

Product potential of paulownia timber

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Summary

FPC Timber Technology assessed the properties of timber from three 10-y-old paulownia (*Paulownia fortunei*) logs from Queensland. The logs were regular in form with some taper. No end checking was evident prior to sawing. Growth stresses were minimal and the logs were sawn without difficulty using a horizontal bandsaw mill to produce straight backsawn and quartersawn timber. Mean green sawn recovery was 55% of log volume. Milling waste that was stored green for eight weeks developed sap stain.

The sawn timber was dried in a heat-and-vent kiln over 45 d, showing good drying quality. Stability in service should be high, although unit shrinkage was not assessed.

The timber was straight-grained with a moderately coarse even texture, a straw yellow to pale brown colour and lightly figured. Grading to the FIFWA (1992) *Industry Standard for Seasoned, Sawn and Skip-Dressed WA Hardwoods* gave 51.8% dry recovery (not dressed) of Prime Grade timber. Mean volumetric shrinkage was estimated as 6.0%. Dressing to the standard dimensions specified in the FIFWA Standard would give dry dressed graded recovery of 38.2%. Air-dry density was 260 kg m⁻³; hardness measured using a modified Janka method was only 0.5 kN.

The timber was ripped, crosscut, planed, sanded and bored without undue difficulty, notwithstanding a need for sharp tools and high cutter speeds. Router cuts were characterised by feathery edges that were improved by sanding. The timber achieved 100% wood failure in PVA glue tests and should therefore glue well. The test panels were fine sanded and finished to a high standard using a clear finish, but staining was less successful.

These results conform with those in previous literature, and indicate that paulownia timber is suitable for wall and ceiling linings, claddings (if treated), decorative mouldings, picture frames, timber blinds, doors and windows. The timber also seems well suited as a substrate in veneered products including doors and tabletops, and as a general carcass material in low-stress situations where weight savings may result from its use.

Keywords: seasoning; wood properties; shrinkage; wood density; working properties; wood utilization; *Paulownia fortunei*

Introduction

Recent changes in Western Australian Government policy and bans on harvesting old-growth native forests have increased the need for plantation-based timber resources. A significant number of paulownia (*Paulownia fortunei*) trees have been planted on farms in several States for sawlog production, and these logs can supplement other hardwood timber resources for non-structural products. FPC Timber Technology was commissioned by Environmental Forest Farms to assess the processing characteristics and physical properties of paulownia logs from a managed plantation in Queensland, and was asked to suggest what products could be produced from the species.

Materials and methods

Log storage and handling

Environmental Forest Farms supplied three logs 3.6 m long from Queensland for the assessment; the small-end diameters under bark were 290–390 mm. Growth rings indicated that the logs were cut from trees 10 y old. On arrival at FPC Timber Technology, the logs were measured and stored in a ‘wet’ shed in an environment maintained at or above 85% relative humidity. Prior to sawing the logs were docked to a length of 2.5 m so that the sawn timber would fit into FPC Timber Technology’s heat-and-vent research kiln. The ends of the logs and their off-cuts were sealed using coloured paints to enable boards cut from them to be identified, and to prevent end splitting. Log volume was calculated using the Smalian method, i.e. length multiplied by the mean cross-sectional area of the large and small ends.

Conversion of logs to sawn timber

The logs and their off-cuts were sawn using a ‘Wood-Mizer’ hydraulic LT40HD portable horizontal bandsaw mill fitted with a 0.88 x 31.75 mm blade, sharpened with a 9° hook and a 0.6 mm set. A backsawing pattern was initially used to cope with any stress-related distortion that might occur, but because movement of the log during sawing was only slight, a mixed pattern was also used to improve recovery. Random-width pieces, 25 mm, 40 mm and 50 mm thick were sawn from the 2.5-m logs and sections of

100 mm x 100 mm were sawn from the log off-cuts to provide a range of section sizes for assessment and utilisation. Recovered timber was tallied and the fraction of log volume converted to green sawn timber was calculated. This recovery figure includes boxed heart and wane.

Dipping for protection against lyctid attack

The green sawn timber was block-stacked and dipped in an 0.2% solution of boric acid for protection against lyctid attack, and then stored under cover for three weeks to allow diffusion and penetration of the chemical prior to drying.

