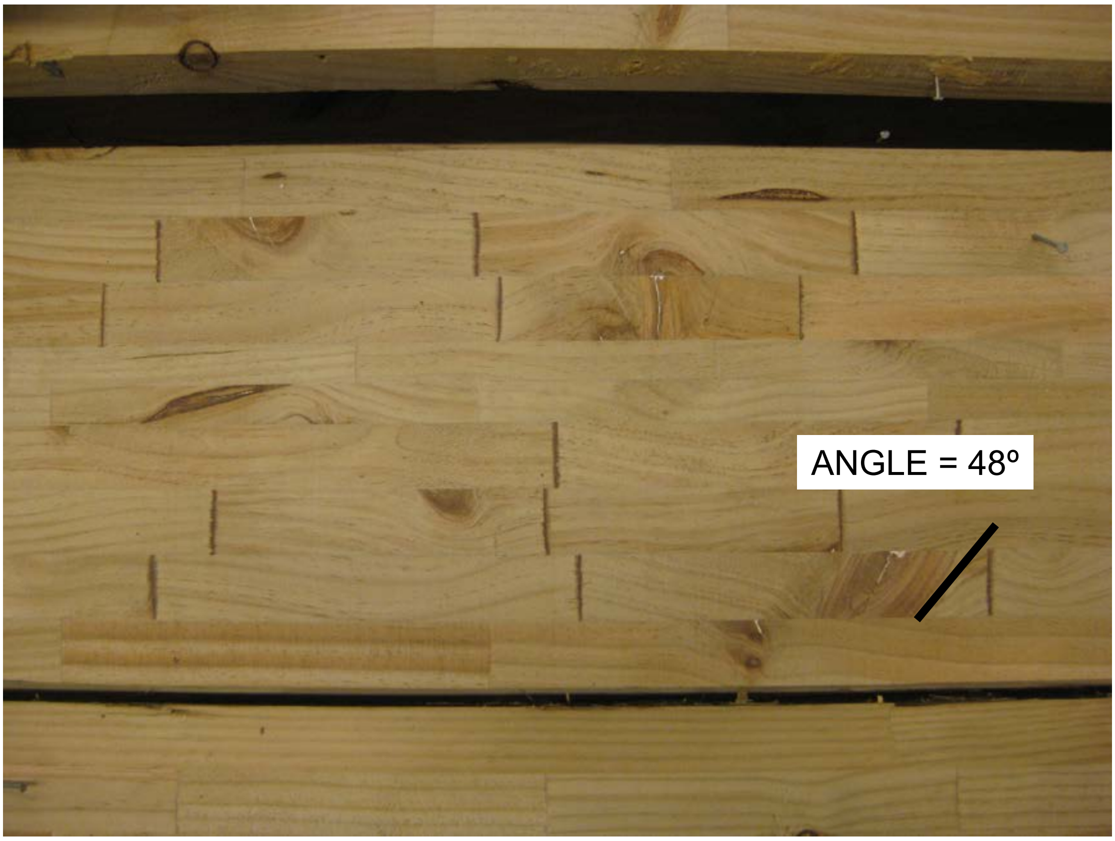
With the benefit of hindsight wisdom it is considered inappropriate to include a penalty in the shook length formula (objective 2). A penalty is built at the qualification stage (see definitions) given that characteristic values are determined in accordance with AS/NZS 4063.2. Advice from the USA is that proof testing of laminations in tension is common but not mandatory. Mandatory proof testing of laminations overcomes problems with bad batches. Voluntary provisions for proof testing are provided in AS/NZS 1328.

A relationship between glulam bending and tension strength and the tension strength of finger joints is reported (objective 3) but the laminating factors vary widely between manufacturers; see Tables A and B immediately below. It should be noted that not all glulam failures occur at finger joints, especially with lower grade softwood lamination stock where failures at knots feature prominently. MGP10 and MGP15 have low tension strengths relative to Norwegian spruce, see Falk et al (1992), upon which AS/NZS 1328:1998 and the GL grades cited in AS1720.1:2010 are based. It is believed that these low values are caused by larger sized knots of Australian softwoods but that once these are reinforced the higher fibre strength of Australian timbers will come to the fore. There is concern that A17 hardwood is not showing the strengths that could be expected from it. It is considered that a more profitable approach for the future will be to test one and two sided reinforced laminations during qualification testing thereby automatically accounting for knot reinforcement and production variables of an individual manufacturer.

Additionally, the values of glulam tension strengths have never been measured previously and were stated conservatively in AS1720.1:2010 and its predecessor. An increase of these strengths is recommended.

Preface

Do Australian standards need to become more prescriptive?



A recent and not uncommon practice found in Australian structural glulam – finger joints formed in the vicinity of severely sloping grain caused by the presence of a knot.

Notation

A_s = shear area for deflections = $1.2bd$ (mm^2)

b = smaller cross section dimension of a lamination or glulam member, (mm)

d = larger cross section dimension of a lamination or glulam member, (mm)

E/G = ratio of elastic to shear modulus taken as 17

E_{Eul} = elastic modulus of a beam as determined using Euler Bernoulli theory (shear deformations excluded) (MPa)

E_{Timo} = elastic modulus of a beam as determined using Timoshenko beam theory (shear deformations included).(MPa)

f_{05} = raw lower 5th percentile value determined in accordance with AS/NZS 4063.2:2010 (MPa)

$f'_{b,fj}$ = characteristic strength of finger joint in bending as used in AS/NZS1328 and determined in accordance with AS/NZS 4063.2:2010, (MPa)

$f'_{b,glulam}$ = characteristic strength of glulam member in bending - made using 1200 mm finger joint spacing and determined in accordance with AS/NZS 4063.2:2010 (factor a_v not applied), (MPa)

$f'_{b,stock}$ = characteristic strength of timber stock in bending taken from AS1720.1:2010, Table H3.1, (MPa)

$f'_{t,glulam}$ = characteristic strength of glulam member in tension, bending - made using 1200 mm finger joint spacing and determined in accordance with AS/NZS 4063.2:2010 (factor a_v not applied), (MPa)

$f'_{t,fj}$ = characteristic strength of finger joint in tension as used in AS/NZS1328 and determined in accordance with AS/NZS 4063.2:2010, (MPa)

$f'_{t,lam}$ = characteristic strength of lamination in tension as measured in this project and determined in accordance with AS/NZS 4063.2:2010 with factor a_v not applied, (MPa)

$f'_{t,lam,\max}$ = maximum characteristic value observed by an individual manufacturer for all finger joint spacings. (MPa)

$f'_{t,stock}$ = characteristic strength of timber stock in tension taken from AS1720.1:2010, Table H3.1, (MPa)

I = second moment of area (mm^4)

I_K/I_G = ratio used in ASTM D 3737 to describe the ratio used in computing glulam beam section properties

K_8, K_{20} = laminating factors defined in AS1720.1-1975.

K_{10} = depth factor defined in AS1720.1-1975.

k_{11} = size factor as defined AS1720.1-1997.

L = test span used in bending or test length used in tension (mm)

$P_{\max}$ = failure load in tension of a lamination or a glulam member, (kN)

S = shook length spacing (m)

$S_{\min}$ = minimum shook length as used in AS/NZS 1328.1:1998, (m)

$V_{b,glulam}$ = coefficient of variation of glulam in bending.

$V_{t,glulam}$ = coefficient of variation of glulam in tension.

$V_{t,lam}$ = coefficient of variation of a series of a lamination tested in tension.

$\lambda_{b,lamt}$ = $f'_{b,glulam} / f'_{t,lam}$

$\lambda_{t,lamt}$ = $f'_{t,glulam} / f'_{t,lam}$

$\lambda_{b,stockb}$ = $f'_{b,glulam} / f'_{b,stock}$

$\lambda_{b,stockt}$ = $f'_{b,glulam} / f'_{t,stock}$

$\lambda_{t,stockb}$ = $f'_{t,glulam} / f'_{b,stock}$

$\lambda_{t,stockt}$ = $f'_{t,glulam} / f'_{t,stock}$

Terms used

finger joint spacing	= distance between finger joints within a lamination
qualification testing	The term is of US origin and is used in the timber industry to replace the more general manufacturing term “process capability study”. Process capability is also defined as the capability of a process to meet its purpose as managed by an organization's management and process definition structures ISO 15504. It is the study that sets values for finger joint strengths in the context of this project with a particular organisation and is the basis by which a manufacturer bases his product descriptions. It is a pity that the timber industry has chosen, unnecessarily, to invent such a neologism
shooks	= pieces of wood used to make up a lamination
shook length	= length of a shook and equal to the finger joint spacing
type testing	= qualification testing but it is the term favoured in EN standards

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Table A Laminating factors based on lamination tension strengths for 1200mm shook length, except for Manufacturer D. For Manufacturer D several laminations failed below 9kN representing a lamination tension strength less than 4 MPa which was not recorded on the read out device with the load cell being used. The value shown for Manufacturer D is for a 900 mm FJ spacing.

Manufacturer	$f'_{b,glulam}$ (MPa)	$f'_{t,glulam}$ (MPa)	$f'_{t,lam}$ (MPa)	$\lambda_{b,glulam}$ $\left(f'_{b,glulam}/f'_{t,lam}\right)$	$\lambda_{t,glulam}$ $\left(f'_{b,glulam}/f'_{t,lam}\right)$
A	35.5	22.6	13.8	2.6	1.6
B	40.8	30.5	22.1	1.8	1.4
C (Series 2)	41.1	33.5	14.2	2.9	2.4
D	19.4	14.0	9.0	2.2	1.6

Table B Laminating factors based on bending and tension strengths of laminating stock as listed values in AS1720.1 – 2010.

Manufacturer	$f'_{b,glulam}$ (MPa)	$f'_{t,glulam}$ (MPa)	$f'_{b,stock}$ Table H3.1 AS1720.1 (MPa)	$f'_{t,stock}$ Table H3.1 AS1720.1 (MPa)	$\lambda_{b,stockb}$ $\left(f'_{b,glulam}/f'_{b,stock}\right)$	$\lambda_{b,stockt}$ $\left(f'_{b,glulam}/f'_{t,stock}\right)$	$\lambda_{t,stockb}$ $\left(f'_{t,glulam}/f'_{b,stock}\right)$	$\lambda_{t,stockt}$ $\left(f'_{t,glulam}/f'_{t,stock}\right)$
A (A17)	35.5	22.6	45	26	0.79	1.37	0.50	0.87
B (MGP15)	40.8	30.5	39	18	1.05	2.27	0.78	1.69
C (MGP15)	41.1	33.5	39	18	1.05	2.28	0.86	1.86
D (MGP10)	19.4	14	17	7.7	1.14	2.52	0.82	1.82

Introduction

Context

This project was undertaken in the context of an out-of-date Australian Standard AS/NZS 1328.1 which taken along with the accompanying AS1720.1 lacks features found in overseas standards which sit within a different framework; see Table 1. What is fundamental to the overseas standards is that glulam bending strengths indicate a strong dependency on lamination tension strengths. One way of aligning AS/NZS standards with their overseas counterparts would involve a comprehensive restructuring along the lines indicated below.

1. AS/NZS aaaa:2013 Glued laminated structural timber – Lamination grades (New)
2. AS/NZS 1328:2013 Glued laminated structural timber – Performance requirements and minimum production requirements (Revision of AS/NZS 1328:1998)

Following a GLTAA meeting, 9 October 2012, a decision was taken to revise AS/NZS 1328:1998 rather than simply confirm the existing version. It is unclear if the there will be one or two standards, or whether all information will be placed in a single document. If the recommendation of this report is followed the following would emerge.

AS/NZS aaaa:2013 would nominate *lamination grade* designations (for example L10 for a lamination having an elastic modulus of 10 GPa) and state all characteristic strength and stiffness values that are relevant to the design and use of structural glulam. It would include test methods for deriving properties of the lamination grades that, in practice, are derived from MGP, F and A grades. There were some philosophical issues of whether or not lamination grades should form part of the standard at all. Consideration is being given to providing formulae that convert lamination strength and stiffness data into the corresponding glulam data and not even mentioning lamination grades. The industry are clear that the GL grades should remain but a view exists that it can be left to the industry as to how they achieve this by simply using the test methods and formulae provided. A considerable problem exists with assigning appropriate values of tension strength to the lamination properties as described in the literature review.

AS/NZS 1328:2013 would set out manufacturing requirements for both the laminations and the assembled glulam members. This would specify the qualities of lamination lumber, finger joints and face/edge joints.

Table 1 Features in standards for the manufacture, testing, evaluation and design of structural glulam.

	Feature	AS/NZS	EN	USA
1	Standard lamination grades	No	Yes	Yes
2	Glulam (GL) grades	Yes	Yes	Yes
3	Design method in AS1720.1 for specifying member lay-up	No	Yes	Yes
4	External/Third Party audits of production	No	Yes	Yes
5	Evaluation methods for glulam properties	Yes	Yes	Yes

Objectives

This project objectives were as follows.

1. To investigate the relationship between lamination and tension strength and finger joint spacing for radiata pine, slash pine and Victorian ash species. Adhesive type was not considered to be a variable nor were vertically laminated members considered part of this investigation.
2. To determine if the coefficient of variation of the lamination strengths can be introduced into the finger joint spacing formula in AS/NZS 1328 so that good finger quality control operations are rewarded and poor ones are penalized.
3. To develop a lamination factor, λ, that allows glulam bending and tension strengths to be determined from finger joint tension strengths.

Literature review

AS/NZS 1328 and Falk et al

Australian Standard, AS/NZS 1328:1998, contains a formula for determining the characteristic strength of glulam beams in bending and tension respectively, $f'_{b,glulam}$, and $f'_{t,glulam}$ based on:

- the stress grade bending, tension strengths of the lamination stock, $f'_{b,stock}$, $f'_{t,stock}$
- the finger joint bending, tension strengths, $f'_{b,fj}$, $f'_{t,fj}$ obtained by testing finger joints.

The relationship between lamination stock and finger joint strengths and the glulam strengths takes the forms:

<u>for bending strength</u>

$$f'_{b,glulam} = 0.75\left(1+0.05S_{\min}\right) f'_{b,fj} \le f'_{b,stock} \qquad \mathbf{1}$$

<u>for tension strength</u>

$$f'_{t,glulam} = 0.75\left(1+0.05S_{\min}\right) f'_{t,fj} \le f'_{t,stock} \qquad \mathbf{2}$$

where $S_{\min}$ = minimum spacing of the finger joints = shook length.

The expression $\left(1+0.05S_{\min}\right)$ in equation 1 is what is referenced in the objective statement 2 as the finger joint spacing formula and the 0.75 is called a lamination factor and is more generally given by the symbol, λ, in Europe. In developing AS/NZS1328, the most comprehensive data available at the time was provided by Falk et al (1992). In an extensive program of testing of glulam made from Norwegian spruce using lamination stock ranging in length from 2.20m to 5.65 m. It was found that relationships existed between

- characteristic strengths in tension and flatwise bending of finger joints,
- established lamination stock strengths and glulam bending strength given by

<u>for glulam bending failures initiated at finger joints representing 44% of all failures</u>

based on finger joint bending strengths $f'_{b,glulam} \approx 0.75 f'_{b,ej}$ **3**

based on finger joint tension strengths $f'_{b,glulam} \approx 1.40 f'_{t,ej}$ **4**

<u>for glulam bending failures initiated away within the shooks 56% of all failures</u>

based on timber stock bending strengths $f'_{b,glulam} \approx 1.05 f'_{b,stock}$ **5**

based on timber stock tension strengths $f'_{b,glulam} \approx 1.50 f'_{t,stock}$ **6**

Ehlbeck and Colling (1986) had also cited a relationship that related the flatwise bending strength of outer laminations given by

$$f'_{b,glulam} = 0.80 f'_{b,ej} \qquad \textbf{7}$$

Standards Australia committee TM004, in developing AS/NZS1328 adopted the compromise formula, equation 1, about which the following can be stated.

- At short laminating lengths it provides as a minimum the strengths indicated from the tests of Falk et al (1992) and once the laminating length reaches 1.3 meters it predicts the more optimistic strengths predicted by Ehlbeck and Colling (1986).
- The AS/NZS1328 formula is prevented from providing unrestrained higher values by the insistence that the bending strengths cannot exceed that of the laminating stock. This is conservative given that a laminating factor of 1.05 on failures initiated in the stock was reported by Falk et al, equation 5.

No data was found in Falk et al (1992) or, for that matter, in any other publication that related a finger joint strength measure to glulam tension strengths. The formula for converting finger joint strengths to glulam tension strengths in AS/NZS1328.1:1998 was, therefore, highly speculative.

Glulam properties determined from lamination properties

Finite element modelling of glulam

The work by Flak et al (1994) and Ehlbeck and Colling (1986) cited is only a small part of the literature available that is dedicated to the task of assessing glulam properties from lamination data. A number of studies are based on mathematical models that take, as input, lamination test data involving wood density, knot frequency and species dependency.

The earliest work available in the literature stems from work by Foschi and Barrett (1980) that used a stochastic finite element model in which the beams were divided into cells (finite elements in other terms) each of which was allocated strength and elastic modulus values. No attempt was made to model the finger joints due to the lack of finger joint strength data.

According to Hernandez et al (1992), a number of models stemmed from the Foschi and Barrett (1980) paper. Research in Germany has focussed around developments by the Karlsruhe group where Ehlbeck et al (1985) developed the so-called Karlsruhe model that included the effect of end joints, according to Hernandez et al (1992), using " a regression approach that generated tensile strength of the joints as a function of the lower density of the two jointed boards." Colling (1990a, 1990b, 1990c) in his work focussed on size effects in glulam. Kline et al (1986) on the other hand developed stochastic models that described the short span variation of modulus of elasticity (MOE) in laminations that are better suited to predicting their tensile strength than long span MOE. This is relevant to typical mathematical models of glulam in which the member is viewed as comprising a number of cells, typically one lamination deep, with a varying number of cells equal in length to the short span length MOE values obtained from stress grading equipment, typically 150 – 300 mm.

Recent developments by the Karlsruhe group

A recent paper by Frese (2010) highlights more recent approaches to the mathematical modeling of glulam for research purposes. The analysis is based on the commercial finite element program ANSYS using its so-called Parametric Design Language. The input involves simulating the stress grading processes based on extensive board data provided by Holzforschung München which includes structural and mechanical data on density, knot size, MOE and tensile strength of boards used to make glulam. The properties are stochastically distributed and auto-correlated, presumably in the manner described by Kline et al (1986) or in some similar manner. The strength of finger joints is also stochastically defined.

ASTM D3737

ASTM D3737 describes a methodology for computing glulam properties from lamination property data using a transformed section approach and composite beam theory. The method is known as the I_k/I_g approach where the second moments of area are adjusted for both varying MOE in different zones but also for the knots whereby the effective width of laminations is reduced. No attempt is made to take into account the fact that many glulam failures are initiated at finger joints. It is clear that the early paper by Foschi and Barrett (1980) was much influenced by this approach although the ASTM D 3737 method implies that isolated finger joint tension strengths increase by a factor of 1.65 when placed in a glulam beam because of laminating effects.

Fracture of finger joints

Bui (1998) attacked the issue of finger joint strength in a fundamentally different way to US and European approaches by examining the nature of stress concentrations that occur at the finger joint tips. Using fracture mechanics principles, he was able to show, experimentally and theoretically, that it is possible to reinforce finger joints and reduce stress concentrations. Although his reinforcement was by the bonding of fibre glass over the finger joint the presence of adjacent laminations in glulam would have the same effect. Bui (1998)'s findings are summarized in Figure 1 and, although showing only one fibre glass thickness, elsewhere in his thesis he presents results for three different thicknesses of 0.55, 0.8 and 1.1 mm. Mode A failure involves the stress concentration factor at the finger tips reaching a critical limit and is of more interest in the context of glulam members. Mode B involves peeling of the fibre glass reinforcement. In no case did the fibre glass fracture meaning that it acted as a spring acting in parallel with the finger joint. The following inferences may be drawn from his work in the context of glulam performance.

- Tension tests were conducted first on laminations with and without double-sided E-glass reinforcement. It is the fibre glass stiffness (the product of its weight and MOE) rather than its strength that is significant in causing the increase in strength of the finger joint overall by acting as spring in parallel. A similar reinforcing effect occurs in glulam with adjacent laminations performing the same role.

- The percentage strength increases seen at 0.5 mm thick fibre glass of around 25% are consistent with the levels achieved in glulam where bending strengths involving outer finger joints in near pure tension have a similar 25% or more strength increase. This may be purely coincidental but it shows at the very least that finger joints can be reinforced.

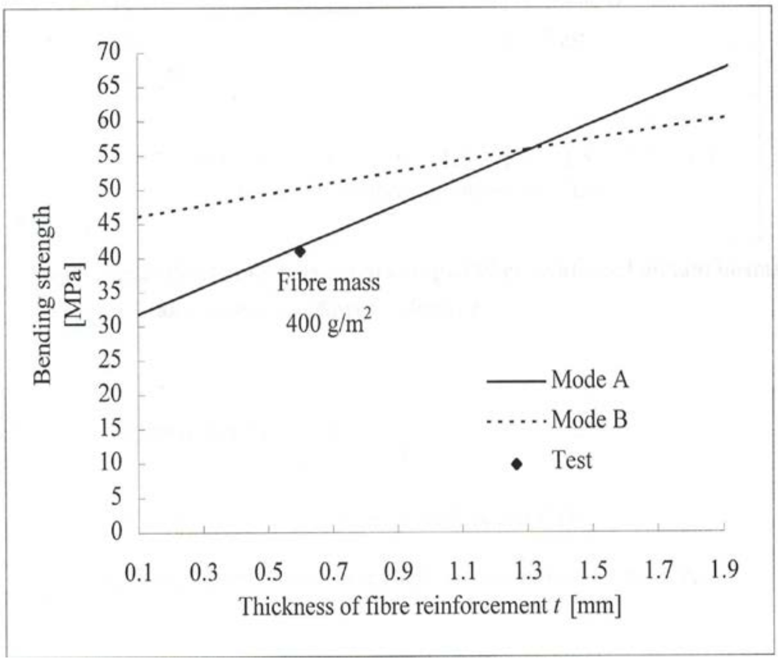

Figure 1 Glass fibre reinforced finger joints showing an increase in finger joint bending strength with double sided reinforcement in absolute and percentage terms. Adhesive was PRF, finger joint details were pitch = 7.2mm, length = 20 mm, cutter tip width = 1.5 mm, tip gap = 1.5 mm.

