Characterisation of plywood properties manufactured from plantation grown eucalypts
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Prepared for
Forest & Wood Products Australia

by
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Publication: Characterisation of plywood properties manufactured from plantation grown eucalypts

Project No: PRB046-0809

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ISBN: 978-1-920883-74-4

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Final report received by FWPA in July, 2009

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Executive summary

Objectives
The key objective was to determine suitability of selected plantation eucalypts for production of plywood.

Quantity and quality of manufactured veneer and plywood produced from 5 species (Eucalyptus agglomerata, E.dunnii, E.grandis, E.pilularis, E.saligna) aged 34 years and also E. dunnii aged 12 and 17 years were assessed. As such 3 ages of E.dunnii were examined.

Veneers were graded to Australian and New Zealand Standard AS/NZS 2269.0:2008. Plywood – Structural, Part 0: Specifications. (Standard Australia, 2008).

Plywood panel quality was determined by evaluating mechanical properties, stress grade, bond strength, moisture content and formaldehyde emissions.

Key Results

- Recovery of veneers depended on species and log diameter. The species component was related to a combination of effects including ‘spin out’, splitting, and factors such as decay/kino.

- Recovery of veneers was reduced by end-split on economics of plantation forestry.

- Formaldehyde emissions was influenced by species in the 34 year old trial, and also between ages in the E. dunnii age trial. Mean emission level was very low and ranged from 0.082 mg/L for E. saligna to 0.267 mg/L for E. pilularis. Formaldehyde emission appears to be significantly affected by wood age with higher emission levels recorded for younger plantations.

- Bond strength was excellent in the 34 year-old E. dunnii and E. grandis (100% of the samples having acceptable Type B bond), followed by E. agglomerata (88%), E. saligna (83%) and E. pilularis (78%).

- The results were of some concern for younger E. dunnii with only a low 27% (12 year-old) and 80% (17 year-old) having acceptable bond strength. A re-test of the E. dunnii population confirmed the poor results, although there was a marked improvement in the pass rate (from 27% to 60%) for the 12 year-old material, but a small decline for the 17 year-old material (from 80% to 70%). The bond quality for re-tested 34 year-old E. dunnii plywood was unchanged with 100% pass.
• The results for *E. dunnii* suggests there is an age effect on bond quality and further work is needed to fully understand the factors involved and for suitable glues to be developed.

• Plywood grade recovery was similar for *E. pilularis, E. agglomerata* and *E. dunnii* with at least 76% of the recovered plywood panels making F27 or better. Recovery of the same grades for *E. grandis* and *E. saligna* was disappointingly low at around 30% - a result most likely attributed to the high presence of injury related gum pockets and borer attack in this study.

• The results from the age effect study for *E. dunnii* produced some surprising and favourable outcomes. The 17 year-old *E. dunnii* gave 80% recovery of F27 or better, whilst the 12 year-old material gave 68% for the same grades. These results were encouraging, particularly when *E. dunnii* is not widely regarded by the timber industry. The potential to produce high grade plywood from a species at such an early age is undoubtedly economically beneficial to forest growers.

• Plywood manufactured from 34 year-old *E. agglomerata* and *E. pilularis* had the highest MOR and MOE (of approximately 110 MPa and 23000 MPa respectively), which were not significantly higher than results for 34 year old *E. dunnii*. MOR and MOE of panels produced from 34 year-old *E. grandis* and *E. saligna* were significantly lower.

• MOR and MOE of the younger *E. dunnii* (12 and 17 year-old) were only slightly lower than of the 34 year-old material. There was no significant difference in MOR and MOE amongst the 12, 17 and 34 year-old *E. dunnii*.

• MOE of test plywood pieces was better able to be predicted from Director HM200 acoustic resonance on logs than Fakopp acoustic velocity on standing trees.

• There was significant difference in hardness between species in the 34 year old species trial. All species except for *E. grandis* compared favourably or reasonably well with hardness values published for solid wood.

• Age had a significant effect on hardness with the older (34 year old) *E. dunnii* plywood having a higher hardness value than the younger 12 and 17 year old material. There was significant difference in hardness between the 12 and 17 year old plywood.
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1 Introduction

Plantation hardwood will meet a greater part of NSW timber supply in future years yet knowledge of its quality to meet high value end product uses is limited. Therefore concern over quality of plantation grown timber is considerable. Forests NSW (FNSW), as the largest wood supplier in NSW, have been working with a number of timber processors to evaluate the end product potential of plantation eucalypts, be that solid wood, manufactured wood or pulp. From a 34 year old eucalypt plantation trial FNSW are evaluating timber qualities of the best performing, in terms of stand volume, eucalypt species including *E. pilularis*, *E. dunnii*, *E. grandis*, *E. saligna* and *E. agglomerata*. For each species 9 trees encompassing a range of diameters were selected for processing.