Drying process

After three weeks the green sawn timber was strip-stacked and a 600 kg concrete weight was placed on top of the stack to minimise any distortion of the timber during drying. The moisture content (mc) of two sample boards was measured using the oven-dry method and the timber was dried in an electric heat-and-vent kiln.

Mass loss and kiln conditions were periodically measured and recorded during drying. Drying continued for 45 d until the sample boards reached 12% mc. The moisture content of all boards was then checked using a Wagner '1601-3' hand-held electromagnetic moisture meter. The dry sawn timber was tallied, because the client did not require it to be dressed. The percentage of log volume converted to dry sawn timber was estimated, and dry dressed recovery was estimated as though the boards had been dressed to standard industry sizes.

Drying quality class

The 100 mm x 100 mm pieces from the log off-cuts were re-sawn into backsawn and quartersawn 100 mm x 25 mm sample boards using a Wadkin 'Power Band' re-saw and planed to 87.5 mm x 22 mm (for later use in test panels) using an SCM 'Superset 23' foursider planer. The drying quality of these boards was assessed using Drying Quality Class 'E' as defined in AS/NZS 4787:2001 (Standards Australia/Standards New Zealand 2001). The Standard requires the individual assessment of moisture content variation, residual drying stresses, checking and collapse, and the assignment of a Drying Quality Class to each assessment. Distortion and checking could also have been assigned a Drying Quality Class using the standard, but were assessed later using the FIFWA Industry Standard (FIFWA 1992).

Density and hardness

The air-dry density of a test piece from each sample board was measured using the method specified in AS 1080.3-1981 (Standards Association of Australia 1981) for prismatic test pieces. The method involved weighing and accurately measuring the dimensions of the air-dry test pieces and calculating density. The hardness of the samples was then assessed using a modified Janka method.

The Janka method given in ASTM D 143 (American Society for Testing and Materials 1994) requires incremental measurement of the force required to embed to half its diameter a steel hemisphere

of diameter 0.444 in. into the face, edge and end grain of a 2 in. x 2 in. x 6 in. test block at a strain rate of 0.25 in. min⁻¹. In this trial, a vice with a modified screw was used to embed a 0.444 in. steel hemisphere into samples 22 mm thick. The maximum load required to embed the hemisphere was determined from the maximum torque applied at the screw with a torque wrench. The rate of indentation was controlled manually by the speed of rotation of the wrench handle to achieve movement at the jaws of about 0.25 in. min⁻¹. The depth of indentation was measured at the jaws using a Vernier caliper. The test was repeated five times on each sample and the results were averaged. The results for air-dry density and air-dry hardness are reported in comparison to published data for some WA commercial species.

Grade and graded recovery

The sample boards were visually graded to *Industry Standard for Seasoned Sawn and Skip-Dressed WA Hardwoods* (FIFWA 1992), which describes Prime, Standard and Reject grades.

Description of appearance

The colour of the sample boards was described using CSIRO's colour features (Ilic 1990). The method involved matching the base colour, and other colour features such as flecks, with standard colours and descriptions given in the *Macro Key*. Texture, grain and figure were then described using CSIRO Trade Circular No. 43 (CSIRO Division of Forest Products 1960). The circular contains standard descriptions for grain (referred to as the prevalent direction of the wood fibres along the length of each board), texture (referred to as the size and position of the wood elements), and figure (described as the patterns in each board due to structural features, including knots and growth rings).

Fabrication of test panels

Two replicate panels were constructed from the dressed sample boards from each log, thus producing six test panels. Each panel comprised quartersawn and backsawn pieces. The machining processes that were later carried out were therefore replicated twice on both backsawn and quartersawn end, face or side matched timber sections from each log. The sections in each panel were edge-glued using Selleys 'Aquadhere' (a proprietary polyvinyl-acetate (PVA) adhesive) with an alternating backsawn/quartersawn assembly pattern. The gluing process involved applying a film of Aquadhere to the edges of the timber within 24 h of planing, followed by clamping for 48 h. Timber shims were used to prevent the sash clamps from indenting the edge pieces of timber.

After 48 h the panels were trimmed to 610 mm in length using a Wadkin 'CP380' panel saw. The 610 mm x 610 mm dimensions of the panels enabled the use of standard machining templates. The off-cuts from the panels were used for assessing glue strength in accordance with AS/NZS 1328.1:1998 (Standards Australia/Standards New Zealand 1998). The glue strength test involved preparing notched samples that were split along the glue line using a bolster and masonry hammer. The separated surfaces were visually assessed and the extent of wood failure was determined in 5% increments on a scale ranging from 0% to 100%.