Differential between tension failure of laminations and their tension failure in glulam

It is also interesting to note Colling and Falk (1993) who make the point that "lamination and beam test results have indicated that the apparent strength increase caused by the lamination effect is a summation of separate, though interrelated, physical effects." These effects are listed as follows.

Effect of tension test procedure, k_{test}

This arises out of non-centred edge effects such as knots. In a lamination tension test the tension load induces bending effects at the knot, an effect which is absent or at least reduced in an assembled glulam members due to the restraining effects of other laminations.

Reinforcement of defects, k_{reinf}

Colling and Falk (1993) also state that "when bonded in a glulam beam, defects (eg knots) and other low-stiffness areas are reinforced (on at least one side) by adjacent laminations." They do not make any comment in relation to the reinforcement of finger joints.

Dispersion of low-strength lumber, k_{disp}

The dispersion effect leads to a situation whereby the bending strength of glulam has, in statistical sense, a lower coefficient of variation than the lumber or timber from which it is derived.

Collectively, these three factors are combined in European standards into a laminating factor, $\lambda_{b,lamt}$, that relates lamination tension strength, $f'_{t,lam}$, to beam bending strength, $f'_{b,glulam}$ by the simple relationship

$$\lambda_{b,lamt} = f'_{b,glulam} \Big/ f'_{t,lam} \qquad \textbf{8}$$

The lamination factor depends on the lamination grade but overall they indicate that, at the 5th percentile level,

$$\lambda_{b,lamt} = 1.15 + 7 \big/ f'_{t,lam} \qquad \textbf{9}$$

Australian Standards AS1720 (1975, 1988, 1997, 2010)

Lamination factor

Lamination grades were provided in AS1720.1:1975 but were deleted from 1997 and 2010 versions. In AS1720:1975 designers and manufacturers were given two options as to how they were to determine glulam strengths. The basic working stresses of glulam were obtained by multiplying the basic working stresses of the laminating stock by factors K_8 or K_{20} chosen at the designer's discretion. K_8 depended only on the number of laminations in the glulam members. K_{20} applied only to glulam where the lamination strength was limited by local defects, such as knots, holes, gum pockets, local grain distortion and grain slope did not exceed 1/16. K_8 and K_{20} amounted to what has been described above as laminating factors, λ, with K_8 being more generally applicable.

Under AS1720:1975 the K_8 factor applied only to glulam manufactured in accordance with what was then the current AS1328 which required finger joints be no weaker than the timber being finger jointed. While this works fine with well jointed softwoods it does not work well with high strength hardwoods. It led to a situation in which some poor quality glulam beams appeared in the marketplace.

To make the point clearer, take the specific case of what, in modern terms, is called GL18 made from F27 stock with a basic working stress of 27.5 MPa made into a 300 mm deep glulam member composed of 10 x 30 mm deep laminations. Using the K_8 factor such a member would have a basic working stress in bending of $K_8 \times 27.5 = 1.33 \times 27.5 = 36.5 MPa$ which in limit states design terms as defined in AS1720.1 – 1997 amounted to a structural design property of $f'_{b,glulam} = 2.95 \times 36.5 = 108 MPa$ where 2.95 was the adjustment factor on material strength in moving from working stress to limit states design. When the GL grades were introduced in 1997, GL18 was assigned a bending strength of $f'_{b,glulam}$ = 50 MPa. The difference between 108 and 50 MPa indicates that some beams existed in the market place that were seriously under strength.[1].

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[1] The version of AS/NZS 1328 applicable at the time (1975) appears to have been based on the view that finger joints were not a point of weakness. In other words, by docking out

Reference to the Falk et al (1992) tests which involved 300 mm deep beams of Norwegian spruce MOE = 13GPa (very similar to Douglas fir), and led to $\lambda = f'_{b,glulam} / f'_{b,fj}$ = 0.75 at the 5th percentile level.

Size penalty factors

AS1720 standards, 1975 to 1997 inclusive, contained a depth factor $K_{10} = (300/d)^{0.167}$ for AS 1720:1975 and $k_{11} = (300/d)^{0.167}$ for AS1720.1:1997 which was less than 1 for glulam beams having depths in excess of 300 mm. This factor was at odds with CEN provisions where it applies only at depths exceeding 600 mm. The depth factor has sensibly been deleted from AS1720.1:2010 although it may have made sense to include a width factor of $(b/150)^{0.167}$ that would penalize knots in the outer tension laminations of very large glulam beams.

Future laminating grades

The development of any system of laminating grades is best based on existing F, MGP and A17 grades. The obvious grades would be described on the basis of modulus of elasticity and labeled L8, L10, L12, L15, L16, L18 corresponding to F8, MGP10, MGP12, MGP15, A17, F27 respectively. The characteristic tension strengths would be set higher to allow for reinforcement of defects and the difference between restrained and unrestrained tension measurements; see Section 0.

Test program

Outline

The aims of the experimental program were two-fold. To assess the laminating factor that operated in glulam members under both bending and tension loading where failure was limited by finger joint strength and to quantify the effect of finger joint spacing on glulam bending and tension strength.

The plan was to tension test laminations comprising finger joints at various spacings in the range 300 to 2100 mm over a fixed length of 4200 mm followed by bending and tension testing of glulam in bending and tension with a fixed finger joint spacing of 1200mm. Weibull theory suggests that, leaving aside failure outside finger joints, the greater the number of finger joints the lower the tension strength.

Lamination materials

The materials used in the project were provided by the industry partners and involved timber species and grades that they commonly used.

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defects, it was always possible to recover the grade strengths. This is a dubious proposition, especially with higher grade hardwoods.

- A17 Vic Ash at the upper end of MOE range (Manufacturer A)- finger joint spacings of 600, 900, 1200, 1800 mm,
- MGP15 radiata pine at the upper end of MOE range (Manufacturer B) - finger joint spacings of 300, 600, 900, 1200, 2100 mm,
- MGP15 slash pine at the upper end of the MOE range the material on the basis of MOE fits into both MGP15 (Manufacturer C) - finger joint spacings of 1200, 1500, 1800, 2100 mm,
- MGP10 radiata pine at the lower end of the MGP grade ranges based on MOE (Manufacturer D) - finger joint spacings of 900, 1200, 2100 mm.

The numbers of finger joints correspond to each spacing are given in Table 2.

Table 2 Number of finger joints over the 4200 mm test length.

Finger joint spacing (mm)	Number of FJs between the grips (mm)
300	14
600	7
900	5
1200	4
1500	3
1800	3
2100	2

Experimental procedure

Supply of laminations

Packs of 4200 mm long laminations were made up into lengths by industry partners with the fixed finger joint spacing stated above. The quantity provided was actually twice the volume of material required for the test program. A decision was taken that there should be as little variation as possible of MOE values. Originally this was to be applied to the laminating stock before finger jointing but industry partners ruled this out because of the additional transportation costs involved. The laminations thus possessed MOE variations and other grading qualities consistent with Australian grading practices.

MOE testing of laminations

All laminations except those from Partner C for test series 2 and from Partner D were delivered to N.F. McDonnell & Sons, 375 Princes Hwy, Tantanoola, South Australia where a stress grader was available that tested laminations on edge in four point bending over a test span of 3600 mm. The machine was operated by Monash University staff who recorded the MOE values. The machine provided only a lengthwise averaged as opposed to short length modulus of elasticity values; refer back to paragraph 3 of Section 0.

In the case of Partner C the material for the first test series had an elastic modulus determined as described in the previous paragraph but it was found in later tension testing that some loss of process control had occurred which resulted clearly in inferior tension strength values, see the 3 lower cumulative strength distributions in Figure 11, so that a second batch was prepared that was subjected only to their normal stress grading procedures. Partner D purchased MGP10 lamination stock on the open market and did not provide laminations in time for MOE testing at N.F. McDonnell & Sons.

Allocation of material following MOE testing

Following MOE testing, some laminations were selected for tension testing that fell within a band of mean ± 0.1 times mean and were dispatched to Monash for tension testing. The balance of laminations was returned to manufacturers with markings indicating those to be made into glulam members, these being the ones that fell into the target MOE band.

Tension testing of laminations

The tension testing of all laminations was conducted at Monash University using their in-house designed tension testing machine. This machine has doubly articulated gripping heads that minimizes the application of secondary bending moments. It has a current NATA calibration certificate. It lacks the ability to accurately detect load values less than 5 kN. See Figure 2 for a schematic drawing of the test arrangement.

Tension and bending tests of glulam

The tension and bending testing of the glulam members was also undertaken at Monash University. The tension testing equipment was the same as that used for the lamination tension testing. The bend testing was undertaken using a dedicated beam testing rig where loading is applied using and Instron servo controlled loading ram. The ram was operated under load control. Load data from the servo controller was coordinated with deflection readings of an LVDT that was used to extract the apparent modulus of elasticity. See Figure 2 and Figure 3 for the test arrangement drawings.

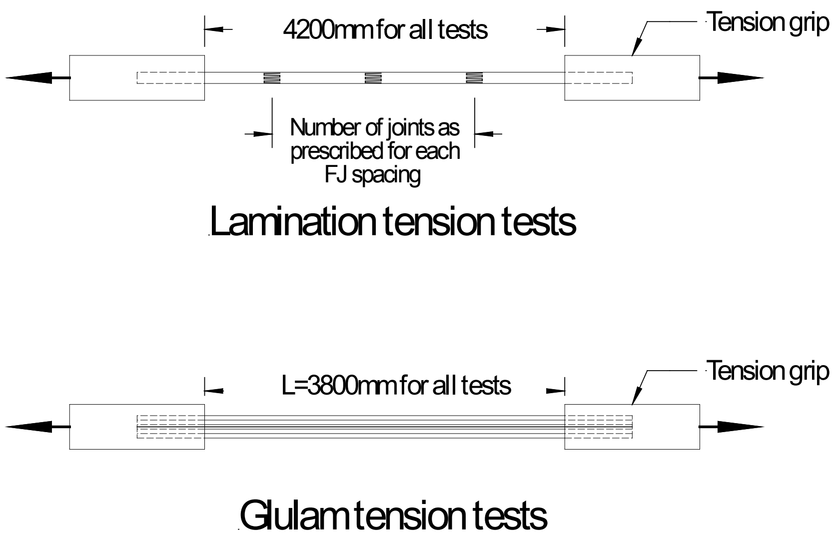
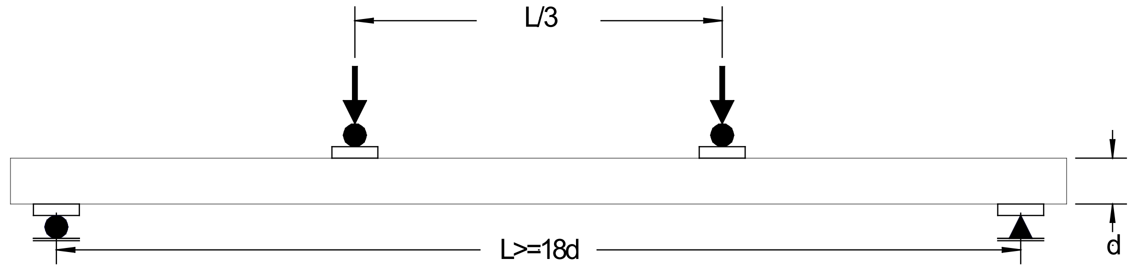


Figure 2 Test arrangement used for tension tests.



Glulam bending tests

Figure 3 Test arrangement for bending tests.

Statistical processing of glulam tension and bending test data

Strength data

AS/NZS 4063.2:2010 uses a different ranking system to Excel. In Excel the cumulative probability is linked to the AS/NZS4063.2 probability by

$$p_{i,Excel} = \left(np_{i,4063} - 0.5\right) / \left(n-1\right) \qquad \mathbf{10}$$

or, for a 5th percentile,

$$p_{05,Excel} = \left(0.05\,p_{05,4063} - 0.5\right) / \left(n-1\right) \qquad \mathbf{11}$$

Substitution of $p_{05,Excel}$ in the Excel percentile function leads to a 5th percentile value fully compliant with AS/NZS 4063.2. In converting a 5th percentile, f_{05}, to a characteristic strength, f', a sample size confidence level factor is applied such that $f' = f_{05}\left(1 - 1.8V/\sqrt{n}\right)$. Although the lamination tension strength data was processed according to AS/NZS 4063.2 there is an underlying requirement that a minimum of 30 test results be available. Monash requested 30 specimens but due to losses of material in transport this was not possible with the glulam tests.

Modulus of elasticity (MOE) values data

Mean values for MOE contain no allowance for confidence level associated with sample size. MOE values were not of primary concern in this project.

Results and discussion

Objective 1 - Finger joint spacing factor

Interpretations used

Not all data collected was regarded as useful for the intended purposes of the project. This perhaps was most evident from the mode of failure data noted during the lamination tension tests based on AS 5068; see Table 3.

The project was initiated on the basis of deciding if a shook length factor existed. The effect, if any, is only observable if other factors known to affect lamination strengths (production and lamination stock variables) are excluded from the test specimens. For each shook length for which lamination tension strengths were required, a minimum of 30 specimens were tested all of which were to be made during a single production run which was aimed at eliminating production variables. The stock used was one of A17, MGP10 and MGP15 and it was assumed that the characteristic strength values were reliable. The matter of production reliability was outside the control of Monash but it was expected that all manufacturers would follow good production practices.

Two factors were considered for assessing the reliability of the test data,

- failure modes of specimens that failed at a load less than $f'_{t,lam,\max}$,
- the consistency of the coefficient of variation of the laminations as the finger joint spacing varied.

For each manufacturer and finger joint spacing a characteristic tension strength, $f'_{t,lam}$ was determined according to AS/NZS 4063.2:2010. A maximum $f'_{t,lam,\max} = \max\left(f'_{t,lam}\right)$, for all shook lengths was noted, Table 3, and the number of values falling below this value was noted against the standardized failure modes shown in Table 4.

In addition a Monte Carlo simulation was undertaken but only in the case of Manufacturers B. The strength of the laminating stock was taken as infinite and the finger joints were assigned strengths equal to the lamination strengths according to a Weibull distribution having a mean 28.5 MPa and coefficient of variation of 0.17. The particular mean and V values were chosen on the basis of test data measured in the case when only 2 finger joints were present. For each trial the requisite number of finger joints were selected randomly and assigned a strength out of which the minimum was selected and its value stored. When this process was repeated 10000 times a mean and coefficient of variation was extracted non-parametrically from the stored data. As a matter of simple observation, these minimum values had approximately the same coefficient of variation of 0.17 that did not change as the number of finger joints varied. Thus any test data reflecting a shook length factor was judged on the basis of the consistency of coefficient of variation, $V_{t,lam}$, as the finger joint spacing varied. Where this did not occur the result has been attributed to inconsistency in production. The following interpretations have been placed on the failure modes.

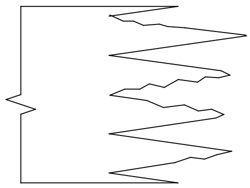
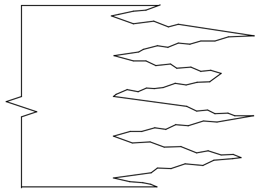
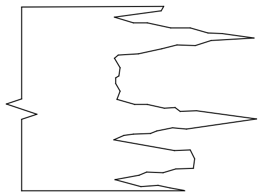
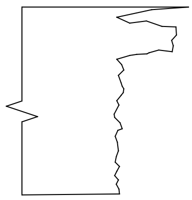
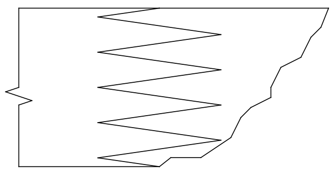
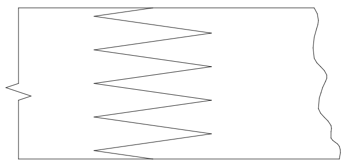
- Mode 1 combined with low strengths (taken to mean less than $f'_{t,lam,\max}$) represents poor finger jointing.
- Modes 2, 3 and 4 combined with low strengths represent weak wood in the vicinity of the finger joint.
- Modes 5 and 6 combined with low strength represents under strength lamination stock; see .

In making these interpretations it is noted that AS/NZS 1328.1 is a performance based standard. Prescriptions in earlier versions have been placed in AS/NZS 1328.2 as "good manufacturing practice" including the closeness of knots to finger joints. The practice of knot docking is notably absent with some glulam manufacturers as can be noted in the detailed results in the Appendix. This can result in wood grain sloping at angles of anything up to 45º which robs the lamination of practically all of its tension strength. Failure Mode 4 also has the appearance of a carroty-like fracture indicating that a finger joint is possibly located, at least partially, in brittle heart. Given that stress concentrations occur at the tips of finger joints and the presumed lower fracture strength of wood in brittle heart, some low strength finger joints fracturing in Mode 4 may well have suffered by such means.

Table 3 Characteristic tension strength of laminations, $f'_{t,lam}$, and coefficient of variation, $V_{t,lam}$, of single laminations. Strengths in megapascals.

Grade/Adhesive	A17/PUR		MGP15/PRF		MGP15/PRF		MGP15/PRF		MGP10/PRF	
Manufacturer	A		B		C (Series 1)		C (Series(2)		D	
Finger joint spacing (mm)	$f'_{t,lam}$	$V_{t,lam}$	$f'_{t,lam}$	$V_{t,lam}$	$f'_{t,lam}$	$V_{t,lam}$	$f'_{t,lam}$	$V_{t,lam}$	$f'_{t,lam}$	$V_{t,lam}$
300			14.4	0.21						
600	13.3	0.31	13.8	0.28						
900	14.3	0.28	18.2	0.20					8.4	0.28
1200	13.8	0.26	20.0	0.20	15.4	0.21	12.0	0.35	0.0	0.52
1500					4.7	0.46	13.2	0.25		
1800	13.9	0.29			6.1	0.48	16.4	0.23		
2100			18.4	0.17	3.8	0.50	18.7	0.17	4.1	0.34

Table 4 Mode of finger joint failure description after AS 5068.

Mode	Description	Example
1	Failure mostly along the bondline surfaces of the joint profile with poor wood failure of any kind (wood failure < 70%)	
2	Failure mostly along the bondline surfaces of the joint profile with good wood failure of any kind (wood failure > 70%)	
3	Failure mostly along the joint profile but some failure at the finger roots or scarf tips. Good overall wood shear failure along the joint profile surfaces.	
4	Mostly tensile wood failure at the finger roots or scarf tips with high overall wood failure. Little failure of any kind along the joint profile.	
5	Failure beginning at the joint (possible due to a stress riser) and progressing away from the joint. Essentially 100% wood failure.	
6	Failure away from the joint (not influenced by the joint) – all wood failure.	

Data assessments

Manufacturer A

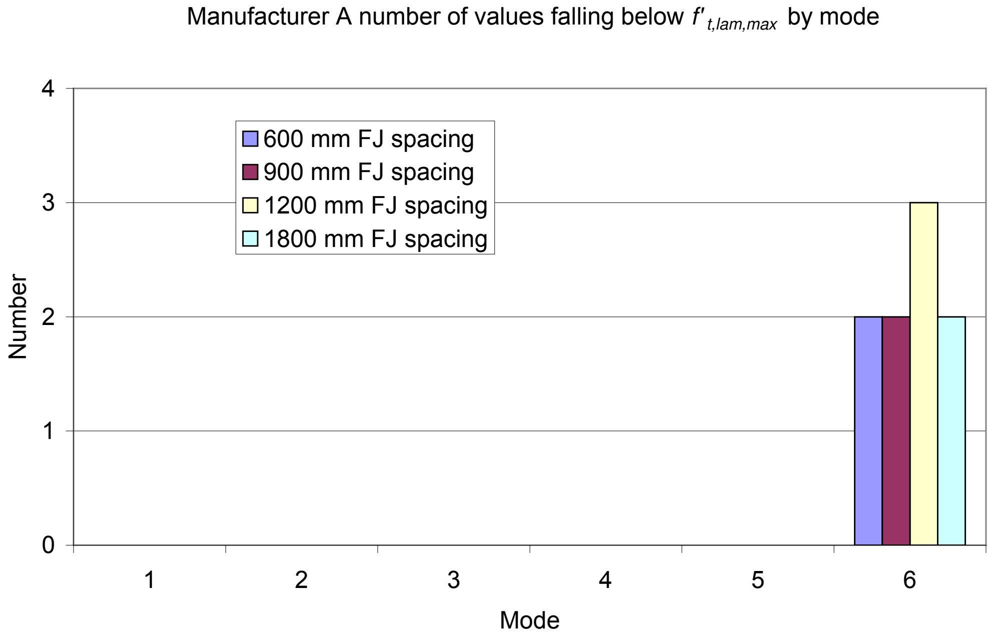


Figure 4 Failure modes for Manufacturer A (A17 Vic ash hardwood) showing the numbers of lamination failures of various types for all failures that were less than $f'_{t,lam,\max}$.

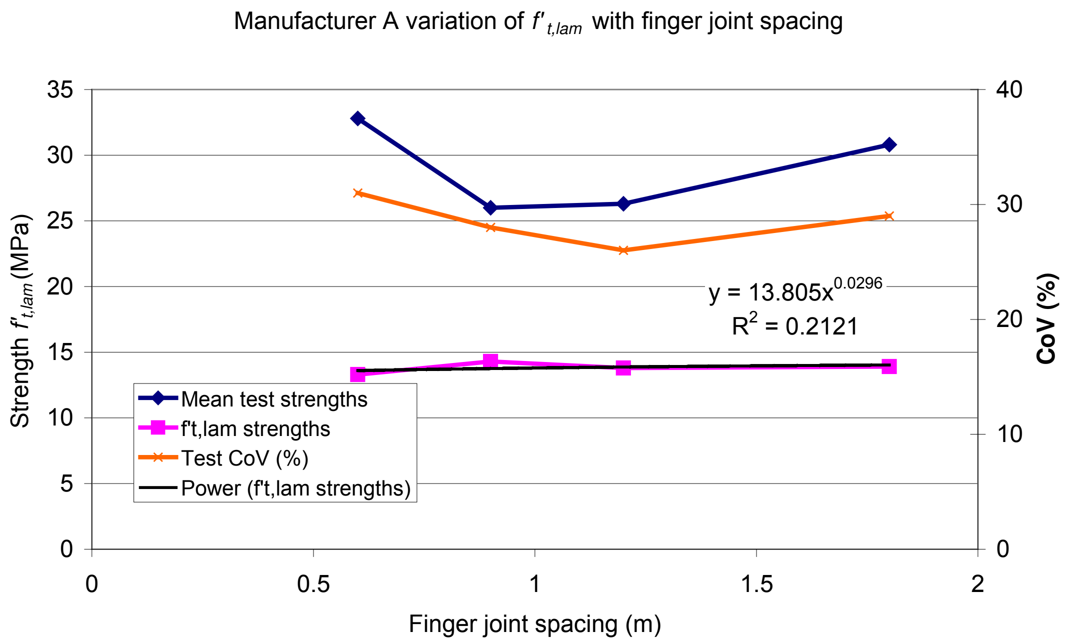


Figure 5 Test data from laminations made by Manufacturer A (A17 Vic ash hardwood).