*Eucalyptus dunnii* from two younger aged plantations aged 12 and 17 years were examined as this species has been planted extensively in recent years to meet expected shortfalls in timber supply yet there is almost no information on manufacturing potential of this timber from plantations in sub-tropical Australia. The information from these younger plantations is combined with the data of *E. dunnii* from the 34 year old plantation to expand the knowledge base about the influence of plantation age on wood quality. Ten trees from each of the younger plantations were selected for processing.

The results from the veneer mill, and plywood quality is reported in this report.
2 Materials and Methods

2.1 Description of Plantation

2.1.1 Wild Cattle Creek (34 year old plantation hardwood species trial)

This species trial (G1214D) located in compartment 557 of Wild Cattle Creek State Forest was established on four sites with Wild Cattle Creek state forest. Two adjoining sites designated as hardwood ridge and rainforest ridge were utilized for this study. The original overstorey vegetation of the hardwood ridge consisted of *Eucalyptus grandis*, *E. saligna*, *E. microcorys* and *Syncarpia glomulifera*, while the original overstorey of the rainforest ridge was dominated by *Cerapetalum apetalum*, *Araucaria cunninghamii*, *Orites excelsia* and *Schizomeria ovata*. The geology of the area is Coffs Harbour association *Coramba beds* (Cccs) of lithofeldspathic wacke, siliceous siltstone, mudstone, metabasalt, chert and hasper. The soil consists of well structured loam to clay topsoil and well structured to moderately structured clay loam to clay subsoils. The elevation of the trial is approximately 640m.

The species trial consisting of 13 species with two seedlots of three of these species was planted in March 1973 and the plantation clearfelled in July 2007. Original stocking was a 3*3 m spacing (1111 stems per hectare). No thinning had been carried out on this site. Tree growth (diameter and height) were measured periodically (typically each 5 years) with the last measurement at age 32 year. On this last measurement date stem form, branching characteristics, height to first branch were also measured. Five species showing better growth performance were selected for more detailed studies. These species were *Eucalyptus pilularis* (Blackbutt), *E. dunnii* (Dunn's white gum), *E. grandis* (Flooded gum), *E. saligna* (Sydney blue gum) and *E. agglomerata* (Blue leaved stringybark).

2.1.2 Newry (17 year old *Eucalyptus dunnii* plantation)

The hardwood plantation in Newry State Forest was established by APM forests on previously clear/semi grazing land. The original forest type would have consisted of *Eucalyptus pilularis* forest types on ridges and upper slopes, mixed hardwoods forest types on lower slopes and moist forest types along major creek lines. The geology of the region within Newry State Forest of interest consists of Nambucca beds/Unnamed phyllite consisting of phyllite and schist. The soil unit type is mapped as south creek, an alluvial soil consisting of brown podzolic soils, however, it is in fact more closely aligned to Bellinger, an alluvial soil consisting of brown earths, and brown podsols grading to highly variable alluvial soils on recent floodplains.
The original plantation was established in 1972 with *Eucalyptus grandis*. This species subsequently failed due to high mortality and poor form of remaining stems as a consequence of being ‘off site’. Part of the plantation was clearfelled and replanted with *E. pilularis* and *E. dunnii* in 1990. Growth of both species was vigorous and the stand in compartment 297 received its first thinning in 2005 with the intended retention of 14m$^3$ ha$^{-1}$. An area of 1.5 hectares of compartment 297 was marked for conversion into a seed stand with an intended stocking of 150 sph. Material from this thinning operation was sourced for this study.

### 2.1.3 Boambee (12 year old *Eucalyptus dunnii* plantation)

The *E. dunnii* progeny trial located in compartment 601 of Boambee State Forest was established in February 1995. The original forest type would have consisted of *E. pilularis* forest types on ridges and upper slopes, mixed hardwoods forest types with wet sclerophyll and rainforest types on the lower slopes and creek margins. The geology is classified as Coffs Harbour association *Blooklana beds* comprising thinly bedded siliceous mudstone and silt with rare lithofeldspathic wacke, locally chert, jasper and metabasalt. The soil in the trial area is classified as Dairyville, an alluvial soil on level to undulating terraces and floodplains consisting of deep well drained alluvial soil. It consists of black loam at the surface to reddish brown clay loam at depth. Parts of the progeny trial which were not sampled in this study consist of Mount Coramba, a soil of steep slopes and narrow ridges consisting of lithosols, minimum krasnozems, red, brown or yellow podsoics or yellow earths.