Box 1. FPC Timber Technology Visual Grade Rules for Assessing Machining Quality

Machined surfaces are visually assessed on a scale from 1 to 5 using the following criteria:

- 1 **Very good** describes a high-quality surface that is virtually free from any defect associated with the particular machining or finishing process.
- 2 **Good** describes a good-quality surface that is free from most defects associated with the machining or finishing process.
- 3 **Fair** describes a surface that is acceptable, but not good.
- 4 **Poor** describes an unacceptable surface that would have to be reworked or a reduced value negotiated.
- 5 **Very poor** describes a surface that would be rejected as unfit for use. If reworking is possible, it probably would not be warranted due to the extent of the work required.

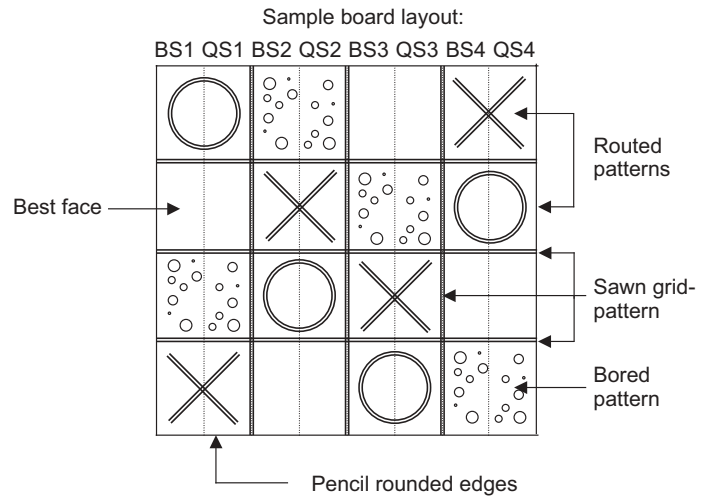


Figure 1. Diagram of standard machining test panel

Machining of test panels

The panels were then planed with and against the grain using a Robinson 36 in. x 7 in. thicknesser adjusted to remove 1 mm of thickness with each pass. The quality of the planed surfaces was graded using the FPC Timber Technology visual grading rules for assessing machining quality (Box 1). The grading rules rank the quality of the planed surface on a scale ranging from 1 (a high quality surface that is virtually free from any defect associated with the particular machining or finishing process) to 5 (a surface that would be rejected as unfit for use).

The panels were then sanded using a Worldmax ‘Sheng Feng A 376’ belt sander fitted with a 120 grit belt, using the method and grading system that had been used for planing. The panel arrises were pencil rounded using a Makita ‘361 2BR’ 6 mm router fitted with a quarter rounding bit of radius 5 mm, and the quality of the machined surfaces was assessed using the FPC grade rules. The double-grid pattern of trenches, 6 mm wide by 5 mm deep, shown in Figure 1 was then cross-cut and ripped into the panels using an Omega ‘RN 600’ radial arm saw. The quality of the cuts was graded using the FPC grade rules given in Box 1. Using standard guides and the Makita router, the circle and cross patterns, 12 mm wide by 5 mm deep shown in Figure 1 were routed into the panels; results were also graded using the FPC grade rules.

Holes were bored to 5 mm depth in the panels in the pattern shown in Figure 1, using an ‘F&R Tough’ pedestal drill-press fitted with a 6 mm brad-point bit. This procedure was repeated using a 12 mm brad-point bit and 16 mm, 19 mm and 25 mm saw-tooth bits. The bored panels were then graded using the FPC grade rules.

The results of the machining trials were compared with those from assessment of local commercial species.

Finishing of test panels

At the completion of the machining trials two panels were sanded by hand with 240 grit paper to produce clean, smooth surfaces suitable for finishing. One panel was stained using Wattyl ‘Craftsman fade resisting interior woodstain — Dark Mahogany’ and finished with Wattyl ‘Isoguard — Clear’ in accordance with the manufacturer’s instructions. The other panel was finished using

only the Wattyl ‘Isoguard — Clear’. The quality of the finished surfaces was assessed using the FPC grade rules (Box 1). A painting treatment was not included because this would have concealed the grain and figure in the timber.