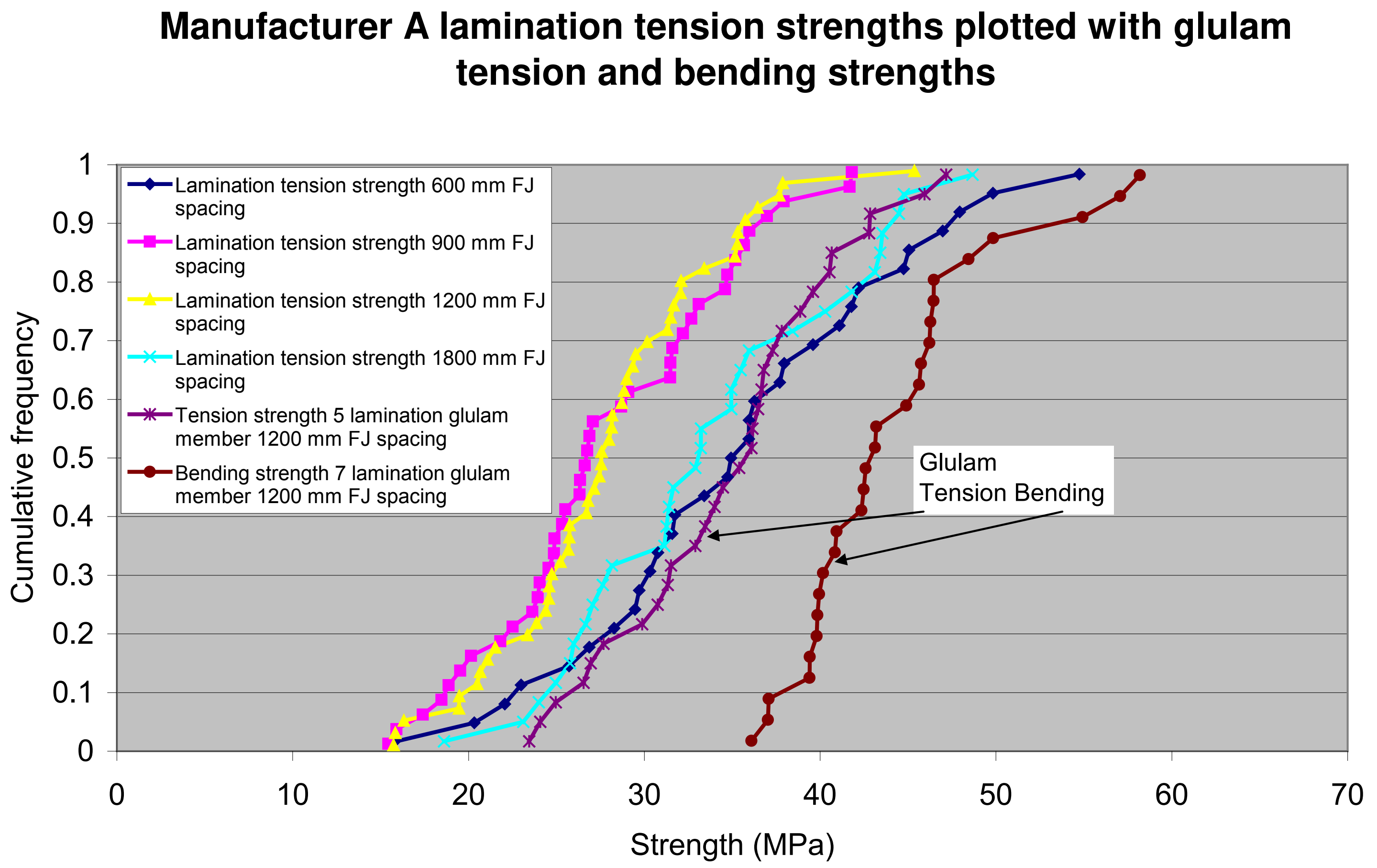


Figure 6 Manufacturer A (A17 Victorian Ash) - Cumulative frequency, as/NZS 4063 ranking method, of lamination tension strength tests together with glulam tension and bending strengths.

Figure 5 shows little, in any, correlation between finger joint spacing and $f'_{t,lam}$ but the coefficient of variation is consistent. All low failures are associated with the lamination stock; see Figure 4. Cumulative frequency plots are given in Figure 6. The $f'_{t,lam}$ strengths are low compared with results cited by Aicher et al (2001) for beech with a similar density. This could be caused by a number of factors including the adhesive used, gluability of the species or manufacturing variables. It is worthy of further investigation but beyond the scope of this project.

Manufacturer B

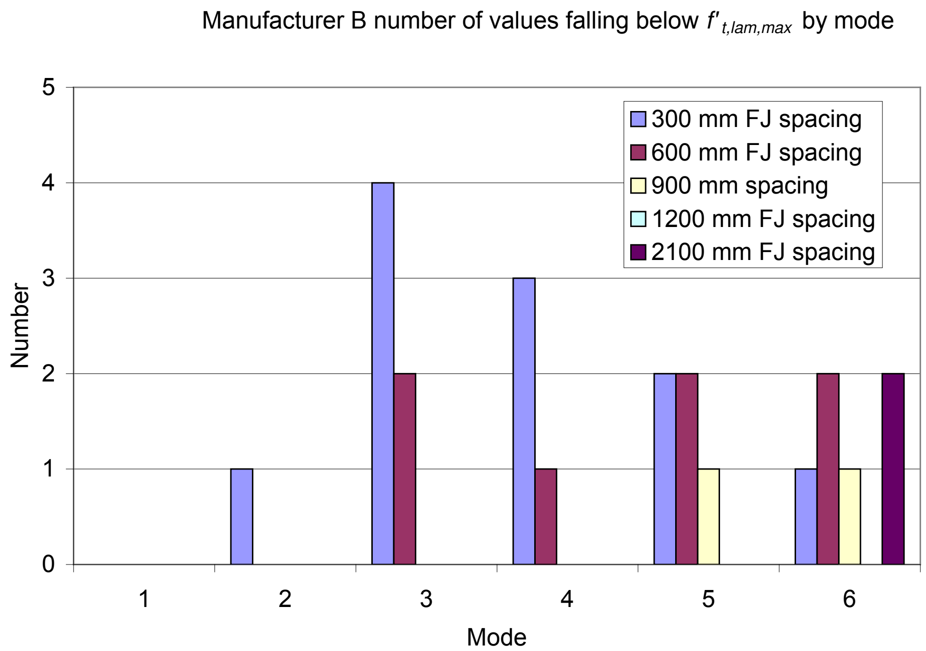


Figure 7 Failure modes for Manufacturer B (MGP15 radiata pine) showing the numbers of lamination failures of various types for all failures that were less than $f'_{t,lam,\max}$**.**

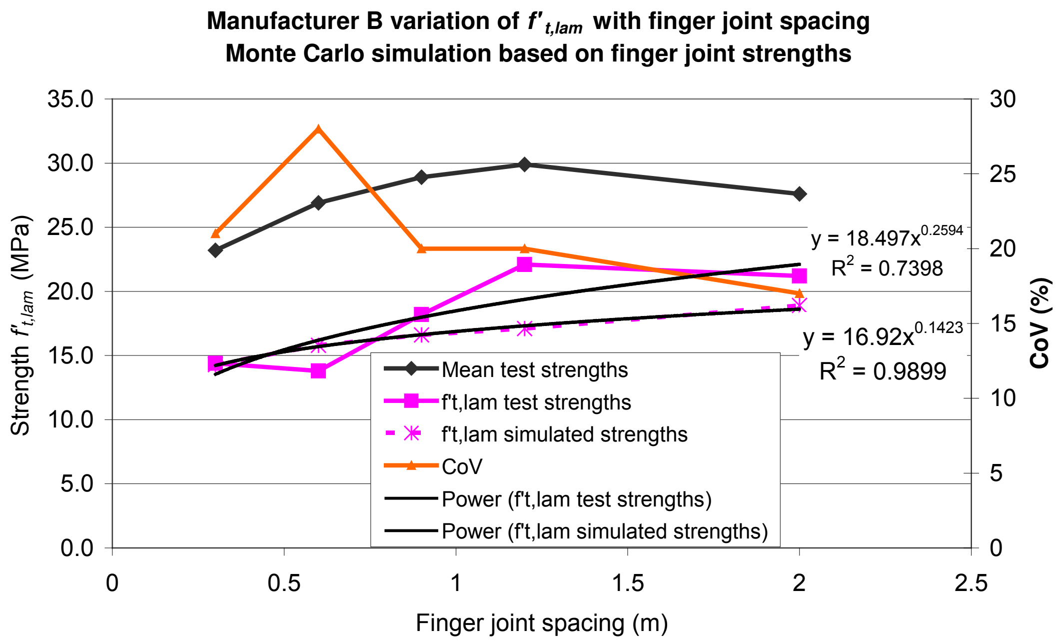


Figure 8 Test data from laminations made by Manufacturer B. The simulation is for a mean strength of 28.5 MPa and V = 0.1

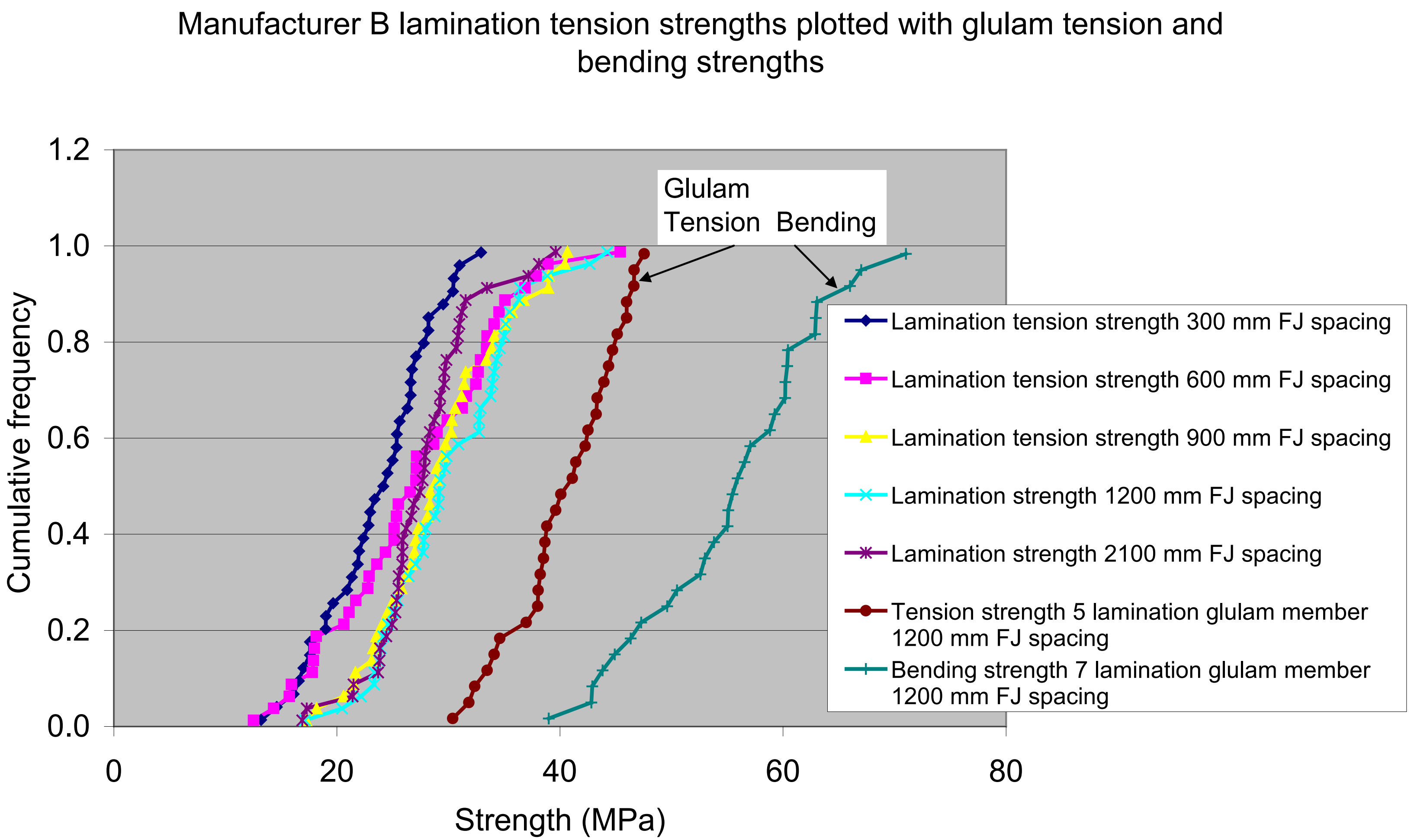


Figure 9 Manufacturer B (MGP15 Radiata Pine)- Cumulative frequency of lamination tension strength tests together with glulam tension and bending strengths.

Figure 8 shows relatively good correlation between finger joint spacing and $f'_{t,lam}$. When the finger joint spacing is 300 mm all low failures are associated with the finger joints – modes 1 - 4; see Figure 7. As the number of finger joints reduces over the fixed test length more low results are associated with the lamination stock. While there is some inconsistency in the coefficient of variation (range from 0.20 to 0.28) it is judged constant so that there are no manufacturing effects contaminating the data. (Monte Carlo simulation predicts that V should remain constant if finger joint quality is maintained.) Cumulative frequency data is given in Figure 9.

Manufacturer C Series 1

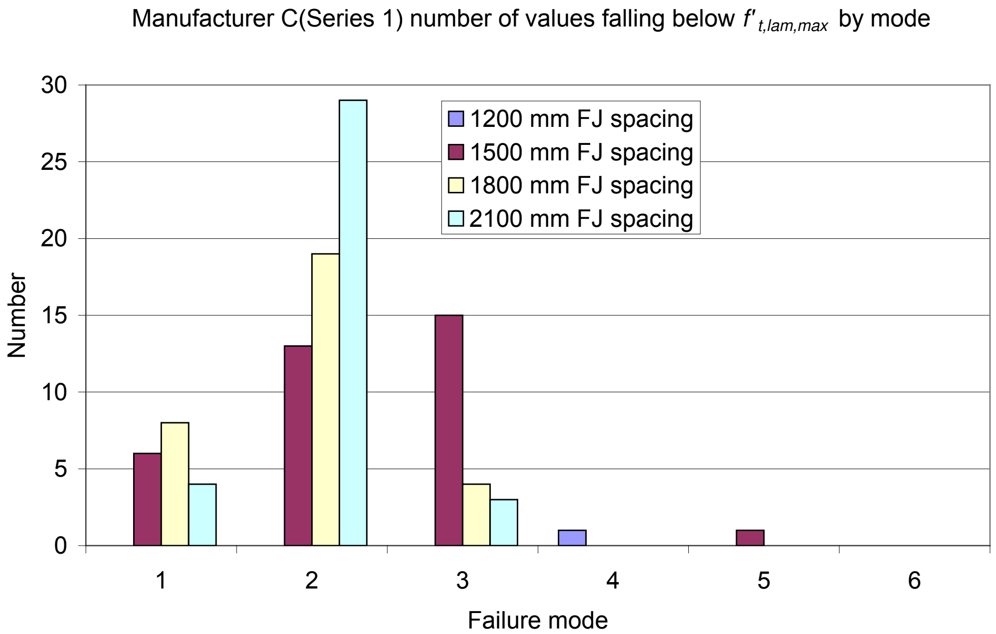


Figure 10 Failure modes for Manufacturer C (Series 1) showing the numbers of lamination failures of various types for all failures that were less than $f'_{t,lam,\max}$.

Manufacturer C (Series 1) variation of $f'_{t,lam}$ with finger joint spacing

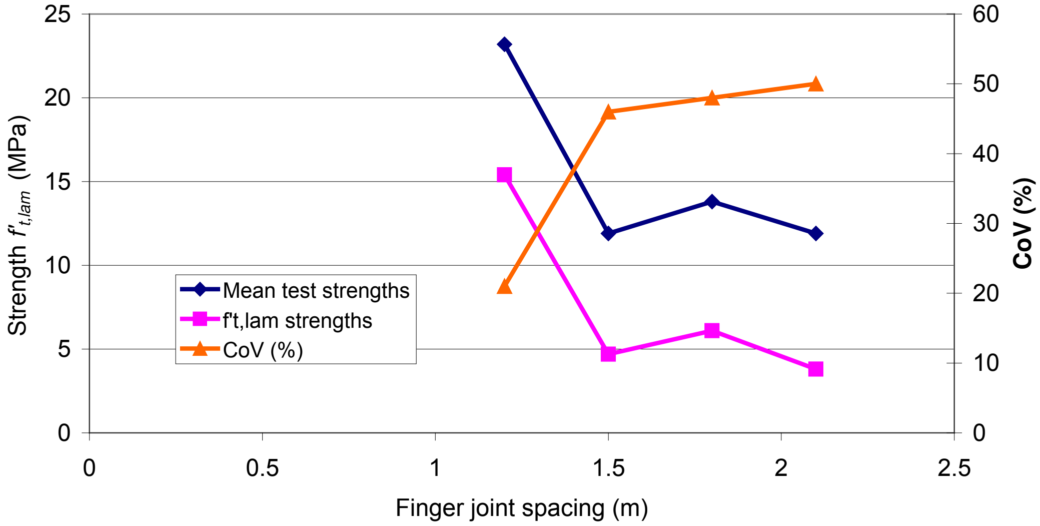


Figure 11 Test data from laminations made by Manufacturer C (Series 1). Data is unusable due to loss of process control.

Figure 10 shows a s ituation i n which the manufacturer completely lost what could b e d escribed as r easonable pr ocess c ontrol. With upw ards o f 60 laminations failing at a level less than $f'_{t,lam,\max}$ in modes 1, 2, 3, 4, which are associated w ith finger j oint failure, n o o ther c onclusion c an be dr awn especially given that $f'_{t,lam,\max}$ was achieved at the smallest finger joint spacing of 1.2m; see Figure 11. The data was regarded as worthless for the purposes of the project.

Manufacturer C Series 2

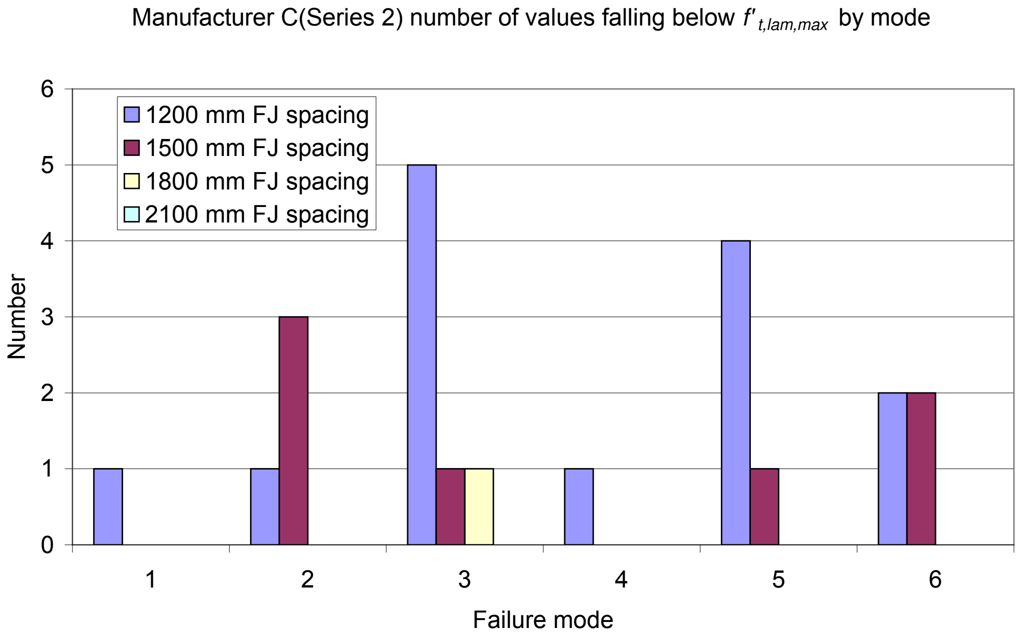


Figure 12 Failure modes for Manufacturer C (Series 2) showing the numbers of lamination failures of various types for all failures that were less than $f'_{t,lam,\max}$.

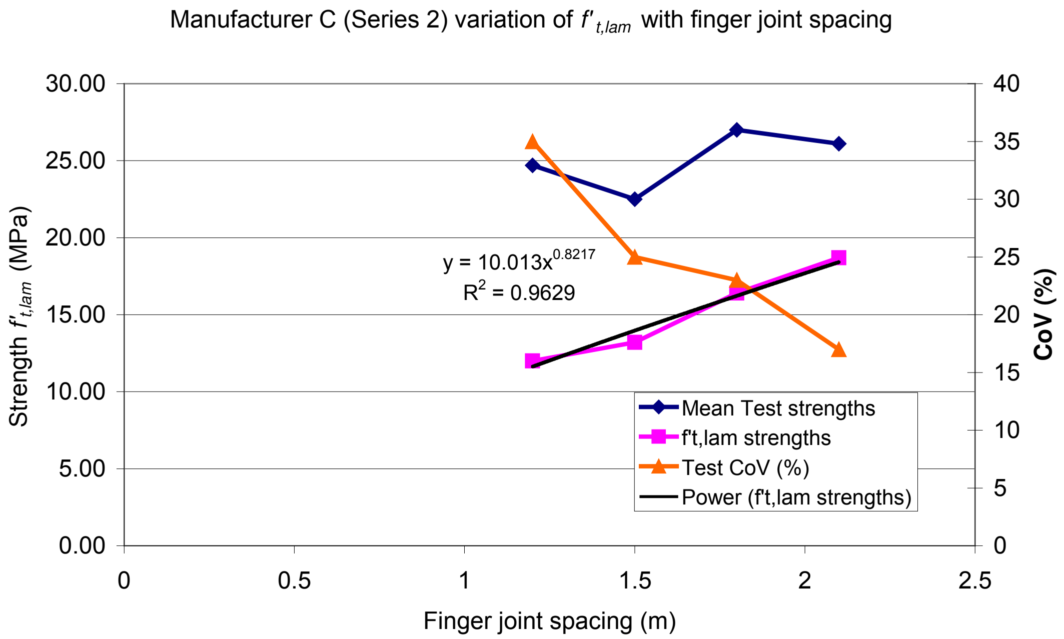


Figure 13 Test data from laminations made by Manufacturer C (Series 2).