A *E. grandis* plantation was established in the 1970’s after regeneration of native forest was deemed to have failed. This *E. grandis* plantation was harvested in the 1990’s and replanted to the current *E. dunnii* trial. The *E. dunnii* progeny trial comprising 219 families/seedlots plus one *E. grandis* seedlot (G023101) at a spacing of 3 m rows and 2.4 m within rows (1389 stems per hectare). Tree plots of four trees per seedlots were established in a randomised block design with 6 replicates.

Boambee is a high quality site with predicted MAI at 20 years of 20 m$^3$ ha$^{-1}$ (Henson and Vanclay, 2004). The Boambee progeny trial had a basal area at 1.3m tree height of 10 m$^2$ ha$^{-1}$ at age 3 (1998). The trial was thinned to 694 stems per hectare (sph) at age 4.5 year following an operation to leave only the two individuals per seedlot per replicate with best stem form and highest volume. The basal area at age 6 was 19.2 m$^2$ ha$^{-1}$ and had increased to 25.2 m$^2$ ha$^{-1}$ at age 8. Pilodyn measurements to determine density of the outer wood, and acoustic properties measured using the FAKOPP were measured in each tree at Boambee in 2003 (aged 8 years).

A seed orchard will be established at Boambee created by retention of the single best (stem form and volume) individual tree per seedlot in each replicate. This seed orchard will have a stocking of approximately 347 sph.
2.2 Climate

Climate data was gathered from Silo datadrill from 1957 to 2005 (Figure 1). There is a distinct seasonality in climate with wet warm summers and cool dry winters prevailing in all three sites (Wild Cattle Creek, Newry, Boambee). Wild Cattle Creek has the lowest minimum temperatures of the three sites but similar maximum temperatures to Boambee. Newry has the hottest maximum temperatures and is the driest with 1507 mm mean annual rainfall. Mean annual rainfall at Wild Cattle Creek is slightly higher at 1599 mm. Boambee has the highest mean annual rainfall with 1853 mm.

At Wild Cattle Creek high monthly rainfall of over 150 mm /month occurs from December to March, and low monthly rainfall from 50 to 100 mm/month occurs from June to September. Monthly maximum temperatures range from 15°C in June -July to 25°C in December –January; while monthly minimum temperatures less than 5 °C occur from June to August.

At Newry high monthly rainfall of over 150 mm /month occurs from January to April; and low monthly rainfall from 50 to 100 mm/month occurs from July to September. Monthly maximum temperatures range from 20°C in June -July to 28°C in December –January; while monthly minimum temperatures less than 10 °C occur from June to August.

At Boambee high monthly rainfall of over 150 mm /month occurs from November to May; and low monthly rainfall from 50 to 100 mm/month occurs from July to September. Monthly maximum temperatures range from 18°C in June -July to 26°C in December –January; while monthly minimum temperatures less than 10 °C occur from June to September.
Figure 1. Monthly climate averages of rainfall, maximum temperature, minimum temperature and daily evaporation of the three plantations: Wild Cattle Creek, Newry and Boambee. Average taken from Silo Data drill from 1957 to 2005.
2.3 Tree selection, Harvesting and Log descriptions

At Wild Cattle Creek plantation a series of non-destructive wood quality measurements were taken on all surviving trees when aged greater than 32 years. These include diameter over bark at 1.3m (DBHOB), Pilodyn pin penetration measurements at 1.3m, and acoustic properties measured using the FAKOPP between 0.3m to 1.8m longitudinally.

At Newry plantation and Boambee plantation tree height and diameter over bark at 1.3m (DBHOB) was measured on each tree of four inventory plots (radial 0.1 ha) established in October 2006 in Newry and two inventory plots at Boambee plantation. Pilodyn measurements were taken to determine density of the outer wood at 1.3m, and acoustic properties measured using the FAKOPP between 0.3m and 1.8m were measured on each tree in the inventory plots.

MOE was calculated from green density (GD) and fakopp acoustic velocity ($V_{Fak}$) as $MOE_{Fak} = GD \times V_{Fak}^2$

“Research” trees were selected to cover a wide range of diameters, and were of good form with minimal sweep, and no branches or obvious scars in the lower 8m tree height. Pilodyn pin penetration and Fakopp were not used as selection traits in this study.

2.3.1 Sample locations from within each ‘Research’ Log

Wild Cattle Creek plantation was harvested in July 2007. Newry was harvested in October 2007 and Boambee in November 2007.