Results and discussion

The dimensions of the logs are presented in Table 1, and the appearance of the logs can be seen in Figure 2.

As shown by Table 1 and Figure 2, the logs were regular in form, though tapered, and comparatively large considering the tree age. The green logs were fairly heavy owing to the very high moisture content of the wood, and needed careful handling to avoid mechanical damage because of the thin bark. Overall green sawn recovery (including heart-in timber) from the logs as a fraction of log volume is given in Table 2. Although the recovery figures were high, log A recorded the lowest recovery because a conservative sawing pattern was initially adopted to accommodate any stress-related distortion. Growth stresses were minimal, however, and logs B and C were both back- and quartersawn, and higher recoveries were achieved.

A smooth sawn finish was obtained using the Wood-Mizer portable bandsaw mill. The logs were easy to saw when the feed speed was fairly high, but the band tended to wander when the feed speed was slow. A band with an increased hook angle and set should handle a faster feed rate than that used in our study.

Table 1. Log length, small- and large-end diameter under bark and log volume

Log	Length (mm)	Sedub (mm)	Ledub (mm)	Taper (mm m ⁻¹)	Log volume (m ³)
A	2400	390	525	54	0.403
B	2400	320	475	62	0.309
C	2400	290	410	48	0.238
Total					0.950

sedub = small-end diameter under bark; ledub = large-end diameter under bark

Table 2. Green sawn, dry and estimated dry dressed volume and recovery

Green sawn		Dry		Estimated dry dressed	
Volume (m ³)	Recovery (%)	Volume (m ³)	Recovery (%)	Volume (m ³)	Recovery (%)
0.524	55.0	0.493	51.8	0.363	38.2

Table 3. Schedule used for drying paulownia boards at FPC Timber Technology

Moisture content (%)	Dry bulb temperature (°C)	Relative humidity (%)	Air speed (m s ⁻¹)
Green	45	88	1.0
50	45	84	1.0
40	50	76	1.0
30	55	67	1.0
20	60	50	1.0

The drying schedule used for drying the timber to 12% mc is given in Table 3. A comparatively conservative schedule was chosen for safety because FPC Timber Technology did not have experience with the species. The timber was air dried for one week prior to kiln drying, during which time its moisture content decreased by about 19%. It was evident that the initial moisture content of the timber was very high and that moisture loss occurred very quickly, particularly in the first week of drying. The entire drying cycle took 45 d, but this could be reduced by using a less conservative schedule. The volumetric loss in shrinkage was estimated as 6.0%, based on the dry and green sawn recoveries in Table 2.

Sample board moisture content and the in-kiln conditions maintained during drying of the timber are given in Table 4. Some minor problems arose during drying. The jarrah strip sticks used to separate the timber caused slight staining, but dressing the boards removed the marks; the use of light-coloured strip sticks is recommended. No difficulties were experienced with the timber that was dried after sawing, but off-cuts that were left to stand

Table 4. Sample board moisture content and in-kiln conditions during drying of paulownia at FPC Timber Technology

Date (d/mo/y)	Sample	Moisture content (%)	Kiln conditions	
			Temp. (°C)	Rel. hum. (%)
19/04/01	S1	155.4	45	88
	S2	144.9	45	88
27/04/01	S1	94.1	45	88
	S2	82.9	45	88
30/04/01	S1	85.6	45	88
	S2	64.0	45	88
02/05/01	S1	58.1	45	84
	S2	51.4	45	84
07/05/01	S1	44.4	50	76
	S2	45.1	50	76
14/05/01	S1	30.6	50	76
	S2	32.5	50	76
23/05/01	S1	23.8	50	76
	S2	26.2	50	76
27/05/01	S1	12.8	50	50
	S2	12.3	50	50

for eight weeks prior to drying were affected by sap-staining fungi. Haslett *et al.* (1992) recommended using an anti-sapstain dip before air drying.

The drying qualities in respect of moisture content, residual drying stress, checking and collapse were all assessed as Class 'E' of AS/NZS 4787:2001 (Standards Australia/Standards New Zealand 2001), i.e. the timber would be suitable for uses where movement in service must be minimised.