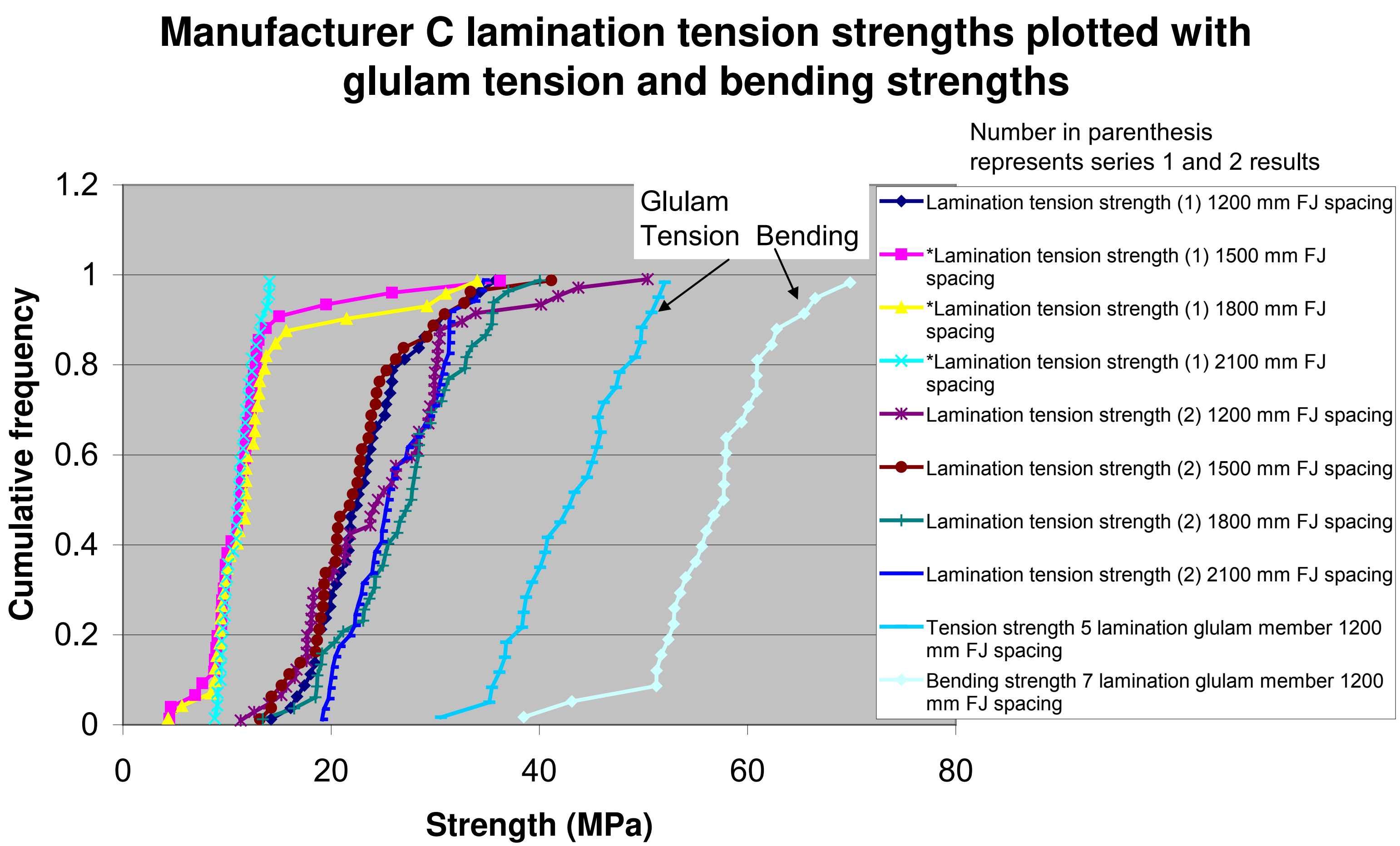


Figure 14 Manufacturer C (MGP15 Slash Pine)- Cumulative frequency of lamination tension strength tests together with glulam tension and bending strengths. Note the out-of-control lamination test data in the group of 3 test results to the left (blue, purple, yellow – Manufacturer C Series 1).

Figure 13 shows excellent correlation between a power fit curve for the variation of strength with finger joint spacing but the coefficient of variation ranges from 0.17 to 0.35 (1200 mm FJ spacing) suggesting that manufacturing problems were playing a role. There is nothing like an even coefficient of variation as the finger spacing changes. Notice in Figure 8 the significant number of low strengths classified as Mode 3 failures. Such failures are often associated with brittle wood and it becomes problematical whether this is regarded as a manufacturing problem that is part of a lamination or a shook length factor. A feature of the results is that 13 low results are associated with finger joints (Modes 1 – 4) and 10 low results with the lamination stock (Modes 5 and 6). At best the data is regarded as dubious with respect to providing any information about the effect of finger joint spacing; see 0. Attempts to simulate the data make no sense because of the unanticipated changes in V from one series to the next. Figure 12 and Figure 14 respectively show the failure modes and cumulative frequency plots.

Manufacturer D

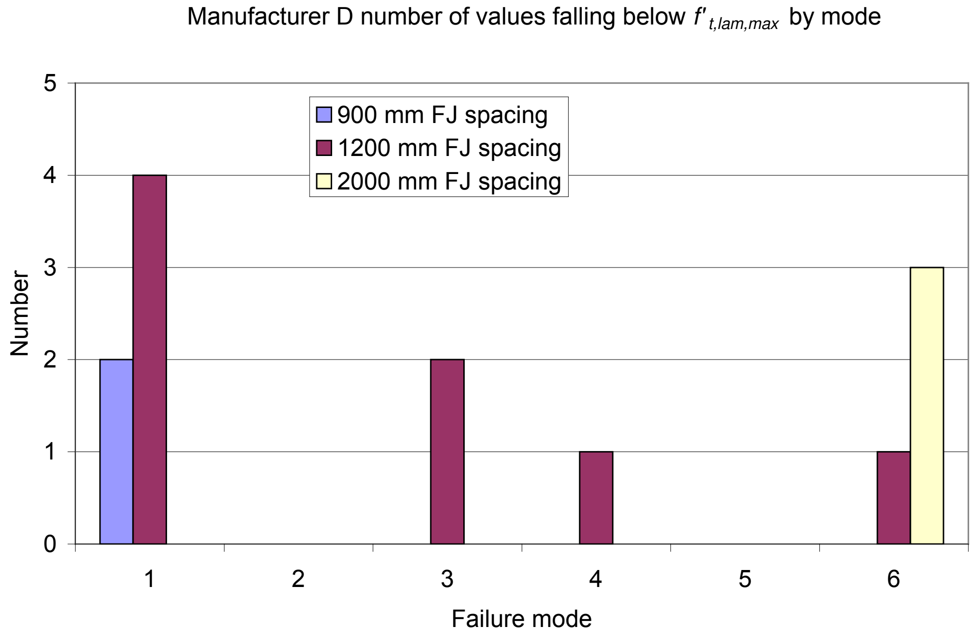


Figure 15 Failure modes for Manufacturer D showing the numbers of lamination failures of various types for all failures that were less than $f'_{t,lam,\max}$.

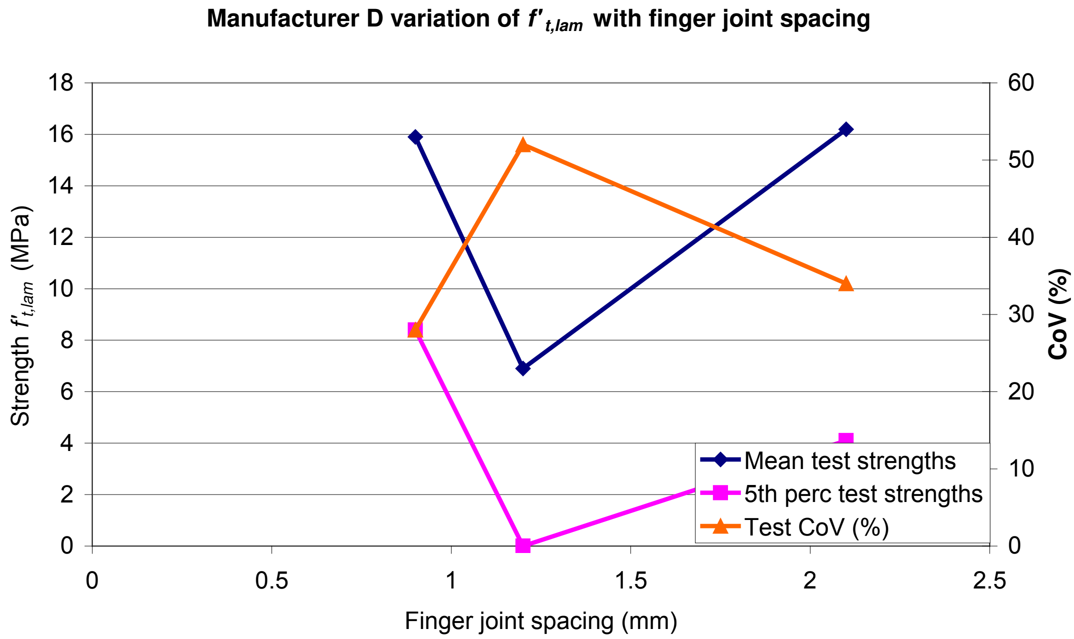


Figure 16 Test data from laminations made by Manufacturer D.

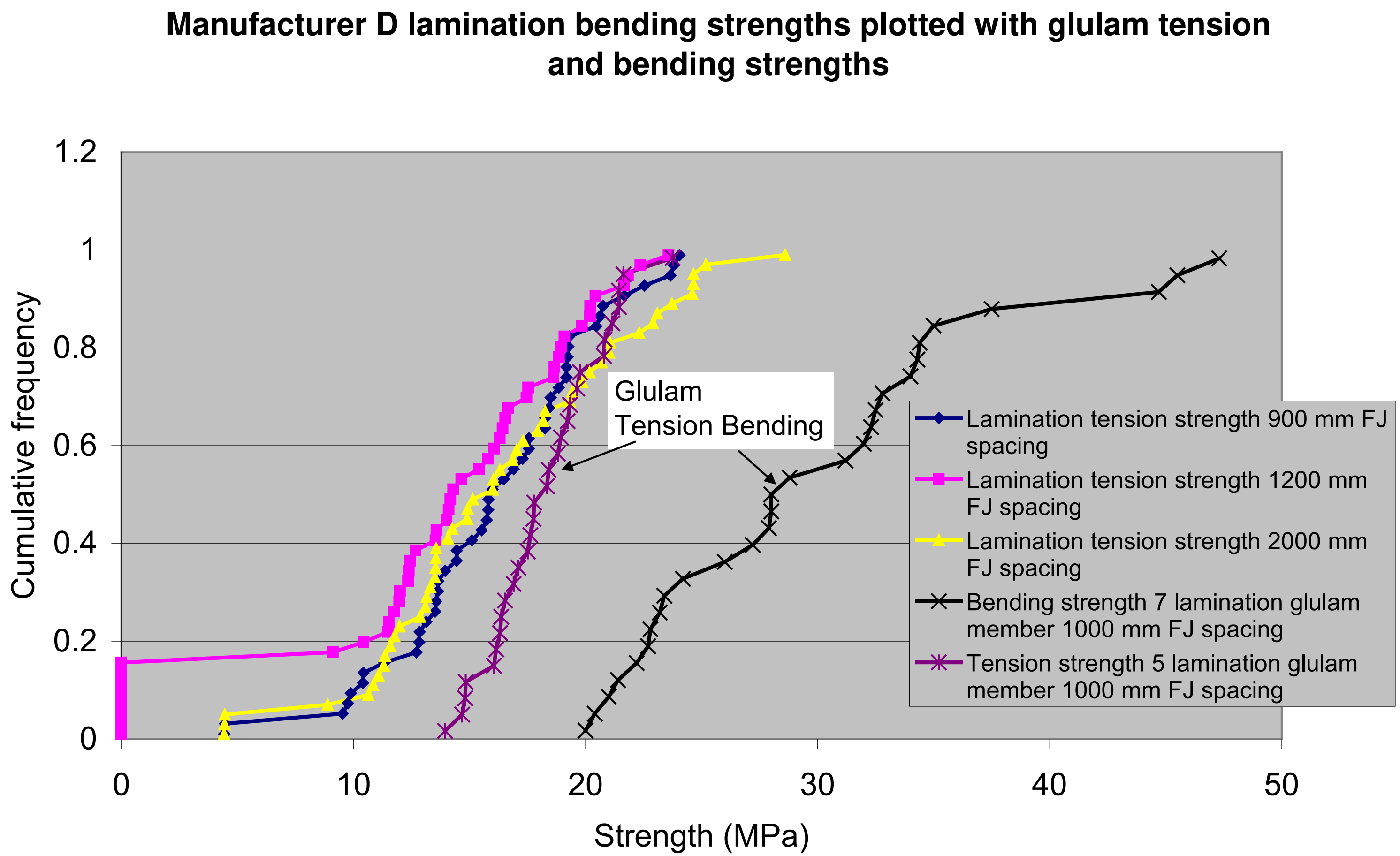


Figure 17 Manufacturer D (MGP10 Radiata Pine)- Cumulative frequency of lamination tension strength tests together with glulam tension and bending. Note the loss of process control with the 1200 mm finger joint spacing results. Cumulative frequency uses AS/NZS 4063.2 method.

Figure 16 illustrates why this data, based on MGP10 laminating stock, provides no useful data with many low strength joints at a 1.2 m finger joint spacing. It is also very obvious in Figure 17. With a lamination size of 30 x 75 it was expected that the laminations would support at least 5 MPa or a load of 11kN. The load cell of the test machine and its accompanying digital read-out did not detect loads less than 9kN and many results fell below that value. As a consequence, the result was recorded as zero. It is also clear in Figure 15 that a number of the low strength failures were in the lamination stock. Classifying Modes 1 – 4 as finger joint failures there were 13 low failures but there were 9 low strength failures in Modes 5 and 6.

Shook length factors

Manufacturer A (A17 hardwood)

A power curve trend line can be placed through the data but the R^2 factor indicates a very poor correlation. It is concluded that there is no shook length factor operating in this case.

Manufacturer B and Manufacturer C Series 2 (MGP15 softwood)

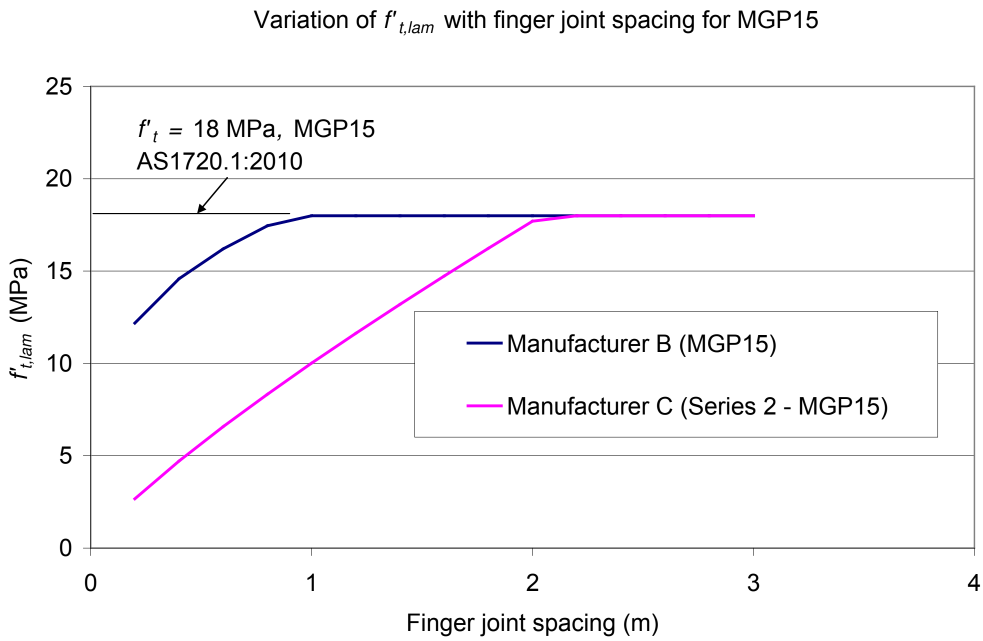


Figure 18 Increase in lamination tension strength with an increase in finger joint spacing based on power curve trend lines.

The trend lines are based on

- Manufacturer B Figure 5, $f'_{t,lam} = 18.497S^{0.2594}$
- Manufacturer C (Series 2), Figure 9, $f'_{t,lam} = 10.013S^{0.8217}$

with an upper limit of 18 MPa taken as the characteristic strength of MGP15 solid wood; see AS1720.1:2010, Table H3.1.

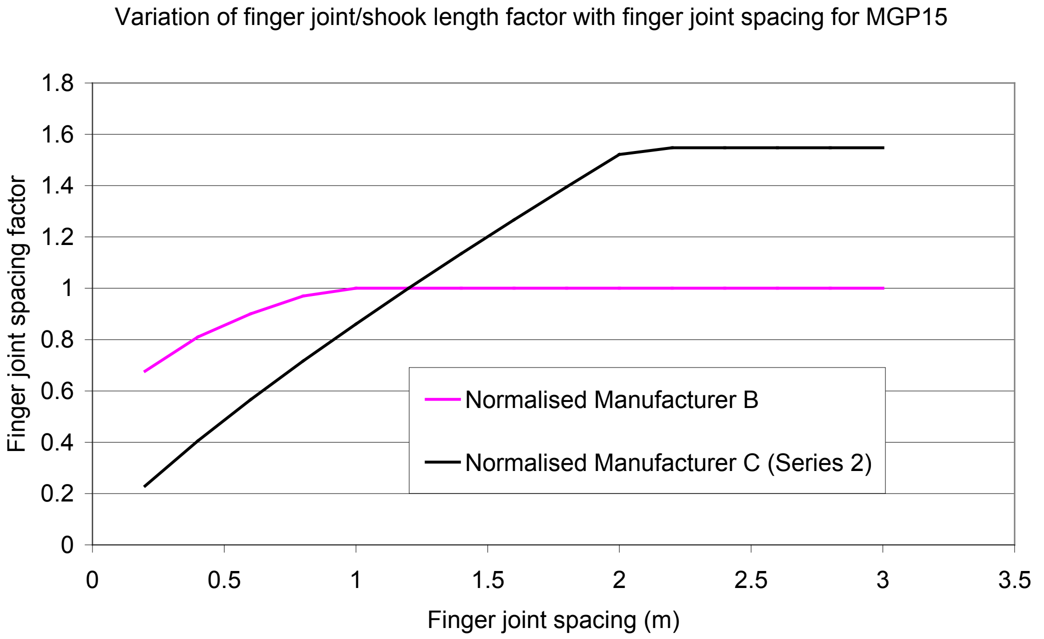


Figure 19 Normalised increase in lamination tension strength with an increase in finger joint spacing based on power curve trend lines.

Both curves are normalised as follows:

Manufacturer B $Factor = 18.497S^{0.2594} / 18.497 \times 1.2^{0.2594} = 0.95S^{0.2594}$

Manufacturer C (Series 2) $Factor = 10.013S^{0.8217} / 10.013 \times 1.2^{0.8217} = 0.86S^{0.8217}$

The choice of the normalising length at 1.2 m is based the later tests of glulam members where a 1.2m finger joint spacing was used throughout. On this basis the data provided by Manufacturer C Series 2 leads to a high expectation of strength increases unobservable with the other manufacturers. The Manufacturer C Series 2 data is simply not credible.

Concluding remarks on finger joint spacing factor

A17 hardwood

There is no finger joint spacing factor observable in the case of A17 hardwood.

MGP15

There is a finger joint spacing factor observable in the case of MGP15 softwood and the result that is viewed as most reliable is provided by the Manufacturer B data and has the form $0.95S^{0.2594}$. There are considerable differences between manufacturers indicating that an entirely different approach is required.

MGP10

The data was unusable.

Objective 2 – Awarding good and penalizing bad finger jointing

The results are too inconclusive to allow a general formula to be developed that would allow penalties to be applied for poor quality finger jointing. Following recent discussion a different approach has been proposed that would involve qualification testing being undertaken on one-sided and two sided reinforced laminations. It follows from the observation of Colling and Falk (1993) as outlined in 0. This takes into account to a greater or lesser extent k_{test}, k_{reinf}, k_{disp} but principally k_{reinf} effects which can be very manufacturer specific. A manufacturer who is less scrupulous about k not docking can choose to go down that path and it may well be that the reinforcing effects dominate lamination performance within a glulam member. This is strongly suggested by the performance of Manufacturer D who used MGP10, who had poor lamination performance but whose glulam members were not commensurately affected.

Objective 3 - Relationship between tension strengths of laminations and glulam members in bending and tension

The performance of the manufacturers involved is listed in Table 5. For glulam in bending the lamination factors are well in excess of those reported in overseas literature for reasons that cannot be identified. The exception is Manufacturer B. Typical values used in US approaches are closer to 1.65 although some conservatism may be built into these values. No overseas data is available from other sources for glulam members in tension so these have to be taken at face value. The anomaly with bending strengths provides a further reason for undertaking tension testing on one and two sided reinforced laminations.

Manufacturer	Lamination $f'_{t,lam}$ (MPa)	Glulam in bending $f'_{b,glulam}$ (MPa)	Lamination factor in bending	Glulam in tension $f'_{t,glulam}$ (MPa)	Lamination factor in tension
A (A17 Hwd)	13.8	35.5	2.57	22.6	1.64
B (MGP15)	22.1	40.8	1.85	30.5	1.38
C (MGP15)					
Series 1	15.4	41.1	2.67	33.5	2.18
Series 2	12.0	41.1	2.79	33.5	2.79
D (MGP10)	8.4	19.4	2.31	14.0	1.67

Table 5 Lamination factors observed as a result of testing based on 1200 mm finger joint spacing except for Manufacturer D where the 900 mm spacing value was used. Both the lamination and the glulam strengths are modified are corrected for sample size (confidence level) factors.