For each “Research” log the first 7.5 m were processed (Figure 2). This allowed detailed examination of mechanical wood properties from 0.5 to 2.0 m tree height and a veneer log of 5.5 m length (from 2.0 to 7.5 m tree height). Detailed knowledge of wood quality are required to determine relationships with processed timber quality and in-service use. These properties are essential for defining the economic value of processed timber, and hence economic value of plantations.
Figure 2 – Schematic of “Research” buttlog

Mechanical and physical wood properties of radial variation in shrinkage, hardness, MOE, and MOR were measured on a central flitch sampled from 0.5 – 1.8m (Figure 3). A central flitch from northern to southern aspect of the tree of 90-100mm thick was sampled. This flitch was sectioned into three pieces from 0.5 – 1.0m (for determining bending, MOR, MOE), 1.0 – 1.4m (for determining hardness), 1.4 – 1.8m (for determining dimensional stability and shrinkage). These measurements are not reported in this study.
Mechanical and physical wood properties of radial variation in density, and grain properties were cut from the log between 1.8m to 2.0m. The first disc was placed in a plastic bag and later used for determining wood density. The remaining discs were air dried. One disc was used to measure interlocking grain. The remaining disc was used as a spare.
2.3.2 Wood density

The 1.8m height disc samples for determination of green and basic densities were processed at the Forests NSW laboratory at West Pennant Hills. A wedge was cut from the northern and southern aspects of each disc and sectioned into three sub-samples (representing inner, intermediate and outer wood) for assessment of variation in basic density across the radial extent (Figure 4). Basic density (oven-dry weight divided by green volume) of the samples was measured gravimetrically in accordance with Australian and New Zealand Standard AS/NZS1080.3:2000 Timber – Method of test – Method 3: Density (Standards Australia, 2000). The displacement method as described in ASTM (2001) was used to determine the green volume. Green density was determined as green weight divided by green volume.

Average green and basic densities for the whole disc was estimated by dividing the combined oven-dry weights by the combined green volumes of the three sub-samples from each disc.

Figure 4 Sectioning of disc sample for basic density measurements.
2.3.3 Heartwood
The width of the sapwood band and the thickness of the heartwood core were measured with a measuring tape to 1 mm accuracy after spraying log ends with 0.1% methyl orange dissolved in methylated spirits. Measurements were recorded at each end of the sample in the longest and shortest diameters in each cross-section. The proportion (%) of heartwood for each log was calculated by first averaging the east-west and north-south directions, then averaging the small-end and butt-end areas (mm²).

2.3.4 Acoustic resonance
The length of the log was measured, and the acoustic resonance of each log determined using a DIRECTOR HM200 tool. MOE was calculated from green density (GD) and Director HM200 acoustic velocity ($V_{Dir}$) as $MOE_{Dir} = GD^*V_{Dir}^2$

2.3.5 Kino
Length (to 1cm accuracy) and radial degree of all Kino gum veins were measured. The total length of Kino veins was calculated per log end then averaged per log. The sum of all radial angles was calculated for each log end and averaged per log (Figure 5).

Figure 5. Determining Kino length and angle.
2.3.6 End-splitting

The extent of end-splitting at large and small ends of logs were scored both prior to and after steaming. Steaming occurred within 5 days of harvest. The method of scoring end-splitting was adapted from Kapp et al (2000) (Figure 6). Length of splits, and the width of peripheral openings were measured. An end-split score was assigned to each split which depended on type, length and width as follows: 1 point for a radial split that was 0.5 the radius long; 1.5 points for a radial split that was 0.75 the radius long; 2 points for a radial split that was full radius long; 1 point per 0.5 radius length for a non radial (tangential split), and 1 point per mm of peripheral opening. The score for each log end was summed and the average log end split score for each log calculated. In addition the distance along log of peripheral splits was measured and averaged for each log.

![Figure 6. Determining end-split score](image)

**Figure 6. Determining end-split score**

### 2.4 Processing and manufacture of plywood

Logs from different aged *E. dunnii* plantations; and from different species aged 34 years were processed at Big River Timbers, Grafton, NSW within 1 week of harvest.
2.4.1 Production of veneers

Logs were steamed for 18 hours prior to trimming to individual billets and peeled in a rotary lathe to produce veneers of 3 mm thickness. Full lengths of veneer (120cm length) were collected, counted, dried and assessed for quality.

The veneers were dried in a “piece dryer” to a target 12% MC, stacked then graded to Australian and New Zealand Standard AS/NZ 2269.0:2008 Plywood – Structural, Part 0: Specifications (Standards Australia, 2008). Veneers were also graded to Big River Timbers’ internal standards of veneers suitable for face veneers (referred to as either ‘Face’ or ‘No holes’), and veneers suitable for cross veneers (referred to as either ‘Cross’ or ‘Holes’).

2.4.2 Plywood manufacture

Plywood (1.2 x 1.2 m) of 15 mm thickness was produced from individual wood billets. Some billets did not produce sufficient veneers to produce any plywood. On occasions veneers from several adjoining billets from an individual logs were grouped together for making plywood.