In Table 5 average values from this assessment of air-dry density and air-dry hardness are compared with data for some Western Australian (WA) commercial species. The average air-dry density of the paulownia timber was 260 kg m⁻³, compared to 260–330 kg m⁻³ quoted by Rao *et al.* (1986) for a range of Chinese species, and compared with 820 kg m⁻³ for

**Figure 2.** Paulownia logs being docked before sawing using a Wood-Mizer portable bandsaw mill

Table 5. Air-dry density and air-dry hardness of paulownia and selected commercial species

Species	Air-dry density (kg m ⁻³)	Hardness (kN) (vice method)	Janka hardness (kN) (Bootle 1983)
Paulownia	260	0.5	Not available
Jarrah	820	8.4	8.5
Karri	900	9.2	9.0
Radiata pine	480	3.1	3.3

Table 6. Aesthetic properties of paulownia assessed using CSIRO's *Macro Key for Hardwood Identification* and Trade Circular No. 43

Characteristic	Description
Grain	Straight
Texture	Moderately coarse
Colour	Heartwood straw to yellow-brown
Figure	Backsawn boards were lightly figured; quartersawn boards had no figure

Table 7. Machining properties of paulownia and other species assessed using the same equipment, procedures and grading methods. The values are scores on an empiric scale ranging from 1 (very good) to 5 (very poor) (see Box 1).

Species	Ripping	Cross-cutting	Planing	Sanding	Routing	Boring
Paulownia	1	1	1	1	2	1
Jarrah	1	2	2	1	2	1
Marri	1	2	3	1	2	1
Karri	1	3	2	1	2	1

jarrah and 480 kg m⁻³ for radiata pine. As density is a good indicator of strength, it can be assumed that the strength of the paulownia would be significantly lower than that of the commercial species. In view of this, paulownia timber would generally be unsuitable for use in structural applications.

Using the vice test, the average Janka hardness of paulownia was 0.5 kN, compared with hardness of 1.3 kN for New Zealand-grown *P. tomentosa* (Haslett *et al.* 1992). Hardnesses of three other WA-grown species also assessed using the vice are compared with data from Bootle (1983) in Table 5. These data confirm that paulownia timber has low resistance to indentation.

All the timber was Prime Grade, with none in Standard or Reject Grades, according to the FIFWA Industry Standard (FIFWA 1992), indicating that timber of particularly high quality was produced. Similar studies at FPC Timber Technology using eucalypt species have produced significantly less Prime Grade timber.

The grain, texture, colour and figure of the timber (Table 6) were described using CSIRO's *Macro Key for Hardwood Identification* (Ilic 1990) and the CSIRO Trade Circular No. 43 (CSIRO Division of Forest Products 1960). Although the timber might be considered bland in comparison to that of eucalypts, it is

particularly well suited for use in picture frames or other products where the inclusion of knots and other natural characteristics might detract from the performance of the product.

In the glue test using AS/NZS 1328.1:1998 all replicates exhibited 100% wood failure, which means that both the adhesion between the wood and the glue, and cohesion within the glue, exceeded the strength of the wood perpendicular to the grain. These data indicate that the timber can be glued successfully, as noted by Rao *et al.* (1986).

All replicates of all treatments in the machining study rated well when assessed using the FPC Timber Technology visual grading rules (Box 1), although the routing was slightly lower in quality than the other operations. When the test pieces were routed against the grain, there was some tearing of fibres and minor chipping. This poor finish was removed by planing and sanding, with a concomitant loss of thickness. Methods for improving routing performance therefore require investigation. The use of sharp high-speed tools is crucial when machining paulownia, as discovered during the drilling tests: poor results were obtained with the drill set on a slow speed (300 rpm), but results on the same samples were good at a higher speed (6000 rpm).

The average machining quality of the six test panels for each operation is compared in Table 7 with the results from previous trials at FPC Timber Technology on commercial species using the same methods, machinery and grade rules. The results show that the timber machined well notwithstanding a systematic problem with routing, and produced better results than the major commercial species previously assessed. Haslett *et al.* (1992) rated machining properties of paulownia as similar to those of radiata pine.