Postscript - lamination and glulam bending MOE values

Although not a specific requirement of the project, stiffness (modulus of elasticity) data was available and was subjected to some investigation. One initially puzzling aspect was the consistent differential between the lamination MOEs as determined in the McDonnell rig and the glulam MOEs as determined in the Monash glulam bending tests; see Table 6. This matter has been investigated as far as determining the influence of test spans noting that both the lamination and glulam beam tests were conducted in four point bending. The lamination tests were conducted at a span of 3.6m because this was a fixed feature of the test machine at N.F. McDonnell & Sons but the test spans of the glulam were conducted according to Table 7.

Using the Euler-Bernoulli then the Timoshenko theory of bending the modulus of elasticity is given respectively by

$$E_{Eul} = \left(\frac{P}{\Delta}\right)\left(\frac{1}{I}\right)\left(\frac{5L^3}{324}\right),\ E_{Timo} = \left(\frac{P}{\Delta}\right)\left(\frac{E}{G}\frac{L}{6A_s} + \frac{5L^3}{324I}\right) \qquad 12$$

The expected ratio for the MOE is therefore

$$\frac{E_{Timo}}{E_{Eul}} = \frac{E}{G}\frac{I}{A_s}\frac{10.8}{L^2} + 1 \qquad 13$$

where

A_s = shear area for deflections $= 1.2bd$

I = second moment of area

L = test span

E/G = ratio of elastic to shear modulus taken as 17

Usually the ratio E/G is in the range 15 to 20 although this was not specifically measured but the MOEs for both lamination and glulam beam tests can be corrected to examine the effect of the test configurations on the E values. It can be seen from values in Table 6 (bottom row) and

Table 7 (right column) that the differential between lamination and glulam beam E values is partially but not totally explained by shear effects. The remainder is attributed to support settlement issues or calibration errors. The glulam beams were supported on pads that distribute the support loads and the deflections measured off a ground base, causing the MOE measurement to always be slightly low. This effect was assumed to be more severe with the glulam given the relative sizes of the support pads that distribute support loads.

The anomaly was accordingly seen as not so large that there was need to regard a loss of flexural stiffness between lamination stock and the glulam member made from it as worthy of further investigation.

Table 6 Adjustment for modulus of elasticity after allowing for the effect of shear deformations.

Manufacturer	Test span (mm)	Width (mm)	Depth (mm)	Span to depth ratio	I_x (mm^4)	A_s (mm^2)	Ratio E_{Eul}/E_{Timo}
Glulam data							
A	5040	65	280	18	1.1891×10^8	15166	1.053
B	4050	65	225	18	5.7677×10^7	11916	1.063
C	4500	65	180	25	3.1590×10^7	9750	1.030
Lamination data							
A	3600	38	75	48	1.3901×10^6	2407	1.007
B	3600	35	70	51	1.0004×10^6	2042	1.006
C	3600	35	70	51	1.0004×10^6	2042	1.006

Note that Euler bending theory ignores shear deformation, while Timoshenko theory includes shear deformation.

Table 7 Measured lamination and glulam beam mean values of modulus of elasticity using Euler and Timoshenko theory.

	Partner A	Partner B	Partner C
Euler basis			
Lamination MOE (MPa)	16900	15900	16200
Glulam MOE (MPa)	15300	14600	15200
Ratio (Lam MOE/Glulam MOE)	1.10	1.09	1.07
Timoshenko basis			
Lamination MOE (MPa)	17000	16000	16300
Glulam MOE (MPa)	16100	15500	15700
Ratio (Lam MOE/Glulam MOE)	1.06	1.03	1.04

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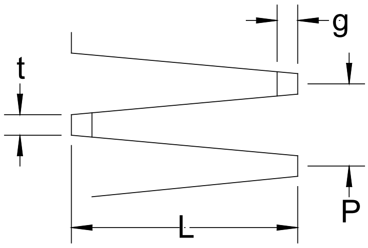
Appendix

1.1 Finger joint profiles

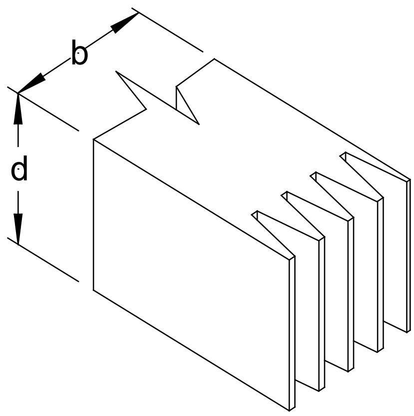
Finger joint profile details are shown immediately below.



Manufacturer	A	B	C	D
Length (L - mm)	15	15	25	20
Pitch (P - mm)	3.8	6.0	6.2	6.2
Tip Width (t - mm)	0	0.5	0.8	1.0
Tip Gap (g - mm)	0.6	0.5	0.75	0.5

Finger joint details.

The term "vertical finger profile" is used in expressing the results. The sense in which the finger profile has been cut is illustrated in Figure 8. *b* is always the smaller dimension.



Definition of a vertical finger profile. *b* is always the smaller dimension.

1.2 Processing of results

All processing of data is in accordance with AS/NZS 4063.2:2010 except for the factor, a_v.

1.3 Manufacturer A results

1.3.1 General details

Species	Adhesive	Finger profile (mm)	Nominal size (d x b) (mm)
Vic ash	Purbond	15 vertical	75 x 40

1.3.2 Finger joint spacing 600mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
75.5	38.1	118.2	41.1	(3)	-	17030
76.9	38.9	112.8	37.7	(3)	-	15770
75.6	38.4	59.0	20.3	(3)	Timber failure through gum vein leading to FJ	14310
77.2	38.6	118.0	39.6	(3)	-	14270
74.9	38.8	66.8	23.0	(5)	Failure initiated at grain deformation	17190
76.2	38.5	137.8	47.0	(3)	-	14530
75.0	38.1	156.4	54.7	(5)	-	16550
75.5	38.5	122.6	42.2	(3)	-	17640
77.2	38.5	106.8	35.9	(5)	-	16810
76.4	38.7	112.2	37.9	(4)	-	14350
75.4	38.6	78.2	26.9	(5)	-	16640
76.0	38.9	107.2	36.3	(3)	-	17410
75.9	37.5	62.8	22.1	(5)	-	17760
75.6	37.7	99.0	34.7	(3)	Knot at FJ	15930
76.0	37.8	88.4	30.8	(3)	-	14170
76.7	38.4	98.4	33.4	(4)	-	17590
76.0	39.3	148.8	49.8	(5)	-	18160
76.0	39.2	134.2	45.0	(5)	-	17660
75.5	38.3	129.4	44.7	(3)	-	16210
76.1	38.3	101.8	34.9	(5)	-	17640
76.0	38.8	83.4	28.3	(5)	-	18290
75.0	38.4	91.4	31.7	(4)	-	15350
75.1	39.4	87.2	29.5	(3)	-	17500
76.4	39.1	124.8	41.8	(3)	-	18980
75.6	38.4	45.8	15.8	(5)	-	16610
75.3	38.9	140.4	47.9	(3)	-	18310
75.8	38.1	91.2	31.6	(3)	-	18260
75.5	39.2	106.4	36.0	(3)	-	18710
75.9	38.4	86.6	29.7	(3)	-	16180
75.8	39.4	76.8	25.7	(3)	-	18070
75.5	39.4	90.2	30.3	(4)	-	15560

76.1	38.3	101.8	34.9	(5)	-	17640
76.0	38.8	83.4	28.3	(5)	-	18290
75.0	38.4	91.4	31.7	(4)	-	15350
75.1	39.4	87.2	29.5	(3)	-	17500
76.4	39.1	124.8	41.8	(3)	-	18980
75.6	38.4	45.8	15.8	(5)	-	16610
75.3	38.9	140.4	47.9	(3)	-	18310
75.8	38.1	91.2	31.6	(3)	-	18260
75.5	39.2	106.4	36.0	(3)	-	18710
75.9	38.4	86.6	29.7	(3)	-	16180
75.8	39.4	76.8	25.7	(3)	-	18070
75.5	39.4	90.2	30.3	(4)	-	15560
76.3	38.5	34.8	11.8	(6)	-	15320
76.1	38.4	104.8	35.9	(6)	-	17180
77.5	37.9	59.6	20.3	(6)	Failure through knot/grain defect	18770
76.0	38.4	59.2	20.3	(6)	-	17570
76.1	39.0	89.0	30.0	(6)	-	16030
76.2	37.9	39.8	13.8	(6)	-	15750
78.3	38.8	83.8	27.6	(6)	-	15200
		$f_{0.05}$	14.6		Mean MOE	16756
		Mean	32.8			
		$V_{t,lam}$	0.31			
		$f'_{t,lam}$	13.3			

1.3.3 Finger joint spacing 900 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
72.7	38.2	52.4	18.9	(3)	-	14710
76.1	38.1	69.4	23.9	(4)	-	17620
76.0	38.4	57.0	19.5	(3)	-	18730
76.6	38.5	73.4	24.9	(5)	-	17120
76.1	38.8	64.4	21.8	(4)	-	17480
76.6	38.2	78.3	26.8	(3)	-	15400
75.7	38.8	101.6	34.6	(2)	-	20540
75.4	38.3	44.6	15.4	(5)	-	16120
76.1	38.6	96.0	32.7	(3)	-	19190
76.0	38.4	105.0	36.0	(4)	-	14260
76.6	38.1	122.0	41.8	(5)	-	14690
74.8	38.4	106.2	37.0	(3)	-	16980
76.2	38.2	78.8	27.1	(4)	-	13810
72.3	38.5	65.8	23.6	(5)	-	14010
76.5	38.7	79.6	26.9	(3)	-	19140
76.2	39.0	106.0	35.7	(3)	-	14970
76.0	38.8	102.4	34.7	(3)	-	18320

75.7	39.2	93.4	31.5	(5)	Knot at FJ	16710
76.3	38.3	121.8	41.7	(3)	-	15310
76.2	38.5	103.2	35.2	(3)	-	17400
76.2	38.7	72.4	24.6	(3)	-	19080
76.0	38.8	59.4	20.1	(4)	-	13020
76.6	37.8	65.2	22.5	(4)	-	13690
75.9	38.7	74.4	25.3	(4)	-	18030
76.7	38.6	73.6	24.9	(3)	-	16150
76.0	39.3	78.6	26.3	(5)	-	15470
76.2	38.3	70.2	24.1	(3)	-	14220
77.0	38.4	84.8	28.7	(3)	-	15430
77.1	38.8	79.6	26.6	(2)	-	22870
76.6	38.4	92.6	31.5	(2)	-	16320
74.5	38.1	72.4	25.5	(3)	-	15490
75.8	38.9	97.6	33.1	(2)	-	14480
75.8	38.8	51.2	17.4	(3)	-	13900
74.1	38.6	52.8	18.5	(5)	-	14270
75.9	39.1	47.2	15.9	(4)	Knot at FJ	13670
75.8	39.0	93.4	31.6	(4)	-	15590
76.9	38.6	95.6	32.2	(4)	-	17060
75.6	38.2	84.0	29.1	(5)	-	18490
76.1	39.1	78.4	26.3	(3)	-	18960
75.9	38.7	111.4	37.9	(3)	-	19090
77.3	39.1	53.4	17.7	(6)	-	14220
76.0	39.1	56.8	19.1	(6)	-	14260
76.1	37.9	49.2	17.1	(6)	Failure through knot	16030
76.0	38.4	60.2	20.6	(6)	-	15110
75.8	39.0	67.8	22.9	(6)	-	15850
75.8	38.2	26.8	9.3	(6)	Failure through gum vein	15690
75.0	38.7	40.2	13.9	(6)	-	13210
76.3	35.8	48.0	17.6	(6)	Failure through grain defect	17090
75.1	38.6	76.4	26.4	(6)	Failure through knot	17120
75.5	38.1	73.2	25.4	(6)	-	15730
		$f_{0.05}$	15.4		Mean MOE	16242
		Mean	26.0			
		$V_{t,lam}$	0.28			
		$f'_{t,lam}$	14.3			

1.3.4 Finger joint spacing 1200 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
75.8	38.5	72.2	24.7	(4)	-	15230
75.0	38.4	96.2	33.4	(3)	-	16020
76.4	38.1	83.6	28.7	(3)	Knot at FJ	17160
76.8	37.3	55.8	19.5	(4)	-	16500

76.3	38.4	72.0	24.6	(4)	-	15530
76.3	39.4	61.6	20.5	(4)	-	16630
76.0	39.5	80.2	26.7	(4)	-	15710
76.3	38.7	48.2	16.3	(4)	-	14030
76.6	38.9	69.6	23.4	(4)	-	15830
76.6	40.0	64.6	21.1	(4)	-	14570
75.9	38.3	69.4	23.9	(4)	-	16520
76.9	39.0	77.2	25.7	(5)	-	14540
76.2	38.6	79.8	27.1	(4)	-	14410
76.3	39.3	47.2	15.7	(3)	Low density	16570
76.3	38.9	76.2	25.7	(4)	-	16110
76.3	38.9	72.4	24.4	(5)	-	16100
75.7	38.4	91.0	31.3	(4)	-	15720
77.0	39.5	59.2	19.5	(4)	-	15560
76.0	38.9	86.4	29.2	(6)	Failure at grain defect	15930
76.2	38.7	29.0	9.8	(6)		16050
76.7	39.4	69.2	22.9	(6)	Failure through grain defect	16110
75.9	39.6	50.0	16.6	(6)	Failure through knot	16110
76.1	39.1	39.4	13.2	(6)	-	17120
76.5	38.6	95.2	32.2	(6)	-	14290
75.2	38.4	79.6	27.6	(3)	-	19340
76.6	38.9	95.6	32.1	(3)	-	20850
75.9	38.2	91.8	31.7	(3)	-	19890
76.4	38.2	62.8	21.5	(5)	Failure initiated at knot	18650
74.9	39.1	82.4	28.1	(5)	Failure initiated through gum vein	18760
77.3	38.4	104.8	35.3	(3)	-	17790
76.2	39.5	88.8	29.5	(4)	-	20470
76.5	38.4	80.6	27.4	(5)	-	20610
76.5	38.4	75.6	25.7	(4)	-	18670
76.4	39.3	136.2	45.4	(3)	-	19050
75.6	38.9	78.8	26.8	(4)	-	18450
76.3	38.7	85.6	29.0	(5)	-	23350
75.4	38.8	84.4	28.8	(3)	-	18490
76.4	38.9	61.4	20.7	(3)	Grain defect at FJ	19100
75.9	37.4	100.2	35.3	(4)	Grain defect at FJ	24360
74.0	38.7	90.2	31.5	(3)	-	18230
76.3	39.4	47.6	15.8	(4)	-	19210
76.4	38.8	74.8	25.2	(3)	-	20230
76.3	38.7	107.6	36.4	(5)	-	20970
75.5	38.9	82.2	28.0	(3)	-	18150
76.1	38.9	105.8	35.7	(4)	-	18990
77.2	39.6	84.2	27.5	(5)	Failure through gum vein	17770
76.2	39.5	113.4	37.7	(3)	-	17590
76.4	39.6	85.2	28.2	(5)	-	18950
76.4	38.7	94.8	32.1	(3)	-	23190

75.8	39.9	91.2	30.2	(5)	Failure through knot	18990
77.2	39.2	74.4	24.6	(3)	-	19500
76.9	39.3	88.7	29.3	(4)	-	18690
75.8	38.8	103.4	35.2	(4)	-	17610
76.1	39.7	114.4	37.9	(3)	-	21410
76.1	38.5	52.2	17.8	(6)	-	19280
75.0	38.3	56.0	19.5	(6)	-	23560
76.5	38.9	90.6	30.4	(6)	Failure at knot	18300
78.0	39.5	66.4	21.6	(6)	Failure through grain defect	17600
76.3	38.6	67.4	22.9	(6)	-	21490
77.2	39.4	76.8	25.2	(6)	-	17380
76.3	39.6	40.6	13.4	(6)	Failure through grain defect	20890
		$f_{0.05}$	14.7		Mean MOE	18101
		Mean	26.3			
		$V_{t,lam}$	0.26			
		$f'_{t,lam}$	13.8			

1.3.5 Finger joint spacing 1800 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
76.6	37.1	126.4	44.5	(3)	-	18120
76.6	39.2	98.8	32.9	(5)	-	18570
76.5	39.8	95.6	31.4	(3)	-	17640
76.1	39.0	92.4	31.1	(3)	-	15510
75.7	38.9	54.8	18.6	(4)	-	15510
75.6	39.1	92.4	31.3	(5)	-	14790
75.5	38.5	92.0	31.7	(5)	-	17030
76.6	38.9	120.0	40.3	(3)	-	17850
76.4	39.3	77.4	25.8	(2)	-	17450
77.3	39.0	126.0	41.8	(3)	-	19000
75.4	39.0	113.0	38.4	(3)	-	17460
76.0	38.5	127.4	43.5	(4)	-	18810
75.9	38.9	128.2	43.4	(5)	-	16180
75.2	38.8	70.0	24.0	(4)	-	18610
75.9	39.0	105.0	35.5	(3)	-	15390
76.7	38.9	84.0	28.2	(3)	-	14000
76.5	39.2	104.8	34.9	(3)	-	15130
75.4	38.8	67.6	23.1	(3)	-	16460
76.4	38.5	78.4	26.7	(5)	-	16420
76.8	38.9	107.4	35.9	(3)	-	17700
73.2	38.8	138.2	48.7	(3)	-	18690
76.3	39.9	106.4	34.9	(3)	-	15330
75.3	38.7	96.8	33.2	(4)	-	15400
76.3	40.0	76.2	25.0	(3)	-	14240

76.0	39.1	80.4	27.1	(4)	-	15050
76.9	37.9	96.8	33.2	(5)	Failure through gum vein	14450
76.5	38.5	81.4	27.6	(5)	Failure through gum vein	15360
75.8	38.9	76.6	26.0	(4)	-	17770
76.0	38.8	132.0	44.8	(3)	-	17600
75.5	38.9	126.6	43.1	(3)	-	17590
76.0	39.0	34.2	11.5	(6)	-	14170
75.9	38.9	64.0	21.7	(6)	-	18880
76.1	38.6	105.0	35.7	(6)	-	17290
75.9	39.0	48.4	16.4	(6)	-	15340
74.3	38.4	98.2	34.4	(6)	-	15550
75.9	38.4	50.4	17.3	(6)	-	16180
75.5	38.7	94.4	32.3	(6)	-	18930
75.4	39.1	57.2	19.4	(6)	-	14000
76.5	39.0	85.6	28.7	(6)	-	15910
76.0	39.5	72.4	24.1	(6)	Failure through grain defect	15480
76.5	38.9	41.0	13.8	(6)	-	16780
		$f_{0.05}$	15.2		Mean MOE	16527
		Mean	30.8			
		$V_{t,lam}$	0.29			
		$f'_{t,lam}$	13.9			

1.4 Manufacturer B results

1.4.1 General details

Species	Adhesive	Finger profile (mm)	Nominal size (d x b) (mm)
Radiata pine	PRF	15 vertical	70 x 35

1.4.2 Finger joint spacing 300 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.8	35.9	59.4	23.4	(3)	-	16500
70.8	36.2	68.2	26.6	(4)	-	15790
69.6	35.6	65.2	26.3	(5)	-	14260
70.7	36.2	78.0	30.5	(3)	-	14560
70.0	35.8	40.4	16.1	(4)	-	16230
70.6	36.2	56.2	22.0	(4)	-	16050
70.6	36.1	57.0	22.4	(3)	-	15160
71.2	36.1	65.2	25.4	(4)	Knot at FJ	16310
70.1	36.3	33.6	13.2	(3)	Knot at FJ	14570
70.7	35.8	54.0	21.3	(3)	-	15660
70.3	36.4	45.0	17.6	(5)	-	16850

70.5	36.2	77.6	30.4	(5)	-	15700
70.9	35.9	37.2	14.6	(3)	-	16400
70.8	35.9	53.2	20.9	(3)	-	14290
70.2	35.8	49.4	19.7	(5)	-	16620
70.4	36.0	42.0	16.6	(3)	-	15800
70.6	35.6	44.2	17.6	(2)	-	17790
71.2	35.8	58.2	22.8	(4)	-	15710
70.2	35.4	63.0	25.4	(3)	-	16520
70.2	35.9	74.4	29.5	(4)	-	16560
70.1	35.7	61.4	24.5	(4)	-	14930
70.1	34.8	67.8	27.8	(3)	-	15440
70.6	35.9	61.2	24.1	(3)	-	14000
70.6	36.0	43.2	17.0	(4)	Knot at FJ	14910
70.9	35.9	63.6	25.0	(3)	-	14870
70.7	35.3	47.4	19.0	(3)	-	16040
70.3	35.5	70.4	28.2	(5)	-	15190
70.0	35.0	65.2	26.6	(4)	-	15760
69.7	35.2	65.6	26.7	(3)	-	16180
70.1	35.5	57.2	23.0	(5)	-	16160
70.7	36.6	49.2	19.0	(4)	-	17240
70.5	36.1	83.8	32.9	(3)	-	18040
70.5	35.7	68.2	27.1	(3)	-	16280
70.5	36.3	65.6	25.6	(5)	-	14120
70.6	35.5	54.8	21.9	(4)	-	16820
69.9	35.6	70.2	28.2	(3)	-	17280
70.4	35.2	76.8	31.0	(3)	-	15150
69.9	35.6	70.2	28.2	(3)	-	17280
70.4	35.2	76.8	31.0	(3)	-	15150
69.5	35.8	43.4	17.4	(6)	Failure through knot	15070
70.7	35.6	53.6	21.3	(6)	-	16810
71.5	36.4	55.2	21.2	(6)	-	15400
		$f_{0.05}$	15.3		Mean MOE	15826
		Mean	23.2			
		$V_{t,lam}$	0.21			
		$f'_{t,lam}$	14.4			

1.4.3 Finger joint spacing 600 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.6	36.0	83.6	32.9	(4)	-	15960
70.9	36.1	68.0	26.6	(4)	-	14000
70.6	35.9	68.8	27.1	(5)	-	15930
70.5	35.7	44.8	17.8	(5)	Failure initiated at knot	14800
70.5	35.6	72.0	28.7	(3)	-	17380