All plywood were of 5-ply standard lay-up construction (15-30-5) and the face veneers were minimum Quality ‘C’ or ‘D’. The minimum quality/grade of the cross band veneers and the long band veneer in the middle of the plywood were ‘D’, but could be as high as ‘A’ if the billet produced sufficient ‘A’ quality veneers. A melamine urea formaldehyde glue was used to achieve the target glue B bond. The plywood was manufactured as a structural product to comply with Australian and New Zealand Standard AS/NZ 2269.0:2008 Plywood – Structural, Part 0: Specifications (Standards Australia, 2008) except for bond quality. Type B bond was used instead of Type A as prescribed by Australian and New Zealand Standard AS/NZS 2269.0:2008 Plywood – Structural, Part 0: Specifications (Standard Australia, 2008).

2.5 Wood Quality testing

The quality of plywood was tested to Australian/New Zealand standards. All test pieces were sampled from a minimum of 100 mm from the plywood edges, and wrapped in plastic bags and stored at room temperature until testing.

Glue bond quality (Type B) and formaldehyde content was tested by Engineered Wood Products Association of Australasia (EWPAA) on test pieces of 300 x 300 mm, and 400 x 400 mm respectively to Australian and New Zealand Standards AS/NZ 2098.2:2006 Methods of test for veneer and plywood - Bond quality of plywood (chisel test) (Standards Australia, 2006) and AS/NZS 2098.11 Methods of test for veneer and plywood - Determination of formaldehyde emissions for plywood (Standards Australia, 2005). Bond quality and formaldehyde content
were measured on one plywood panel per log. This plywood was randomly selected from all plywood panels produced from the bottom billet of each log. In addition bond quality was tested on one plywood panel sourced from the top billet of each *E. dunnii* log.

Structural properties (MOE, MOR) were determined on all plywood panels at Forests NSW’s wood laboratory in accordance with Australian and New Zealand Standard AS/NZ 2269.1:2008 Plywood – Structural, Part 1: Determination of structural properties – Test methods (Standards Australia, 2008). Bending test pieces parallel to face grain, 780 x 300 mm, were cut from each panel and tested in a four-point bending test configuration using an Avery (Grade A) universal testing machine. Loading was applied at the third points of the span (720 mm) until failure occurred, whilst deflection of the test piece was measured at the mid-span. Load-deflection readings were recorded automatically and also plotted, which enabled the gradient of the straight-line portion of the curve (P'/Δ) to be determined for calculation of MOE. The maximum load was used to determine MOR.

Moisture content was determined on all bending test pieces immediately after the MOR test using the oven-dry method in accordance with Australian and New Zealand Standard AS/NZS 1080.1:1997. Timber - Methods of Test - Moisture content. (Standard Australia, 1997)

Hardness (Janka) was tested on a sample piece of 150 x 150 mm in accordance with Mack (1979). This test consists of measuring the force required to indent the surface of the test piece with a hemispherical end of a steel rod of 11.28 mm diameter to a depth of 5.64 mm.

### 2.6 Plywood grading

Grading in a plymill is normally done by passing each panel through a stress grader, which automatically measures MOE and assigns a grade. The grading threshold (minimum MOE) applicable to each grade is given in Table 1. For this study, plywood grade was similarly assigned to each panel, however, MOE was based on the test value as determined on the test piece and not the whole panel. Provided the test piece was representative of the panel, the MOE derived by either method could be considered the same for all intent and purposes.
Table 1  Thresholds used for plywood grades (Source: Adkins & Lyngcoln, 1985)

<table>
<thead>
<tr>
<th>Stress grade</th>
<th>Cut off point for grade (MPa)</th>
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<tr>
<td>F34</td>
<td>21500</td>
</tr>
<tr>
<td>F27</td>
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<td>F8</td>
<td>9100</td>
</tr>
<tr>
<td>F7</td>
<td>7900</td>
</tr>
</tbody>
</table>

2.7 Evaluation of design properties

An evaluation of the design properties for a graded population of plywood (eg., F27) requires a minimum number of tested samples. According to Australian and New Zealand Standard AS/NZS AS/NZ 2269.1:2008. Plywood – Structural, Part 1: Determination of structural properties – Test methods. (Standard Australia, 2008) the minimum number of samples shall not be less than 30 test pieces for strength (MOR) and not less than 20 for stiffness, for a given grade and product type (thickness & panel construction).

This evaluation is normally undertaken as part of a mill’s on-going quality assurance program to ensure the characteristic properties of a graded population (eg., F27 plywood) continue to meet or exceed the design properties as claimed for that grade.