The assessment of finishing quality indicated that the timber finished very well with the clear finish (Finish Grade 1), but did not stain very well, exhibiting unstained residual patches (Finish Grade 3). Although a poor rating for staining was given by FPC Timber Technology, good staining properties have been reported in the production of timber blinds (Gosatti¹, *pers. comm.*). The quality of the finish was not compared to that of commercial species tested by FPC Timber Technology because the other species were not assessed using the same grade rules. Although painting properties were not assessed because viewing the grain and figure was considered important, the timber should paint well with opaque coatings, after filling, because it has a coarse texture and is largely defect free. Trials would be required to confirm this expectation.

Conclusion

Although logs from only three Queensland-grown *Paulownia fortunei* trees were assessed, the trial gave a good indication of the potential of paulownia timber. The logs had definite taper but were otherwise of good form, and based on the 10-y age estimate the trees had grown rapidly when compared with logs of other plantation species. The logs were unexpectedly heavy due to high water content, and care was needed to avoid damage because the thin bark did not offer much protection. The logs were not prone to end splitting.

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The timber dried quickly, though it was susceptible to sap stain. Sawn sections were largely free of characteristics such as knots, and the wood had a moderately coarse uneven texture. High wood quality combined with low growth stresses resulted in high recovery. The timber machined well in most treatments, notwithstanding a need for sharp tools and suitable cutter and feed speeds. More work is required to improve routing performance.

The timber finished well with a clear coating, but staining was less successful. The light colour of the timber means that it has potential for staining, but further assessment of this property is required. The timber should paint well after its coarse texture is filled, but this expectation requires confirmation. The timber glued well with water-based PVA adhesive, but suitability of other glue formulations should be assessed. Natural durability was not assessed.

Due to its low density the timber was deemed unsuitable for use in furniture where moderate to high strength and hardness are required. Inappropriate uses would include chair legs and tabletops. The timber is also unsuitable for use in building structure and decoration where strength and hardness are required. Inappropriate building uses include flooring, skirting, stair treads and bench tops.

There is, however, a wide range of applications to which the physical and aesthetic qualities the timber are well suited. Rao *et al.* (1986), Haslett *et al.* (1992) and Rural Industry Business Services (1998) also discussed a range of possible products from paulownia, and there is general agreement about possible uses. Outdoor use is an option if effective preservative treatment is possible. Potential uses include, but are not limited to, wall and ceiling linings, wall claddings and trim (if treated), eaves linings, decorative interior and exterior mouldings, picture frames, timber blinds, doors and window joinery. The timber also seems well suited for use as a substrate for veneered products including doors

and tabletops and as a general carcass material in situations where it would not be over stressed and weight savings would result from its use.

References

- American Society for Testing and Materials (1994) *Standard Test Methods for Small Clear Specimens of Timber*. ASTM Standard D 143. American Society for Testing and Materials, West Conshohocken.
- Bootle, K.R. (1983) *Wood in Australia — Types, Properties and Uses*. McGraw-Hill Book Company, Sydney.
- CSIRO Division of Forest Products (1960) *Figure in Timber*. Trade Circular No. 43 (Revised). CSIRO, Melbourne.
- FIFWA (1992) *Industry Standard for Seasoned, Sawn and Skip-Dressed WA Hardwoods*. Forest Industries Federation WA Inc., Western Australia.
- Haslett, A.N., Young, G.D., Simpson, I.D. and Britton, R.A.J. (1992) Paulownia: the timber of the future? *What's New in Forest Research* No. 225. New Zealand Forest Research Institute.
- Ilic, J. (1990) *The CSIRO Macro Key for Hardwood Identification*. Division of Forestry and Forest Products, CSIRO, Melbourne, pp. 16–27.
- Rao, A.N., Hsuan, K., Corlett, R., Dkanarajan, G. and Sastry, C.B. (eds) (1986) *Paulownia in China: Cultivation and Utilisation*. Asian Network for Biological Sciences and International Development Research Centre.
- Rural Industry Business Services (O'Sullivan, M. and Switala, J.) (1998) *Paulownia — A Commercial Overview*. Department of Primary Industries, Queensland, Q198043. 30 pp.
- Standards Association of Australia (1981) *Methods of Testing Timber — Determination of Density*. AS 1080.3–1981, 4 pp.
- Standards Australia/Standards New Zealand (1998) *Glued-Laminated Structural Timber*. AS/NZS 1328.1:1998.
- Standards Australia/Standards New Zealand (2001) *Timber — Assessment of Drying Quality*. AS/NZS 4787:2001.