70.5	35.7	54.6	21.7	(5)	-	14100
70.4	35.9	61.6	24.4	(3)	-	14210
70.9	36.1	52.8	20.6	(3)	-	16190
70.9	35.5	98.0	38.9	(3)	-	16090
70.1	36.2	63.8	25.1	(4)	-	15430
70.4	35.9	39.8	15.7	(4)	Knot at FJ	14140
70.5	35.1	78.2	31.6	(5)	-	15880
70.5	35.4	86.2	34.5	(4)	-	14920
69.5	35.3	82.0	33.4	(5)	-	15530
70.5	35.8	40.2	15.9	(3)	Insufficient glue	17280
70.0	35.6	85.0	34.1	(3)	-	15150
70.8	35.0	45.0	18.2	(5)	-	14110
70.3	35.9	45.4	18.0	(5)	-	15450
70.8	34.8	77.0	31.3	(3)	-	16550
70.3	35.7	63.6	25.3	(4)	-	16460
70.8	35.6	31.6	12.5	(3)	Abnormal joint profile	14140
70.2	35.8	53.0	21.1	(5)	-	17720
70.5	35.3	67.6	27.2	(5)	-	16860
70.4	35.2	91.4	36.9	(3)	-	16900
70.9	35.9	115.6	45.4	(5)	-	16070
70.3	35.5	81.0	32.5	(4)	-	15440
71.1	35.6	68.6	27.1	(3)	-	17920
69.9	35.4	86.8	35.1	(5)	-	15900
70.6	35.2	81.2	32.7	(6)	Failure through knot	16740
70.4	36.2	45.6	17.9	(6)	Failure through knot	15290
70.4	35.5	63.8	25.5	(6)	-	14350
70.7	36.1	36.6	14.3	(6)	Failure at grain defect	18850
69.5	34.8	60.8	25.1	(6)	Failure through knot	14750
70.0	35.7	57.2	22.9	(6)	Failure through knot	15000
70.0	35.2	71.4	29.0	(6)	-	14000
69.9	35.3	56.2	22.8	(6)	Failure through knot	16060
69.4	35.0	92.0	37.9	(6)	Failure through knot	16090
70.4	36.0	59.8	23.6	(6)	Failure through knot	15190
69.0	35.6	82.2	33.5	(6)	Failure through knot	16060
70.5	35.2	74.2	29.9	(6)	Failure through knot	17850
		$f_{0.05}$	15.0		Mean MOE	15769
		Mean	26.9			
		$V_{t,lam}$	0.28			
		$f'_{t,lam}$	13.8			

1.4.4 Finger joint spacing 900 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.1	35.3	84.4	34.1	(3)	-	14470
69.8	34.9	63.8	26.2	(4)	-	16540

70.2	36.2	93.4	36.8	(3)	-	14850
71.1	36.1	72.2	28.1	(4)	-	16780
70.7	35.8	63.4	25.0	(5)	-	15270
70.4	35.9	90.2	35.7	(4)	-	15550
71.4	35.9	46.6	18.2	(5)	-	17700
71.1	35.9	68.8	27.0	(5)	-	17310
71.5	36.8	78.2	29.7	(3)	-	15080
70.3	35.2	73.0	29.5	(3)	-	17730
70.5	35.5	88.0	35.2	(4)	-	15310
70.6	35.4	58.8	23.5	(3)	-	16580
70.0	35.1	95.8	39.0	(5)	-	16200
70.1	35.6	72.2	28.9	(6)	Failure through knot	16860
70.7	35.4	72.4	28.9	(6)	-	16630
70.2	35.3	59.6	24.1	(6)	Failure through knot	16630
70.4	35.8	68.8	27.3	(6)	Failure in grips	15970
70.5	35.6	76.8	30.6	(6)	-	15680
70.9	36.0	77.2	30.2	(6)	Failure through knot	15330
70.6	35.8	71.6	28.3	(6)	Failure through knot	17000
70.4	35.9	67.4	26.7	(6)	Failure through knot	16220
71.1	35.8	79.4	31.2	(6)	-	17660
71.1	35.7	54.6	21.5	(6)	-	16150
70.9	35.2	51.4	20.6	(6)	Failure through knot	15760
70.7	35.4	75.8	30.3	(6)	Failure through knot	16890
71.0	35.9	103.0	40.4	(6)	Failure through knot	15980
71.3	36.3	59.8	23.1	(6)	Failure through knot	14870
70.4	36.2	72.2	28.3	(6)	Failure through knot	14000
70.6	35.8	102.8	40.7	(6)	Failure through knot	17600
70.8	36.8	87.0	33.4	(6)	Failure through multiple knots	14390
70.6	35.6	68.0	27.1	(6)	Failure through knot	16100
70.6	36.3	86.8	33.9	(6)	Failure through knot	17370
70.3	34.4	52.4	21.7	(6)	Failure through knot	17580
71.4	35.6	99.0	38.9	(6)	-	16250
70.8	35.7	43.6	17.2	(6)	Failure through knot	14510
70.2	35.3	77.8	31.4	(6)	Failure through grain defect	17610
71.1	36.0	66.0	25.8	(6)	-	16140
70.6	36.1	80.4	31.5	(6)	-	17850
69.5	34.9	56.4	23.3	(6)	Failure through knot	15120
71.6	36.2	63.6	24.5	(6)	Failure through knot	14310
		$f_{0.05}$	19.3		Mean MOE	16146
		Mean	28.9			
		$V_{t,lam}$	0.20			
		$f'_{t,lam}$	18.2			

1.4.5 Finger joint spacing 1200 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.4	35.6	86.0	34.3	(3)	-	Not available
71.1	35.7	64.8	25.5	(5)	-	
70.2	34.9	108.4	44.2	(3)	-	
70.2	35.6	58.4	23.4	(3)	-	
70.8	35.3	81.8	32.7	(3)	-	
69.6	35.7	58.0	23.3	(5)	-	
70.0	35.1	87.2	35.5	(3)	-	
70.4	35.5	84.4	33.8	(3)	-	
70.5	35.4	73.0	29.3	(5)	Failure initiated at knot	
70.2	34.9	60.2	24.6	(3)	Knot at FJ	
70.4	35.1	73.4	29.7	(3)	-	
71.1	35.4	60.8	24.2	(5)	-	
71.0	35.8	70.6	27.8	(5)	-	
71.2	35.8	83.8	32.9	(4)	-	
70.9	35.7	98.4	38.9	(3)	-	
71.0	35.8	74.0	29.1	(4)	-	
70.5	35.3	84.8	34.1	(3)	-	
69.7	34.9	103.8	42.7	(3)	-	
69.6	35.6	90.2	36.4	(3)	-	
71.2	35.5	88.8	35.1	(3)	-	
70.1	35.1	68.8	28.0	(3)	-	
70.1	35.0	70.6	28.8	(4)	-	
70.8	35.5	68.0	27.1	(4)	-	
71.1	36.1	65.4	25.5	(5)	-	
70.6	35.5	60.0	23.9	(5)	-	
71.2	35.7	67.2	26.4	(4)	-	
70.0	35.2	54.6	22.2	(4)	Knot at FJ	
71.2	35.7	60.4	23.8	(6)	Failure through knot	
71.2	35.6	86.0	33.9	(6)	Failure through knot	
70.9	35.6	43.2	17.1	(6)	Failure through knot	
70.7	35.4	51.2	20.5	(6)	Failure through knot	
70.6	35.3	81.6	32.7	(6)	Failure through knot	
69.6	35.3	85.0	34.6	(6)	Failure through knot	
69.7	34.9	72.6	29.8	(6)	Failure through knot	
70.5	35.9	88.6	35.0	(6)	Failure through knot	
70.7	35.5	91.2	36.3	(6)	Failure through knot	
71.1	36.1	74.8	29.1	(6)	Failure through knot	
71.7	36.3	65.2	25.1	(6)	Failure through multiple knots	
70.1	35.0	68.0	27.7	(6)	Failure through knot	
71.1	35.6	78.2	30.9	(6)	-	
		$f_{0.05}$	21.2		Mean MOE	

		Mean	29.9			
		$V_{t,lam}$	0.20			
		$f'_{t,lam}$	20.0			

1.4.6 Finger joint spacing 2100 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
69.5	35.8	72.8	29.3	(5)	Failure initiated at knot	16610
70.2	35.8	64.2	25.5	(3)	-	17030
70.3	36.4	101.4	39.6	(3)	-	14140
70.3	35.9	96.2	38.1	(3)	-	15860
70.2	35.9	70.2	27.9	(5)	-	14650
70.7	36.0	65.8	25.9	(5)	Failure initiated at knot	14870
70.8	36.1	61.0	23.9	(5)	-	17280
69.9	35.7	74.4	29.8	(4)	-	15160
69.6	35.3	52.6	21.4	(5)	Failure initiated at knot	14840
70.1	36.7	65.2	25.3	(6)	Failure through knot	16330
70.0	35.9	78.4	31.2	(6)	Failure through knot	15820
68.8	35.6	64.2	26.2	(6)	-	15580
69.5	36.0	62.4	24.9	(6)	-	15790
70.8	35.9	78.4	30.8	(6)	Failure through knot	15860
71.0	36.3	61.4	23.8	(6)	Failure through knot	14350
70.3	36.1	74.2	29.2	(6)	Failure through knot	14750
69.4	35.4	70.6	28.7	(6)	Failure through knot	16700
70.4	35.1	62.4	25.3	(6)	Failure through sloped grain	14560
70.9	36.3	70.6	27.4	(6)	-	14500
70.4	36.2	72.2	28.3	(6)	-	15010
70.1	35.4	64.2	25.9	(6)	Failure through grain defect	15770
70.7	36.1	68.6	26.9	(6)	-	14950
71.0	36.0	43.2	16.9	(6)	-	14450
70.7	36.4	61.0	23.7	(6)	Failure through knot	17180
70.4	36.1	54.6	21.5	(6)	-	15310
70.1	35.8	70.0	27.9	(6)	Failure through knot	16030
70.1	36.3	44.0	17.3	(6)	Failure through knot	15690
70.0	35.7	78.8	31.5	(6)	-	17290
71.0	35.8	67.8	26.7	(6)	Failure through knot	14420
70.9	36.0	85.4	33.5	(6)	-	16390
70.7	35.9	78.6	31.0	(6)	-	17350
69.8	35.7	92.6	37.2	(6)	-	15790
71.1	36.1	76.0	29.6	(6)	Failure through knot	14360
70.6	35.8	77.6	30.7	(6)	Failure in grips	15540
69.6	35.3	68.0	27.7	(6)	-	16690
70.8	36.3	65.6	25.5	(6)	Failure through knot	15380
69.6	35.3	69.0	28.1	(6)	Failure through knot	15890

71.6	35.8	62.6	24.4	(6)	Failure through knot	14910
70.5	35.8	74.8	29.6	(6)	Failure through knot	14880
70.8	35.7	65.4	25.9	(6)	Failure through knot	14510
		$f_{0.05}$	19.4		Mean MOE	15562
		Mean	27.6			
		$V_{t,lam}$	0.17			
		$f'_{t,lam}$	18.4			

1.5 Manufacturer C Series 1 results

1.5.1 General details

Species	Adhesive	Finger profile (mm)	Nominal size (d x b) (mm)
Slash pine	PRF	20 vertical	70 x 35

Manufacturer C produced two series of test data.

1.5.2 Finger joint spacing 1200 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
69.9	35.8	56.6	22.6	(3)	-	18000
70.1	35.0	42.8	17.4	(5)	Failure initiated at knot	16830
70.4	35.6	54.8	21.9	(4)	-	16630
70.7	35.4	49.8	19.9	(4)	-	14000
70.0	35.5	67.2	27.0	(4)	Knot at FJ	16420
70.9	36.1	84.2	32.9	(4)	-	14370
70.6	36.0	60.4	23.8	(5)	Failure initiated at knot	17900
70.0	35.3	63.4	25.7	(5)	-	17690
70.4	35.4	60.6	24.3	(3)	-	17710
70.4	35.2	62.6	25.3	(3)	-	15760
70.7	35.3	40.2	16.1	(3)	-	17980
69.9	35.6	58.0	23.3	(3)	-	14930
70.7	35.4	47.6	19.0	(4)	-	15330
70.8	35.4	46.2	18.4	(5)	-	16850
70.3	35.4	54.4	21.9	(5)	-	15500
69.6	34.9	70.4	29.0	(3)	-	16500
71.0	35.9	57.2	22.4	(4)	-	17870
70.7	35.8	65.4	25.8	(3)	-	16420
70.7	35.8	36.0	14.2	(4)	Knot at FJ	17040
70.6	35.3	49.8	20.0	(5)	Failure initiated at knot	17470
70.5	35.4	45.0	18.0	(3)	-	15140
69.9	35.2	63.6	25.8	(3)	-	15900
70.3	35.5	46.2	18.5	(4)	-	17140

70.8	35.9	54.4	21.4	(3)	-	16050
70.6	35.4	51.2	20.5	(4)	-	17070
69.4	35.4	56.8	23.1	(3)	-	16750
70.0	35.3	53.6	21.7	(4)	-	16810
70.1	35.5	62.6	25.2	(3)	-	16280
70.4	35.4	89.2	35.8	(3)	-	17030
70.2	35.7	75.4	30.1	(3)	-	16030
70.7	35.7	86.6	34.3	(3)	-	16390
70.1	35.2	76.4	31.0	(4)	-	15340
70.5	35.3	59.6	23.9	(5)	-	17800
70.2	35.5	70.8	28.4	(4)	-	16150
70.3	35.4	58.4	23.5	(3)	-	15210
70.3	35.6	46.4	18.5	(6)	Failure through knot	16900
70.4	35.7	49.0	19.5	(6)	Failure through multiple knots	16520
69.9	35.4	53.6	21.7	(6)	Failure through knot	16000
70.9	35.6	42.2	16.7	(6)	Failure through knot	14330
70.7	35.5	52.4	20.9	(6)	Failure through knot	15260
		$f_{0.05}$	16.4		Mean MOE	16399
		Mean	23.2			
		$V_{t,lam}$	0.21			
		$f'_{t,lam}$	15.4			

1.5.3 Finger joint spacing 1500 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.5	35.6	49.0	19.5	(3)	-	14010
70.0	35.1	89.0	36.2	(3)	-	16640
70.4	35.4	64.4	25.8	(4)	-	14950
69.4	35.0	31.0	12.8	(2)	-	14600
70.8	36.2	28.6	11.2	(1)	-	16620
69.1	35.1	16.8	6.9	(2)	-	17380
69.9	34.8	24.0	9.9	(3)	-	16980
70.6	35.0	28.2	11.4	(3)	-	16160
70.2	35.2	24.8	10.0	(3)	-	17980
70.7	35.2	23.6	9.5	(2)	-	16120
70.0	34.8	25.4	10.4	(3)	-	15680
70.5	35.1	24.4	9.9	(3)	-	15410
70.7	35.3	23.8	9.5	(2)	-	16720
69.2	35.0	21.4	8.8	(5)	-	14610
70.0	35.2	31.0	12.6	(3)	-	18000
70.5	35.4	28.8	11.5	(3)	-	15780
70.3	35.5	22.4	9.0	(2)	-	16790
69.5	34.7	36.2	15.0	(2)	-	15040
70.5	35.1	11.4	4.6	(1)	-	16850

70.0	34.5	23.4	9.7	(2)	-	17570
69.9	34.6	21.2	8.8	(2)	-	15310
70.8	35.4	34.4	13.7	(3)	-	14050
69.7	35.4	29.0	11.8	(3)	-	16220
69.7	35.0	30.2	12.4	(3)	-	16720
70.4	34.9	29.0	11.8	(3)	-	15330
69.7	34.9	23.0	9.5	(2)	-	15480
70.1	35.3	30.4	12.3	(3)	-	14560
70.3	35.2	27.2	11.0	(2)	-	16270
70.7	35.0	28.0	11.3	(2)	-	16180
70.5	35.4	30.8	12.3	(3)	-	17900
70.4	35.5	32.6	13.0	(3)	-	15590
69.7	34.9	27.6	11.3	(3)	-	16920
70.3	35.0	18.8	7.6	(1)	-	16760
69.6	34.7	31.0	12.8	(2)	-	16480
70.5	35.4	29.6	11.9	(1)	-	17230
70.3	35.3	29.8	12.0	(2)	-	16290
70.4	35.7	11.2	4.5	(1)	-	14040
70.0	35.5	22.6	9.1	(1)	-	16760
8	-	-	-	-	Failed prior to testing	
26	70.2	35.5	0.0	(1)	Failed prior to loading	
		$f_{0.05}$	5.4		Mean MOE	16105
		Mean	11.9			
		$V_{t,lam}$	0.46			
		$f'_{t,lam}$	4.7			

1.5.4 Finger joint spacing 1800 mm (Specimens not straight)

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.3	35.6	77.6	31.0	(4)	-	17820
68.6	34.9	51.4	21.5	(5)	Failure initiated at knot	15620
69.7	35.4	84.0	34.0	(3)	-	17910
70.4	35.4	72.8	29.2	(5)	-	14690
70.7	34.9	25.4	10.3	(1)	Insufficient glue	14810
70.3	35.6	14.2	5.7	(1)	-	18000
70.7	35.8	34.4	13.6	(2)	-	16190
70.9	35.5	34.6	13.7	(3)	-	15060
70.8	35.9	23.6	9.3	(1)	Insufficient glue	15560
69.9	34.7	21.4	8.8	(1)	Insufficient glue	18000
70.2	35.6	29.6	11.8	(2)	-	17460
70.6	35.6	31.8	12.7	(2)	-	17410
71.1	35.6	23.6	9.3	(2)	-	17630
70.7	35.6	22.2	8.8	(2)	-	16790
70.6	35.6	29.4	11.7	(2)	-	17530

70.9	35.5	25.2	10.0	(1)	-	17010
70.2	35.7	27.6	11.0	(2)	-	15010
70.6	35.7	21.2	8.4	(2)	-	15140
69.0	35.7	30.8	12.5	(1)	-	14000
70.3	35.5	23.6	9.5	(2)	-	17770
69.3	34.5	31.4	13.1	(2)	-	17680
69.4	35.2	10.6	4.3	(1)	Insufficient glue	15080
69.7	35.0	23.6	9.7	(2)	-	16980
71.1	35.6	32.0	12.6	(2)	-	16080
70.6	35.6	22.6	9.0	(1)	-	15990
70.7	35.3	23.4	9.4	(3)	-	15440
71.0	35.6	32.6	12.9	(2)	Insufficient glue	16450
70.4	35.5	39.2	15.7	(3)	-	15990
70.5	35.6	28.0	11.2	(2)	-	16520
69.8	35.1	28.6	11.7	(2)	-	16990
69.4	35.0	28.6	11.8	(2)	-	15290
69.8	35.9	32.8	13.1	(2)	-	17710
70.2	35.4	36.4	14.6	(3)	-	17120
70.4	35.7	24.6	9.8	(2)	-	17870
69.9	35.5	29.4	11.8	(3)	-	14280
70.1	35.4	29.6	11.9	(2)	-	16100
70.4	35.5	53.0	21.2	(6)	Failure through knot	14630
70.3	35.6	51.0	20.4	(6)	Failure through knot	14700
70.2	35.1	67.0	27.2	(6)	Failure through knot	15320
69.8	35.6	45.0	18.1	(6)	Failure through knot	14670
		$f_{0.05}$	7.0		Mean MOE	16258
		Mean	13.8			
		$V_{t,lam}$	0.48			
		$f'_{t,lam}$	6.1			

1.5.5 Finger joint spacing 2100 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
70.6	35.6	28.2	11.2	(2)	-	14840
71.4	35.3	27.4	10.9	(2)	-	17220
70.5	36.2	24.2	9.5	(1)	-	14500
70.2	35.0	23.2	9.4	(2)	-	15280
69.9	35.1	28.4	11.6	(2)	-	17110
70.4	35.7	29.0	11.5	(2)	-	15180
70.9	35.7	30.6	12.1	(2)	-	15110
70.6	35.6	25.4	10.1	(2)	-	15250
70.5	35.5	24.0	9.6	(2)	-	15250
70.2	35.4	29.2	11.8	(2)	-	18000
70.8	35.8	23.8	9.4	(1)	-	17040

69.9	35.9	28.0	11.2	(2)	-	15090
71.0	35.8	28.6	11.3	(2)	-	16590
71.1	35.7	31.4	12.4	(2)	-	17970
70.0	35.5	35.0	14.1	(2)	-	16380
70.8	35.9	23.8	9.4	(2)	-	16850
70.2	35.5	35.0	14.0	(2)	-	15650
70.7	35.5	24.8	9.9	(2)	-	18000
70.2	35.4	31.8	12.8	(2)	-	17400
70.3	35.5	22.6	9.1	(3)	-	16660
70.6	35.7	29.8	11.8	(2)	-	17570
69.9	35.2	24.6	10.0	(2)	-	17750
70.9	36.0	27.8	10.9	(2)	-	16580
70.5	36.0	24.8	9.8	(2)	-	15730
69.5	35.1	32.4	13.3	(2)	-	16100
70.2	35.3	27.6	11.1	(2)	-	16030
70.0	35.1	34.0	13.8	(3)	-	17470
69.4	35.6	24.2	9.8	(2)	-	14000
70.5	35.8	33.2	13.2	(2)	-	15080
69.6	35.5	30.6	12.4	(2)	-	14010
70.4	35.6	22.8	9.1	(1)	-	16110
70.7	35.7	27.6	10.9	(2)	-	17930
70.5	35.7	22.2	8.8	(3)	Insufficient glue	14490
69.9	35.7	26.4	10.6	(2)	-	15750
70.3	35.1	29.8	12.1	(2)	-	16110
70.7	36.0	57.2	22.5	(6)	Failure through knot	18000
69.9	35.4	82.8	33.5	(6)	Failure through knot	17990
70.0	35.6	80.4	32.3	(6)	Failure through knot	16950
70.0	35.4		0.0	(1)	Failure prior to testing (insufficient glue)	16890
71.1	35.7		0.0	(2)	Failure prior to testing	17310
		$f_{0.05}$	4.4		Mean MOE	16331
		Mean	11.9			
		$V_{t,lam}$	0.50			
		$f'_{t,lam}$	3.8			

1.6 Manufacturer C Series 2 results

1.6.1 Finger joint spacing 1200 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
36.9	72.6	79.0	29.5	3		Data not availabl e
37.1	73.2	48.0	17.7	5		
36.8	72.4	81.0	30.4	5		
37.3	72.8	82.0	30.2	5		
36.6	73.0	80.5	30.1	3		