2.8 Statistical analysis

The two experiments i.e. five species of 34 year old plantation material; and the influence of E.dunnii age were analysed as separate experiments. Covariate analysis was used to determine the effect of factors such as log size and the many measurements of log quality on recovery and quality of veneer and plywood. Data were analysed using Genstat 11.
3 Results and Discussion

3.1 Log size and quality

The characteristics of the trees used to source logs for peeling, and the logs themselves are shown on Tables 2 and 3. Overall *E.dunnii* and *E.pilularis* logs were largest and *E.saligna* logs smallest. Density was lowest in *E.grandis* and highest in *E.agglomerata*. Density of *E.dunnii* was comparable to *E.pilularis*. Heartwood percentage was lowest at 64% in *E.saligna*. Kino was present in all species, but not all individuals. A species ranking for Kino was difficult to determine owing to the large within-species variation, but *E.grandis* and *E.pilularis* could be considered amongst the worst for this trait. Splitting was worst for *E.grandis* then *E.dunnii* and increased during the steaming process. The end-split score attributable to extent of openings was less than that attributed to length of splits. This was particularly the case when splitting post steaming was measured.

Table 2. Characteristics of trees and of the logs sourced from Wild Cattle Creek. Means ±SEM (n=9) with range shown in parenthesis.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th><em>E.agglomerata</em></th>
<th><em>E.dunnii</em></th>
<th><em>E.grandis</em></th>
<th><em>E.pilularis</em></th>
<th><em>E.saligna</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics of the tree</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBHOB (cm) at 34 years</td>
<td>44.2 ±1.9</td>
<td>47.9 ±1.9</td>
<td>40.9 ±1.0</td>
<td>46.8 ±1.5</td>
<td>38.4 ±1.6</td>
</tr>
<tr>
<td></td>
<td>(37.9-54.1)</td>
<td>(39.2-58.7)</td>
<td>(36.5-45.0)</td>
<td>(40.7-53.1)</td>
<td>(32.1-45.5)</td>
</tr>
<tr>
<td>Height (m) at 32 years</td>
<td>36.3 ±0.7</td>
<td>42.2 ±0.7</td>
<td>42.2 ±1.2</td>
<td>41.6 ±0.9</td>
<td>35.2 ±0.5</td>
</tr>
<tr>
<td>Acoustic velocity (km s⁻¹) from Fakopp</td>
<td>3.57 ±0.01</td>
<td>3.50 ±0.01</td>
<td>3.50 ±0.01</td>
<td>3.85 ±0.01</td>
<td>3.55 ±0.01</td>
</tr>
<tr>
<td></td>
<td>(3.12-3.82)</td>
<td>(3.13-3.83)</td>
<td>(3.16-3.88)</td>
<td>(3.49-4.16)</td>
<td>(3.33-3.82)</td>
</tr>
<tr>
<td>Basic density (kg m⁻³)</td>
<td>676 ±13</td>
<td>623 ±16</td>
<td>548 ±9</td>
<td>642 ±11</td>
<td>628 ±13</td>
</tr>
<tr>
<td>Green density (kg m⁻³)</td>
<td>1195 ±9</td>
<td>1175 ±9</td>
<td>1040 ±10</td>
<td>1130 ±10</td>
<td>1133 ±10</td>
</tr>
<tr>
<td><strong>Characteristics of the log</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter of Large end (cm)</td>
<td>35.8 ±1.7</td>
<td>40.7 ±1.6</td>
<td>36.5 ±1.1</td>
<td>39 ±1.5</td>
<td>33.3 ±1.5</td>
</tr>
<tr>
<td></td>
<td>(27.3 - 43.7)</td>
<td>(33.6 - 49.5)</td>
<td>(32 - 41.6)</td>
<td>(32.9 - 44)</td>
<td>(26.5 - 42.2)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Diameter of Small end (cm)</td>
<td>29.7 ±1.2</td>
<td>35.8 ±1.4</td>
<td>33.1 ±1.0</td>
<td>33.6 ±1.5</td>
<td>28.8 ±1.3</td>
</tr>
<tr>
<td></td>
<td>(23.6 - 35.7)</td>
<td>(30.1 - 43.8)</td>
<td>(29 - 38.7)</td>
<td>(28 - 39.8)</td>
<td>(22.8 - 35.8)</td>
</tr>
<tr>
<td>Heartwood (%)</td>
<td>77 ±0.9</td>
<td>68 ±1.0</td>
<td>72 ±1.2</td>
<td>77 ±0.8</td>
<td>64 ±1.9</td>
</tr>
<tr>
<td>Length of Kino veins (cm)</td>
<td>4.7 ±3.4</td>
<td>7.7 ±1.5</td>
<td>9.7 ±2.7</td>
<td>8.1 ±3.7</td>
<td>4.2 ±2.3</td>
</tr>
<tr>
<td>Angle of Kino veins (°)</td>
<td>27 ±20</td>
<td>48 ±9</td>
<td>89 ±21</td>
<td>73 ±38</td>
<td>51 ±28</td>
</tr>
<tr>
<td>Pre-steam End-split score</td>
<td>4.7 ±1.3</td>
<td>8.3 ±1.0</td>
<td>12.9 ±4.2</td>
<td>5.9 ±0.8</td>
<td>4.7 ±0.7</td>
</tr>
<tr>
<td>Pre-steam End-split score due to splits</td>
<td>3.4 ±0.7</td>
<td>5.6 ±0.4</td>
<td>6 ±0.5</td>
<td>5.4 ±0.5</td>
<td>4.2 ±0.5</td>
</tr>
<tr>
<td>Pre-steam End-split score due to openings</td>
<td>1.3 ±0.6</td>
<td>2.7 ±0.7</td>
<td>6.9 ±3.9</td>
<td>0.6 ±0.3</td>
<td>0.5 ±0.3</td>
</tr>
<tr>
<td>Post-steam End-split score</td>
<td>7.8 ±3.4</td>
<td>20.3 ±3.8</td>
<td>38.9 ±16.3</td>
<td>8.8 ±2.7</td>
<td>5.8 ±1.0</td>
</tr>
<tr>
<td>Post-steam End-split score due to splits</td>
<td>3.4 ±0.7</td>
<td>6.2 ±0.4</td>
<td>6.0 ±0.5</td>
<td>6.2 ±0.5</td>
<td>4.2 ±0.5</td>
</tr>
<tr>
<td>Post-steam End-split score due to openings</td>
<td>4.4 ±2.7</td>
<td>14.7 ±3.5</td>
<td>32.9 ±16.0</td>
<td>10.8 ±2.4</td>
<td>1.6 ±0.6</td>
</tr>
<tr>
<td>Acoustic resonance (km s⁻¹) from HM200</td>
<td>3.95 ±0.05</td>
<td>4.19 ±0.09</td>
<td>4.06 ±0.06</td>
<td>4.2 ±0.04</td>
<td>3.87 ±0.05</td>
</tr>
<tr>
<td></td>
<td>(3.71 - 4.21)</td>
<td>(3.82 - 4.52)</td>
<td>(3.79 - 4.29)</td>
<td>(4.05 - 4.35)</td>
<td>(3.62 - 4.06)</td>
</tr>
</tbody>
</table>
Eucalyptus dunnii trees and logs sourced from the older plantation were larger than the younger plantation with only minor differences between logs sourced from the 12 and 17 year old plantation. Basic density increased with plantation age, whereas green density showed less variation. Heartwood percentage differed little with plantation age ranging from averages of 63 to 68%. Kino was present in all plantations, but not all individuals, and was generally more extensive in the older plantation. Splitting was worst for logs sourced from younger plantations and increased during the steaming process. The end-split score attributable to extent of openings was less than that attributed to length of splits. This was particularly the case when splitting post steaming was measured.