37.1	73.1	81.0	29.9	5	
36.6	72.0	51.0	19.4	3	
37.7	72.4	89.0	32.6	3	
36.3	72.7	44.0	16.7	3	
37.9	73.5	73.0	26.2	5	
36.5	72.4	46.5	17.6	5	
36.3	71.9	62.0	23.8	5	
37.6	72.9	80.5	29.4	5	
36.6	72.0	110.0	41.8	4	
35.9	71.4	103.0	40.2	3	
37.1	72.8	34.0	12.6	3	
36.5	73.0	48.0	18.0	3	
36.9	72.7	80.5	30.0	3	
36.4	72.0	48.0	18.3	4	
36.8	71.6	53.5	20.3	3	
35.6	71.6	40.0	15.7	1	
36.8	71.7	37.0	14.0	2	
36.9	72.4	44.0	16.5	3	
36.0	71.7	87.5	33.9	4, 5	Failed at 2 FJ's
36.6	71.8	115.0	43.8	4	
37.1	72.2	48.5	18.1	5	
35.5	70.8	46.0	18.3	3	
35.5	71.9	61.5	24.1	5	
35.3	70.8	54.5	21.8	5	
36.5	72.0	40.0	15.2	3	
36.1	71.7	55.5	21.4	5	
35.8	71.2	72.0	28.3	4	
35.7	71.7	51.5	20.1	3	
36.2	71.4	73.5	28.4	5	
37.1	73.2	48.0	17.7	5	
36.8	72.4	81.0	30.4	5	
37.3	72.8	82.0	30.2	5	
36.8	72.6	74.0	27.7	6	Knot failure
37.1	73.1	81.0	29.9	5	
37.9	73.5	73.0	26.2	5	
36.5	72.4	46.5	17.6	5	
36.3	71.9	62.0	23.8	5	
37.6	72.9	80.5	29.4	5	
37.4	73.4	71.0	25.9	5	Knot near FJ
36.2	71.2	77.0	29.9	6	Knot failure
36.6	71.3	73.5	28.2	6	Knot failure
35.7	71.7	46.5	18.1	6	Knot failure
36.1	70.9	54.5	21.3	5	Failure initiated by knot
36.1	71.3	63.0	24.5	5	Failure initiated by knot
35.4	71.3	28.5	11.3	6	Knot failure
36.1	71.4	130.0	50.4	6	Knot failure

35.3	70.4	53.0	21.3	6	Knot failure	
36.2	71.2	64.5	25.1	6	Knot failure	
		$f_{0.05}$	13.3			
		Mean	24.7			
		$V_{t,lam}$	0.35			
		$f'_{t,lam}$	12.0			

1.6.2 Finger joint spacing 1500 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
37.0	71.2	62.0	23.6	5		Data not available
36.4	72.3	54.0	20.5	3		
37.5	72.1	38.5	14.3	2		
36.1	72.4	57.0	21.8	5		
36.3	71.3	34.0	13.2	2		
36.9	71.9	51.0	19.2	2		
37.3	72.5	38.5	14.2	2		
37.0	72.2	49.5	18.5	3		
36.3	71.9	66.0	25.3	5		
36.7	70.9	53.0	20.4	3		
37.5	72.2	51.5	19.0	3		
36.9	72.6	66.0	24.6	3	Knot near FJ	
37.0	71.7	58.5	22.1	3		
35.8	71.6	53.0	20.6	3		
37.5	71.8	52.0	19.3	4		
37.0	71.8	49.5	18.6	3		
37.4	72.4	51.0	18.9	2		
36.1	71.8	39.5	15.2	5		
36.6	72.5	71.5	27.0	5		
36.5	72.3	51.0	19.3	5		
36.9	72.2	55.5	20.9	3		
35.9	71.5	61.0	23.8	4		
36.92	72.8	60.5	22.5	4		
36.3	72.1	78.0	29.8	4		
35.9	71.4	105.5	41.2	4, 3	Failed at 2 FJ's	
36.0	70.9	74.5	29.2	3		
37.4	72.1	46.0	17.0	6	Knot failure	
37.1	72.3	64.0	23.9	6	Knot failure	
37.6	73.1	53.5	19.5	5	Failure initiated by knot	
37.0	72.0	60.5	22.7	6	Knot failure	
36.57	71.9	54.0	20.5	6	Knot failure	
36.97	72.2	87.5	32.8	6	Knot failure	
36.1	71.3	67.5	26.2	5	Failure initiated by knot	
37.4	72.4	66.0	24.4	6		

36.7	72.3	88.5	33.4	6	Knot failure	
37.3	72.8	62.0	22.8	6	Knot failure	
36.7	71.6	42.0	16.0	6	Knot failure	
36.4	71.1	80.0	30.9	6	Knot failure	
35.9	71.6	59.0	23.0	6	Knot failure	
36.3	71.5	63.0	24.3	6	Knot failure	
		$f_{0.05}$	14.3			
		Mean	22.5			
		$V_{t,lam}$	0.25			
		$f'_{t,lam}$	13.2			

1.6.3 Finger joint spacing 1800 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
36.0	70.6	83.5	32.9	4		Data not available
37.4	70.9	74.5	28.1	5		
36.2	71.0	34.5	13.4	3		
35.6	70.7	61.0	24.2	3		
36.8	71.4	49.0	18.6	3		
35.9	71.0	70.5	27.7	5		
36.4	70.8	95.5	37.0	4		
35.6	70.5	48.0	19.1	3		
35.5	70.6	60.5	24.2	5		
35.4	71.0	59.5	23.7	5		
36.8	71.1	43.0	16.4	3		
35.5	70.8	74.5	29.6	4		
35.6	70.7	71.5	28.4	3		
36.3	71.4	73.5	28.4	5		
35.5	71.1	68.5	27.1	4		
35.9	71.1	90.5	35.5	3		
37.1	71.9	68.0	25.5	2		
35.8	71.2	102.0	40.0	3		
35.7	70.7	84.5	33.5	3		
35.9	71.4	84.5	33.0	5		
37.1	71.9	83.5	31.3	4		
35.2	72.0	77.5	30.6	4		
35.4	71.3	89.5	35.4	3		
36.3	70.3	54.0	21.2	5	Failure initiated by knot	
36.1	70.9	79.0	30.9	5	Failure initiated by knot	
36.9	71.3	50.0	19.0	6	Knot failure	
36.2	70.6	75.5	29.6	6	Knot failure	
35.7	70.5	67.0	26.6	6	Knot failure	
36.2	71.2	72.0	28.0	6	Knot failure	
36.8	71.6	61.0	23.2	6	Knot failure	

35.1	70.6	62.5	25.2	6	Knot failure	
35.4	70.3	46.5	18.7	6	Knot failure	
35.8	71.1	47.0	18.5	6	Knot failure	
35.8	70.9	67.0	26.4	6	Knot failure	
36.6	71.5	93.0	35.6	5	Failure initiated by knot	
35.9	71.1	89.0	34.8	6	Knot failure	
35.4	70.7	62.5	25.0	6	Knot failure	
35.4	71.1	70.0	27.8	6	Knot failure	
36.2	71.5	73.5	28.4	5	Failure initiated by knot	
36.0	71.2	52.0	20.3	6	Timber failure	
35.7	71.0	58.5	23.1	6	Knot failure	
		$f_{0.05}$	17.5			
		Mean	27.0			
		$V_{t,lam}$	0.23			
		$f'_{t,lam}$	16.4			

1.6.4 Finger joint spacing 2100 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
36.1	71.5	57.5	22.3	3		
35.8	71.6	80.5	31.5	4		
36.3	71.3	58.5	22.6	5		
36.6	72.4	83.0	31.3	3		
36.4	71.5	60.0	23.1	5		
36.3	71.8	73.5	28.2	5		
37.6	72.1	73.5	27.2	5		
35.9	71.2	78.5	30.7	4		
36.3	71.6	76.5	29.4	5		
35.8	71.4	64.5	25.2	5		
36.7	72.2	89.5	33.8	3		
36.9	71.6	91.5	34.7	4		
36.1	70.8	58.5	22.9	3		
35.7	70.9	63.0	24.9	3		
37.0	72.5	64.5	24.1	3		
36.4	72.5	65.5	24.9	3		
35.7	71.2	78.5	30.9	5		
35.9	71.6	61.5	23.9	3		
35.6	71.0	63.5	25.1	4		
36.0	71.0	66.5	26.0	5		
36.9	72.4	51.0	19.1	3		
35.9	71.6	80.5	31.3	5		
35.8	70.9	79.5	31.4	5		
36.3	71.5	51.5	19.9	5		
36.8	72.0	53.0	20.0	3		Data not available

35.9	70.8	69.5	27.4	5		
35.9	71.2	65.0	25.4	4		
35.2	70.6	54.0	21.8	3		
35.8	70.9	49.0	19.3	5		
35.4	71.0	75.0	29.9	5		
35.6	71.1	77.0	30.4	4		
37.3	72.4	54.5	20.2	4		
36.0	71.0	62.0	24.2	3		
35.4	70.6	86.0	34.4	4		
35.9	70.7	65.0	25.6	5		
37.3	72.7	60.5	22.3	3		
36.3	71.5	75.0	28.9	6	Knot failure	
36.6	72.4	54.0	20.4	6	Knot failure	
35.6	71.0	79.0	31.3	6	Knot failure	
36.3	71.2	51.0	19.8	6	Knot failure	
35.5	70.4	75.5	30.2	6	Knot failure	
35.9	71.0	66.0	25.9	6	Knot failure	
35.2	70.4	51.5	20.8	6	Knot failure	
		$f_{0.05}$	19.6			
		Mean	26.1			
		$V_{t,lam}$	0.17			
		$f'_{t,lam}$	18.7			

1.7 Manufacturer D results

1.7.1 General details

Species	Adhesive	Finger profile (mm)	Nominal size (d x b) (mm)
Radiata pine	PRF	20 vertical	70 x 30

1.7.2 Finger joint spacing 900 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
29.9	75.2	25.5	11.3	5		
30.0	75.3	29.0	12.8	1		
29.5	75.0	48.0	21.7	4		
29.6	75.1	53.0	23.8	1, 4	2 FJ Failures	
30.0	75.3	53.5	23.7	4	Knot in FJ	
30.0	75.4	31.5	14.0	4	Knot in FJ	
30.0	74.9	39.5	17.6	3		
30.0	75.1	21.5	9.5	3		
30.0	75.0	35.5	15.8	3		
30.0	75.1	46.0	20.5	4, 6	2 failure, one influenced by knot	

30.0	75.0	34.0	15.1	4	Knot in FJ	
29.8	75.0	43.0	19.2	4		
29.9	75.1	38.0	16.9	2		
29.9	75.0	43.0	19.2	1, 6	2 failures	
30.0	74.9	32.5	14.5	3		
30.0	75.0	23.5	10.4	3		
29.9	75.0	41.5	18.5	3		
30.0	75.1	43.5	19.3	3		
30.0	75.0	32.5	14.4	3		
29.9	74.9	28.5	12.7	5		Data not available
30.0	75.2	10.0	4.4	1	Knot in FJ	
30.0	75.0	36.0	16.0	4	2 failures	
29.9	75.0	35.5	15.8	4, 6	2 failures, 1 in grips	
30.1	74.9	46.5	20.6	4	2 FJ Failures	
30.0	74.9	37.0	16.5	3		
29.8	75.0	30.5	13.6	3		
30.1	75.0	35.0	15.5	2		
30.0	75.1	22.0	9.8	6		
30.1	75.0	29.0	12.9	3		
29.9	75.0	10.0	4.5	1		
29.7	75.0	41.0	18.4	6	Knot	
30.0	75.3	30.5	13.5	6	Knot	
29.9	75.1	46.5	20.7	6		
30.0	75.5	51.0	22.5	5, 6	2 failures, both knot influenced	
29.9	75.0	43.0	19.2	6	2 knot failures	
29.9	75.5	35.5	15.7	5	Knot influenced	
30.1	75.1	23.5	10.4	6	Knot	
30.0	74.9	41.0	18.3	6	Knot	
29.9	75.0	41.0	18.3	6	Knot	
29.9	75.0	54.0	24.1	6	Grip failure	
29.7	74.8	22.0	9.9	6	Knot	
30.1	75.1	43.5	19.3	6	Knot	
30.1	74.9	42.5	18.8	6	Knot	
30.0	75.2	39.0	17.3	6	Grip failure, knot	
29.8	75.0	30.5	13.7	6	Knot	
29.9	75.0	29.5	13.1	6	Knot	
30.0	75.0	39.5	17.6	6	Knot	
30.0	74.9	30.5	13.6	6	Knot	
		$f_{0.05}$	9.0			
		Mean	15.9			
		$V_{t,lam}$	0.28			
		$f'_{t,lam}$	8.4			

1.7.3 Finger joint spacing 1200 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)

30.0	75.2	30.5	13.5	1	2 FJ failures	
29.9	75.0	< 10	0.0	5	Rogue piece of timber	
30.0	75.1	39.5	17.5	3		
29.9	75.2	< 10	0.0	1	Rogue FJ	
30.0	75.0	31.5	14.0	3	2 FJ failures	
30.1	75.4	36.5	16.1	3		
30.0	75.1	28.5	12.7	1		
29.9	75.2	49.0	21.8	1		
30.1	75.4	< 10	0.0	1	Rogue FJ	
30.0	75.2	23.5	10.4	1		
30.1	75.1	32.0	14.2	1		
30.2	75.2	37.0	16.3	1		
30.2	74.9	26.0	11.5	1		
30.0	75.1	< 10	0.0	3	Rogue FJ	
30.0	75.0	37.0	16.4	1		
30.4	75.4	45.5	19.8	1		
30.0	75.2	42.0	18.6	3		
29.8	75.1	39.0	17.5	1		
29.9	75.3	28.0	12.4	1		
30.0	75.0	43.0	19.1	1, 3	2 FJ failures	
30.1	75.4	43.0	18.9	3		
30.3	75.1	35.0	15.4	1		
30.0	75.1	42.5	18.9	1		
30.3	75.6	< 10	0.0	3	Rogue FJ	
30.2	75.2	37.5	16.5	3		
30.0	75.2	33.0	14.6	3		
29.9	75.1	30.5	13.6	1, 6	2 failures, one at knot	
30.0	75.0	35.5	15.8	1		
29.8	75.0	48.5	21.7	1, 4	2 FJ failures	Data not available
30.0	75.2	50.5	22.4	1, 4	2 FJ failures	
30.0	75.1	< 10	0.0	1	Rogue FJ	
30.0	75.0	45.5	20.2	1		
30.0	75.3	28.0	12.4	4		
30.0	75.0	45.5	20.2	3		
30.0	75.1	46.0	20.4	1, 6	2 failures, one at knot	
29.9	74.8	32.0	14.3	1		
30.0	75.1	< 10	0.0	1	Rogue FJ	
30.0	75.1	42.0	18.7	3		
30.0	75.2	26.5	11.7	1		
29.7	75.1	31.5	14.1	1		
30.0	75.0	20.5	9.1	3	Knot in FJ	
30.0	75.0	37.5	16.7	1		
30.1	75.0	26.0	11.5	6		
30.2	75.2	28.0	12.4	6	Knot failure	
29.9	75.2	27.0	12.0	5	Knot near FJ	

29.9	75.3	27.0	12.0	6	Failure in grips - knot	
30.0	75.1	< 10	0.0	6	Knot failure (Rogue piece of timber)	
30.0	75.6	53.5	23.6	6	Knot	
		$f_{0.05}$	0.0			
		Mean	6.9			
		$V_{t,lam}$	0.52			
		$f'_{t,lam}$	0.0			

1.7.4 Finger joint spacing 2000 mm

b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Comments	MOE (MPa)
30.0	75.1	30.5	13.6	5		Data not availabl e
30.2	74.6	27.0	12.0	1		
29.9	74.8	55.0	24.6	3		
29.9	75.0	29.5	13.1	4		
30.2	75.2	45.0	19.9	2		
29.9	74.8	36.5	16.3	3		
30.1	75.2	44.0	19.4	6		
30.0	75.2	25.5	11.3	2		
30.0	75.0	20.0	8.9	1		
30.0	75.0	55.5	24.7	1, 3	2 failures	
30.0	75.0	29.0	12.9	3		
30.0	75.1	10.0	4.4	2, 6	2 failures	
30.0	75.0	32.0	14.2	4		
29.9	74.7	45.0	20.2	3, 4	2 failures	
30.1	75.1	64.5	28.6	4		
30.0	75.0	30.5	13.5	3		
30.1	75.1	38.5	17.0	4	Knot near FJ	
30.1	75.0	38.0	16.9	3		
30.0	75.0	36.0	16.0	4, 5, 6	3 failures	
29.9	75.1	46.5	20.7	1		
30.0	75.0	55.5	24.7	5		
30.0	75.1	30.0	13.3	2		
29.9	75.1	25.5	11.4	3		
30.1	75.0	47.5	21.0	6	Knot	
30.0	75.2	39.0	17.3	6	Knot	
30.0	75.1	29.5	13.1	6	Knot	
30.0	74.7	50.0	22.3	6	Knot	
30.0	75.1	43.5	19.3	6	Knot	
30.1	75.3	57.0	25.2	6	Knot	
30.0	75.1	24.0	10.6	6	Knot	
30.0	75.2	24.5	10.8	6	Knot	
30.0	74.9	26.0	11.6	6	Knot	

30.0	74.8	10	10.0	6	Knot	
30.0	75.2	52.0	23.1	6	Knot	
30.0	75.1	41.0	18.2	6	Knot	
30.1	75.0	30.5	13.5	6	Knot	
30.2	74.9	10	10.0	6	Knot	
30.0	75.0	26.5	11.8	6	Knot	
30.0	75.0	51.5	22.9	6	Knot	
30.1	75.0	47.5	21.1	6		
30.0	75.0	33.5	14.9	6	Knot	
30.0	75.0	30.5	13.6	6	Knot	
30.1	74.9	40.5	17.9	6	Knot	
29.9	74.9	31.5	14.1	6	Knot	
29.9	75.0	33.5	14.9	6	Knot	
30.1	75.0	53.5	23.7	6	Knot	
30.0	75.1	36.0	16.0	6	2 failures, both Knot influenced	
29.9	75.0	41.0	18.3	6	Knot	
30.0	75.2	25.0	11.1	6	Knot	
29.9	75.0	34.0	15.1	6	Knot	
		$f_{0.05}$	4.5			
		Mean	16.2			
		$V_{t,lam}$	0.34			
		$f'_{t,lam}$	4.1			

Glulam tension results

1.8 Manufacturer A tension results

Member detail	Adhesive	Finger joint profile	Finger joint spacing	Grip spacing
Vic Ash A17 - Glulam - 5 Laminations @ ~32mm	PUR	15mm vertical	1100 mm	3800mm

ID	b	d	Pmax	Tension	Mode of Failure
	(mm)	(mm)	(kN)	(MPa)	
17	45.2	179.7	190.5	23.5	FJ failure in 1st, 5th laminations; also knot in FJ in 5th
7	45.2	179.6	195.5	24.1	FJ failure in top lamination
26	45.5	179.6	204.0	25.0	Knot failure in 1st lam and 5th. FJ failure in lams 2, 3, 4
18	45.1	179.2	214.5	26.5	FJ failure in 1st, 3rd and 4th laminations
23	45.3	179.8	219.5	26.9	FJ failure near grips - in 1st, 2nd, 3rd and 5th laminations
4	45.4	179.5	225.5	27.7	Knot in bottom lamination
22	45.3	179.9	243.5	29.9	FJ failure in bottom lamination
1	45.0	179.2	248.0	30.8	FJ failure in top and bottom lams,
11	45.1	179.4	253.5	31.3	FJ failure in 2nd, 3rd laminations
8	45.1	179.1	254.5	31.5	FJ failure in top lamination
13	45.1	179.3	266.0	32.9	FJ failure in 1st, 3rd, 4th and 5th laminations
9	45.2	179.2	271.0	33.5	FJ failure in 3rd, 4th and 5th laminations
16	45.1	179.4	275.0	34.0	FJ failure in 1st lam, Knot failure in 2nd lamination
28	45.3	179.3	280.0	34.5	FJ failure in 4th, 5th laminations.
5	45.5	179.5	289.0	35.4	FJ failure in 1st, 2nd laminations
29	45.3	179.5	293.5	36.1	FJ failure in 1st, 2nd, 4th, 5th lams - Knot failure 3rd lam
21	45.2	178.7	292.0	36.2	FJ failure in 1st, 2nd laminations
14	45.5	179.3	297.5	36.5	Knot failure in 1st lam, FJ failure in 2nd, 3rd laminations
2	45.5	179.8	300.0	36.7	Failure near grips - FJ failure in 1st, 4th laminations
19	45.0	179.4	297.0	36.8	FJ failure in 1st, 4th, 5th laminations.
25	45.7	179.8	306.5	37.3	FJ failure in 1st, 4th and 5th laminations
6	45.6	179.8	310.0	37.8	FJ failure in all laminations
15	45.3	179.8	316.5	38.9	FJ failure in all laminations
30	45.5	179.3	323.0	39.6	FJ failure in 1st, 4th and 5th laminations
3	45.3	180.0	330.5	40.5	FJ failure in 3rd lamination
27	45.3	179.7	331.0	40.7	FJ failure in 1st, 2nd, 4th, 5th lams, Knot failure in 3rd
20	45.3	179.8	348.5	42.8	Failure near grips - FJ failure in 2nd, 3rd laminations
10	45.3	179.3	348.0	42.8	FJ failure in 2nd, 3rd laminations
24	45.3	180.0	374.5	45.9	FJ failure in 1st, 2nd, 4th, 5th lams. Knot in FJ in 1st lam

Summary Manufacturer A tension

Number of	Mean tension	Coefficient of variation,	Characteristic tension strength,

specimens	strength (MPa)	$V_{t,glulam}$ (%)	f_k (75% tol) (MPa)
30	**34.8**	**18.0**	**22.6**

1.9 Manufacturer B glulam tension results

Member detail	Adhesive	Finger joint profile	Finger joint spacing	Grip spacing
Radiata Pine MGP15 - Glulam - 5 Laminations @ ~32mm	PRF	15mm vertical	1000 mm	3820mm