Table 3. Characteristics of E. dunnii trees and of the logs sourced from different aged plantations used for producing veneer. Means and SEM (n=9 or 10) with range shown in parenthesis.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Boambee 12 years</th>
<th>Newry 17 years</th>
<th>WCC 34 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics of the tree</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBHOB (cm) [mean (range)]</td>
<td>43.1 ±0.9 (39.2-48.0)</td>
<td>41.6 ±1.0 (33.3-46.8)</td>
<td>47.9 ±1.9 (39.2-58.7)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>36.9 ±0.6</td>
<td>38.5 ±0.5</td>
<td>42.2 ± 0.7</td>
</tr>
<tr>
<td>Fakopp velocity (km s⁻¹)</td>
<td>3.51 ±0.05 (3.16-3.79)</td>
<td>3.57 ±0.06 (3.26-3.76)</td>
<td>3.50 ±0.01 (3.13-3.83)</td>
</tr>
<tr>
<td>Basic density (kg m⁻³)</td>
<td>538 ±9</td>
<td>557 ±10</td>
<td>623 ± 16</td>
</tr>
<tr>
<td>Green density (kg m⁻³)</td>
<td>1123 ±6</td>
<td>1120 ±7</td>
<td>1175 ±9</td>
</tr>
<tr>
<td><strong>Characteristics of the log</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter of Large end (cm)</td>
<td>37.4 ±0.8 (32.4-41.6)</td>
<td>37.0 ±0.9 (33.9-41)</td>
<td>40.7 ±1.6 (33.6 - 49.5)</td>
</tr>
<tr>
<td>Diameter of Small end (cm)</td>
<td>31.5 ±0.7 (27.9-35.4)</td>
<td>31.8 ±0.9 (28-35.7)</td>
<td>35.8 ±1.4 (30.1 - 43.8)</td>
</tr>
<tr>
<td>Heartwood (%)</td>
<td>63 ±2</td>
<td>64 ±1</td>
<td>68 ±1.0</td>
</tr>
<tr>
<td>Length of Kino veins (cm)</td>
<td>1.2 ±0.6</td>
<td>1.0 ±1.0</td>
<td>7.7 ±1.5</td>
</tr>
<tr>
<td>Angle of Kino veins (°)</td>
<td>4 ±2</td>
<td>7 ±7</td>
<td>48 ±9</td>
</tr>
<tr>
<td>Pre-steam End-split score</td>
<td>13.8 ±3.9</td>
<td>15.5 ±3.1</td>
<td>8.3 ±1.0</td>
</tr>
<tr>
<td></td>
<td>Group 1</td>
<td>Group 2</td>
<td>Group 3</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Pre-steam End-split score due to splits</td>
<td>3.9 ±0.8</td>
<td>3.7 ±0.8</td>
<td>5.6 ±0.4</td>
</tr>
<tr>
<td>Pre-steam End-split score due to openings</td>
<td>9.9 ±3.3</td>
<td>11.8 ±2.5</td>
<td>2.7 ±0.7</td>
</tr>
<tr>
<td>Post-steam End-split score</td>
<td>26.6 ±7.6</td>
<td>17.0 ±3.2</td>
<td>20 ±3.8</td>
</tr>
<tr>
<td>Post-steam End-split score due to splits</td>
<td>6.8 ±0.6</td>
<td>6.2 ±0.7</td>
<td>5.6 ±0.4</td>
</tr>
<tr>
<td>Post-steam End-split score due to openings</td>
<td>19.2 ±7.2</td>
<td>10.8 ±2.6</td>
<td>14.7 ±3.5</td>
</tr>
<tr>
<td>Acoustic resonance (km s(^{-1})) from HM200</td>
<td>3.83 ±0.06 (3.48-4.03)</td>
<td>3.99 ±0.04 (3.77-4.15)</td>
<td>4.19 ±0.09 (3.82 - 4.52)</td>
</tr>
</tbody>
</table>
3.2 Veneer recovery for 34-year-old species trial