ID	b	d	Pmax	Tension	Mode of Failure	Min FJ
	(mm)	(mm)	(kN)	(MPa)		Spacing (mm)
1	50.0	159.9	320.5	40.1	FJ failure in all laminations	250
2	49.9	160.7	341.0	42.5	FJ (1,2,5), Timber (3,4)	<10
3	50.0	160.3	243.5	30.4	FJ (3,4,5), Timber (1,2)	200
4	50.2	160.0	382.0	47.6	FJ (1,2,3), Timber (4,5)	<10
5	50.0	160.0	304.0	38.0	FJ (3,4,5), Timber (1,2)	350
6	50.1	159.9	255.0	31.8	FJ (4), Timber (1,2,3,5)	100
7	50.0	161.2	298.0	37.0	FJ (3,4), Timber (1,2,5)	100
8	49.9	160.2	309.0	38.7	FJ (1,3,4), Timber (2,5)	300
9	49.9	160.3	310.5	38.8	FJ (3,5), Timber (1,2,4)	150
10	50.1	160.7	331.0	41.1	FJ (1,2,3,5), Timber (4)	200
11	50.1	160.4	269.0	33.5	FJ (3,5), Timber (1,2,4)	400
12	49.9	160.1	272.5	34.1	FJ (1,2,4), Timber (3,5)	150
13	50.0	159.8	354.5	44.4	FJ (1,2,3,5), Timber (4)	80
14	49.9	160.6	306.5	38.2	FJ failure in all laminations	200
15	50.1	160.1	362.0	45.1	FJ (2,3,4), Timber (1,5)	150
16	50.2	160.1	369.5	46.0	FJ (1,2,3,4), Timber (5)	<10
17	50.3	159.9	340.0	42.3	FJ (2), Timber (1,3,4,5)	200
18	50.0	160.5	369.0	46.0	FJ (2,4,5), Timber (1,3)	300
19	50.2	160.7	349.0	43.3	FJ (1,2), Timber (3,4,5)	150
20	49.9	160.0	372.5	46.7	FJ failure in all laminations	200
22	49.9	160.7	347.5	43.3	FJ (1), Timber (2,3,4,5)	<10
23	50.1	160.5	306.0	38.1	FJ (1,2,4), Timber (3,5)	450
24	50.0	160.7	278.0	34.6	FJ (1,3,5), Timber (2,4)	100
25	50.1	160.2	318.0	39.6	FJ (2,3), Timber (1,4,5)	<10
26	50.0	160.0	373.0	46.6	FJ (1,4,5), Timber (2,3)	200
27	50.0	160.8	359.5	44.7	FJ (4,5), Timber (1,2,3)	<10
28	49.9	160.0	307.5	38.5	FJ (1,4,5), Timber (2,3)	50
29	50.1	160.3	353.0	44.0	FJ (1,2,3), Timber (4,5)	30
30	49.9	160.1	331.0	41.4	FJ (2,3,5), Timber (1,4)	250

Summary Manufacturer B tension

Number of specimens	Mean tension strength (MPa)	Coefficient of variation, $V_{t,glulam}$ (%)	Characteristic tension strength, f_k (75% tol)

			(MPa)
30	**40.6**	**11.6**	**30.5**

1.10 Manufacturer C glulam tension results

Member detail	Adhesive	Finger joint profile	Finger joint spacing	Grip spacing
Slash Pine MGP15 - Glulam - 5 Laminations @ ~30mm	PRF	30 mm vertical	1000 mm	3800mm

ID	b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Min FJ Spacing (mm)
9	59.6	150.0	273.0	30.5	Knot failure in 1st, 3rd laminations; FJ failure in 2nd, 4th laminations	9
28	59.7	149.7	314.5	35.2	FJ failure in 1st, 4th laminations	28
2	60.3	149.7	320.0	35.4	Knot failure in 1st and 5th laminations.	2
8	59.9	150.0	325.0	36.2	FJ failure in 1st, 4th laminations	8
7	60.1	149.9	330.5	36.7	FJ failure in all laminations	7
10	60.0	149.6	330.5	36.8	Knot failure in 1st, 5th laminations	10
4	59.4	150.0	341.5	38.3	Knot failure in 1st, 3rd laminations. FJ failure in 4th lamination	4
5	59.7	149.7	344.0	38.5	Failure near grips - FJ failur ein 1st lamination, subsequent timber failure in other laminations	5
18	59.8	149.8	347.0	38.7	Failure near grips - FJ failure in 1st, 3rd and 4th laminations	18
1	59.9	149.7	352.5	39.3	Knot failure in 1st and 4th laminations; FJ Failure in 2nd, 3rd and 5th laminations. Insufficient glue between 2nd and 3rd laminations	1
12	59.8	149.4	358.0	40.1	FJ failure in 1st, 5th laminations	12
27	59.5	150.0	362.0	40.6	FJ failure in 1st, 5th laminations	27
29	59.8	150.0	366.0	40.8	FJ failure in 2nd lamination, Knot failure in 5th lamination	29
3	58.8	150.0	370.5	42.0	Knot failure in top lamination, FJ failure in 2nd, 3rd lamination	3
20	60.0	149.9	385.0	42.8	FJ failure in 1st lamination; Knot failure in 4th lamination	20
24	59.9	149.7	389.0	43.4	Failure near grips - Knot failure in 1st lamination, FJ failure in 3rd, 5th laminations	24
21	59.4	149.9	397.0	44.6	FJ failure in 2nd, 3rd laminations; Knot failure in 5th lamination	21
19	59.5	150.1	402.5	45.1	FJ failure in 1st, 5th laminations. Knot failure in 4th lamination	19

13	59.6	149.8	406.5	45.5	FJ failure in 1st, 2nd laminations	13
6	59.4	150.0	409.0	45.9	Knot failure in 2nd, 5th laminations; FJ failure in 1st, 3rd laminations	6
11	60.2	150.0	412.0	45.6	Knot failure in 2nd lamination; FJ failure in 4th lamination	11
15	59.9	149.8	414.5	46.2	Knot failure in 1st and 5th laminations; FJ failure in 3rd lamination	15
26	59.7	149.8	423.5	47.4	FJ failure in 2nd, 3rd and 5th laminations	26
23	59.9	149.8	428.0	47.7	Failure near grips - FJ failure in 1st, 2nd lamination	23
17	59.6	149.9	439.5	49.2	FJ failure in 1st, 3rd laminations	17
22	59.8	149.6	445.0	49.7	FJ failure in 1st lamination. Knot failure in 5th lamination	22
16	59.9	150.3	448.5	49.8	FJ failure in 1st, 3rd laminations	16
30	59.7	149.6	453.5	50.8	FJ failure in 2nd, 3rd laminations; Knot failure in 4th lamination	30
14	59.6	149.7	459.0	51.4	FJ failure in 1st, 2nd and 3rd laminations	14

Summary Manufacturer C tension

Number of specimens	Mean tension strength (MPa)	Coefficient of variation, $V_{t,glulam}$ (%)	Characteristic tension strength, f_k (75% tol) (MPa)
30	**42.9**	**5.6**	**33.5**

1.11 Manufacturer D glulam tension results

Member detail	Adhesive	Finger joint profile	Finger joint spacing	Grip spacing
Radiata Pine MGP10 - Glulam - 5 Laminations @ ~30mm	PRF	20 mm horizontal	1000 mm	3800mm

ID	b (mm)	d (mm)	Pmax (kN)	Tension (MPa)	Mode of Failure	Min FJ Spacing (mm)
21	64.3	151.0	135.5	14.0	Failure in grips - Knot in 1st and 3rd laminations	
14	63.7	150.8	141.0	14.7	Cross sectional failure - FJ failure failure in 1st, 3rd and 5th laminations	
5	65.0	150.1	144.5	14.8	Failure 400mm from grip, FJ failure in top lamination, subsequent timber failure through all laminations	
3	63.9	149.8	142.0	14.8	Knot failure in top lamination, subsequent timber failure through all laminations	
4	63.9	150.2	154.0	16.0	Failure 300mm from grip, FJ failure in top lamination, subsequent timber failure through all laminations	
22	64.7	150.7	157.5	16.2	FJ failure in 1st, 3rd laminations - subsequent timber failure through all laminations	
26	65.2	150.9	160.5	16.3	Cross sectional failure - FJ in 1st, 3rd and 5th laminations	
2	65.2	149.9	160.0	16.4	FJ failure in top lamination, subsequent timber failure through all laminations	
13	63.6	150.3	158.0	16.5	FJ failure in 1st and 5th laminations, subsequent timber failure	
19	65.8	150.6	167.5	16.9	Knot failure in 1st, 3rd laminations, FJ failure in 4th lamination 200mm across; subsequent timber failure	
15	64.1	150.9	165.5	17.1	Knot failure in top lamination, FJ influenced in bottom lamination	
10	64.7	151.4	171.5	17.5	FJ failure in 2nd and 4th laminations, subsequent timber failure through all other laminations	
29	65.1	150.8	173.0	17.6	Failure 400mm from grips - cross sectional failure - FJ failure in 1st, 3rd and 5th laminations	
16	64.0	150.9	171.5	17.8	Cross sectional failure - FJ failure in 3rd lamination	
9	63.7	150.9	171.0	17.8	Knot failure in top lamination, FJ failure in 2nd lamination, subsequent timber failure	

					through other laminations	
24	65.3	150.8	180.5	18.3	Cross sectional failure; FJ in 1st, 3rd and 5th laminations	
17	64.9	151.4	181.0	18.4	FJ failure in top lamination and 4th lamination (300mm across); subsequent timber failure	
12	64.7	150.8	183.5	18.8	Failure 400mm from grips, cross sectional failure - knot failure in 1st and 4th laminations, FJ failure in 3rd and 5th laminations	
25	64.3	151.1	184.0	18.9	Knot in top and bottom laminations, subsequent timber failure through all laminations	
7	64.2	150.7	186.0	19.2	Failure 300mm from grip, cross sectional failure, FJ failure in 1st, 3rd and 5th laminations	
6	64.4	150.6	187.5	19.3	Failure in Grips, Cross sectional timber failure - FJ failure in 2nd and 4th laminations	
1	64.1	148.9	187.5	19.6	Cross sectional failure - Knot failure in top and bottom laminations, FJ failure in 2nd and 4th laminations	
23	64.6	150.0	191.5	19.8	Cross sectional failure - knot in top lamination, FJ on 3rd and 5th laminations	
28	64.7	150.9	203.0	20.8	Failure in Grips - knot in top lamination, FJ failure in 2nd and 4th laminations	
20	65.2	151.0	205.0	20.8	Failure 300m from grips - Knot in top lamination, FJ failure in bottom lamination	
27	65.5	150.5	208.5	21.2	Failure in Grips - Knot in top and bottom laminations	
30	65.0	150.7	210.0	21.4	Failure 400mm from grips - FJ in top lamination, subsequent timber failure through all laminations	
8	64.7	150.3	208.5	21.4	Cross sectional failure - FJ failure in 1st, 3rd and 5th laminations, Knot failure in 4th lamination	
11	65.6	151.1	214.5	21.6	Failure in Grips	
18	64.7	150.0	230.5	23.8	Failure 400mm from grips - cross sectional failure - FJ failure in 1st, 3rd and 5th laminations	

Summary Manufacturer D tension

Number of specimens	Mean tension strength (MPa)	Coefficient of variation, $V_{t,glulam}$ (%)	Characteristic tension strength, f_k (75% tol) (MPa)
30	**18.3**	**13.2**	**14.0**

Glulam bending results

Manufacturer A glulam bending results

General details

Member detail	Victorian ash - Glulam - 7 Laminations @ ~40mm
Adhesive	PRF
Finger joint profile	15mm vertical
Finger joint spacing	1000 mm
Test span	5040 mm

Test data with strength values in ascending order

Sample ID	MOR MPa	MOE MPa	Mode of Failure
17	36.1	16380	shear of laminate join between 6 and 7
26	37.0	17184	finger join failure in laminate 7
8	37.1	13969	finger joint failure in laminate 7. Propagating along join of laminates 6 and 7
3	39.4	14640	shear along laminates 6 and 7 as well as parallel timber
10	39.4	16208	finger joint failure in Laminate 7
18	39.8	15325	shear failure of laminate between 6 and 7
14	39.8	15178	initial minor failure of finger join in laminate 7 then shearing of timber in laminate 7
22	39.9	15026	shear failure of timber in laminate 7, initialised at a knot
24	40.2	14335	finger joint failure of laminate 7
28	40.8	15361	finger join failure in laminate 6 and 7
5	40.9	14893	majority timber failure initiated at finger joint in laminate 7
30	42.4	16631	shear of laminate join between 6 and 7

29	42.5	15324	initial shear of laminate joins between 6 and 7, finger join failures in 5, 6 and 7
2	42.6	14722	Laminate failure of 6 and 7 initiated at a finger joint, minimal glue
16	43.1	15049	finger joint failure of Laminate 7 propagating to shear of joint in 6 and 7
15	43.2	15218	finger joint failure in Laminate 7, shear of timber in lam7
27	44.9	17248	shear failure of laminates between laminate 6 and 7
9	45.6	14056	initial failure of finger joint in Laminate 7, then multiple splits between Laminate 5and6 and 6and7
20	45.7	16819	shearing of timber at laminate 7
11	46.2	14402	finger joint failure of laminate 7. shear of timber face in laminate 6 and 7
19	46.3	15234	finger joint failure in laminate 7. Shearing of laminate between 6 and 7
4	46.5	15344	finger joint initiated timber failure at laminates 6 and 7
7	46.5	14987	finger joint failure of laminate 7 initially. Them 6 and 5, shear of parallel joint 5 and 6
1	48.4	14892.9	shear failure of timber between laminates 6 and 7
6	49.8	14790	finger joint failure at Laminate 7 and shear of joint between Laminate 5 and 6
12	54.9	13708	timber failure in Laminate 7 propagating to the finger joint in Laminate 7
13	57.1	15066	multiple finger joint failure at laminate 7,6 and 5
23	58.2	15898	initial finger joint failure

Summary Manufacturer A glulam bending

	Number of specimens	Mean value (MPa)	Coefficient of variation $V_{b,glulam}$ (%)	Estimated 5th percentile strength (Excel) (MPa)
Strength	27	44.4	12.5	35.5
Elastic modulus	27	15120	5.9	15120

Manufacturer B glulam bending results

General details

Member detail Radiata Pine - Glulam - 7 Laminations @ ~32mm
Adhesive PRF
Finger joint profile 15mm vertical
Finger joint spacing 1000 mm
Test span 4050 mm

Member detail	Radiata Pine - Glulam - 7 Laminations @ ~32mm
Adhesive	PRF
Finger joint profile	15mm vertical
Finger joint spacing	1000 mm
Test span	4050 mm

Test data with strength values in ascending order

Sample ID	MOR MPa	MOE MPa	Min FJ spacing (mm)	Moisture Content (%)	Mode of Failure
30	39.0	14850	200	11	FJ failure in bottom lamination. Subsequent failure in lamination 6
18	42.8	14890	120	11	FJ failure in bottom lamination. Subsequent failure in lamination 6
05	42.9	13550	300	9	FJ failure in bottom lamination. Subsequent failure in laminations 5,6
16	43.8	15770	300	9	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
14	44.9	14130	<10	10	FJ failure in bottom lamination. Subsequent failure in lamination 6
13	46.3	14720	50	10	FJ failure in bottom 2 laminations, FJ's stacked. Subsequent failure in lamination 5
02	47.3	15380	250	11	FJ failure in bottom lamination. Subsequent failure in laminations 5,6
27	49.6	13750	250	10	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
29	50.5	14910	80	10	FJ failure in bottom lamination. Subsequent failure in laminations 3,4,5,6
20	52.6	13770	50	10	Failure at knot in bottom lamination. Subsequent failure in laminations 3,4,5,6
08	53.0	15310	100	10	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
06	53.8	13600	300	9	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
23	55.0	15040	200	10	Failure at knot in bottom lamination. Subsequent failure in laminations 4,5,6

17	55.1	14290	250	11	Failure at knot in bottom lamination. Subsequent failure in laminations 3,4,5,6
25	55.5	15650	400	10	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
07	55.9	14850	100	9	Failure at knot in bottom lamination. Subsequent failure in all laminations
01	56.6	14020	350	9	Failure at knot in bottom lamination. Subsequent failure in laminations 3,4,5,6
09	57.1	14220	80	9	FJ failure in bottom lamination. Subsequent failure in laminations 5,6
03	58.8	14970	300	10	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
21	59.2	13990	130	11	FJ failure in bottom lamination. Subsequent failure in laminations 3,4,5,6
28	60.2	14450	300	10	FJ failure in bottom lamination. Subsequent failure in laminations 5,6
12	60.2	14180	100	8	FJ failure in bottom lamination. Subsequent failure in laminations 2,3,4,5,6
19	60.4	14730	150	10	Failure at knot in bottom lamination. Subsequent failure in laminations 2,3,4,5,6
11	60.4	14880	80	10	FJ failure in bottom lamination. Subsequent failure in laminations 3,4,5,6
26	62.9	15260	400	9	FJ failure in laminations 7,6,5. Subsequent failure in lamination 4
15	62.9	14630	100	9	FJ failure in bottom lamination. Subsequent failure in laminations 3,4,5,6
04	63.0	14680	<10	10	FJ failure in bottom 2 laminations, FJ's stacked. Subsequent failure in laminations 3,4,5
22	66.0	16180	50	10	FJ failure in bottom lamination. Subsequent failure in laminations 4,5,6
24	67.0	14050	30	10	FJ failure in bottom 2 laminations, FJ's stacked. Subsequent failure in laminations 2,3,4,5
10	71.0	14910	150	9	FJ failure in bottom lamination. Subsequent failure in laminations 3,4,5,6

Summary Maufacturer B glulam bending

	Number of specimens	Mean value (MPa)	Coefficient of variation $V_{b,glulam}$ (%)	Characteristic value, f_k (MPa)
Strength	30	55.1	14.4	40.8
Elastic modulus	30	14570	4.5	14570

Manufacturer C glulam bending results

General details

Member detail Slash Pine - Glulam - 6 Laminations @ ~30mm
Adhesive PRF
Finger joint profile 15mm vertical
Finger joint spacing 1000 mm
Test span 4500 mm

Test data with strength values in ascending order

Sample	MOR	MOE	Mode of Failure
ID	MPa	MPa	
16	38.5	14823	shear of timber in laminate 5 and 6
13	43.1	14943	finger joint failure in laminate 6 under right loading pad, knot present
11	51.2	14168	shear of timber in laminate 6, at centre of beam
2	51.3	15308	knot failure in laminate 6
20	51.7	14752	shearing of timber throughout beam, initiated in laminate 5 and 6
9	52.4	14237	finger joint failure in laminate 6 under left loading pad
26	52.9	16107	shear of timber in laminate 6, from left support to right loading pad. This piece broke off
6	53.0	14337	shear of timber in laminate 6
17	53.5	14058	finger joint failure in laminate 6 and shear of timber in laminate 6
24	54.1	14549	shear of timber in laminate 6 under the left loading pad
4	55.0	15465	finger joint failure in laminate 6 under left loading pad
10	55.6	16025	knot failure in laminate 6 under right loading pad
27	56.1	14632	finger joint failure in laminate 6 under left loading pad
21	56.8	16001	finger joint failure in laminate 6 150mm left of centre
1	57.7	14775	finger joint failure in laminate 6, under left loading pad

8	57.7	14960	finger joint failure in laminate 6 400mm left of centre
22	57.8	15259	finger joint failure in laminate 6 under left loading pad
5	57.9	15667	finger joint failure in laminate 6, 200mm left of centre
30	57.9	14206	finger joint failure in laminate 6, 200mm left of centre
28	59.4	15348	finger joint failure in laminate 6, 100mm left of left loading pad
3	60.1	16227	finger joint failure in laminate 6, near centre of beam
25	60.9	15456	multiple finger joint, shearing of laminate joins and a knot failure in beam. Beam broke into 4 pieces
15	60.9	14980	finger joint failure in laminate 6 under left loading pad
19	60.9	15211	finger joint failure in laminate 6 under left loading pad
23	62.3	16057	shear of timber and finger joint failure in laminate 6, 600mm left of centre
29	62.8	17046	finger join failure in laminate 6 at the centre of beam
18	65.4	15213	finger joint failure in laminate 6 in centre of beam
14	66.5	15171	finger joint failure in laminate 6 300mm left of centre
7	69.9	15710	knot failure 500mm left of centre

Summary Manufacturer C glulam bending

	Number of specimens	Mean value (MPa)	Coefficient of variation $V_{b,glulam}$ (%)	Characteristic value, f_k (75% tol) (MPa)
Strength	29	56.7	11.4	41.1
Elastic modulus	29	15100	4.7	15100

Manufacturer D glulam bending results

General details

Member detail	Radiata pine - Glulam - 7 Laminations @ ~30mm
Adhesive	PRF
Finger joint profile	20mm vertical
Finger joint spacing	1000 mm
Test span	3780 mm

Test data with strength values in ascending order

Sample	MOR	MOE	Mode of Failure
ID	MPa	MPa	
9	20.0	9828	Knot failure under loading pad in lam 7
13	20.4	9847	Finger joint failure in lam 7 under the left loading pad
4	21.0	9290	Failure of finger joint in lam 7, knot present
20	21.4	9895	Finger joint failure in lam 7 under right loading pad
26	22.2	10301	Finger joint failure in lam 7 under the right loading pad
24	22.7	9753	Finger joint failure in lam 7 under right loading pad
23	22.8	9471	Finger joint failure in lam 7 under right loading pad
8	23.2	9630	Finger joint Failure in lam 7
16	23.4	8724	Shearing timber through entire beam
15	24.2	9102	Finger joint failure in lam 7 near the left loading pad
3	26.0	10153	Initial shear of timber in lam 6 and 7, propogating all the way to the top of beam - Beam split in half
25	27.2	10556	Finger joint failure in lam 7 under the right loading pad
21	27.9	10525	Finger joint failure in lam 7 under the right loading pad
10	28.0	10192	Finger joint and shearing of timber failure in lam 7, close to loading pad
22	28.0	9441	Finger joint failure in lam 7 under left loading pad

17	28.8	9643	Knot failure in lam 7
5	31.2	10228	Spontaneous shearing of all laminates. Beam snapped in half
29	32.0	8773	Finger joint failure in lam 7 below right loading pad
27	32.3	10009	Finger joint failure in lam 7 under right loading pad
11	32.5	8953	Finger join failure in lam 7 and 5, directly above each other
18	32.8	9160	Finger join failure in lam 7 under right loading pad
6	34.0	11087	Finger joint failure in lam 7
28	34.3	9969	Multiple finger joint failure in lam 3,5 and 7 under right loading pad
14	34.4	9870	Finger joint failure in lam 7 and shearing of timber in lam 7
19	35.0	10467	Finger joint failure in lam 7 under right loading pad
2	37.5	11353	Shearing of timber in lam 7, propagating all the way to the join of lam 1 and 2
1	44.7	10485.4	Spontaneous failure of lam 7,6 and 5. Clear knot defects
12	45.5	10240	Finger joint failure in lam 7 under left loading pad
30	47.3	20908	Knot failure in lam 7 near right loading pad

Summary Manufacturer D glulam bending

	Number of specimens	Mean value (MPa)	Coefficient of variation $V_{b,glulam}$ (%)	Characteristic value, f_k (75% tol) (MPa)
Strength	29	30.0	7.4	19.4
Elastic modulus	29	7850	3.6	5620