Total volume of veneer recovered depended on species and log diameter (either DBHOB or SED of the log) (P<0.05) but the position in the log from which billets were sourced did not affect recovery. The species component was related to a combination of effects including 'spin out' related to splitting, and factors such as decay/kino.

![Graph showing green off-lathe recovery for different species](image)

Figure 7. Green off-lathe recovery (m$^3$ and % volume) of five 34 YO species.
Recovery of veneers was reduced by greater extent of end-split (measured either before or after steaming) \( (P<0.05) \) highlighting the importance of splitting on economics of plantation forestry.

Percent of volume recovered after dying and grading veneers to either Australian and New Zealand Standard \textit{AS/NZS 2269.0:2008. Plywood – Structural, Part 0: Specifications.} (Standard Australia, 2008) (i.e. Grade A – D as grade E considered discard) or Big River Timbers internal standards was not affected by species or billet position within a log \( (P>0.05) \). However log size (DBHOB or SED) showed a positive trend with increased \%Recovery, whereas extent of end-splitting did not affect \%Recovery.

\section*{3.3 Veneer recovery from \textit{Eucalyptus dunnii} age trial}

Volume of veneer produced at the lathe (prior to grading) was dependent on diameter of logs and age of plantation \( (P<0.05) \). The relationship was more apparent when relating volume recovered with the smallest diameter of the logs’ small end rather than the average diameter of the logs’ small end.
Both the percentage of log volume recovered as useable veneer which ranged from 30 to 55% with recoveries typically ranging from 35 - 45%, and percent of volume recovered after dying and grading veneers to either Australian and New Zealand Standard AS/NZS 2269.0:2008. Plywood – Structural, Part 0: Specifications. (Standard Australia, 2008) or to Big river Timber internal standards were related to log diameter or plantation age (P<0.05).

There was no relationship between log diameter and percentages of particular grades of veneers (i.e. A grade, A+B grade, or FACE) that were recovered. Surprisingly the total recovery of veneer or of particular veneer grades was not affected by extent of end-splitting, but this may have been related to similar extend of end-splitting in all three plantations.

### 3.4 Formaldehyde Emmision

All samples tested for formaldehyde emissions met the lowest E₀ class limit specified in Australian and New Zealand Standard AS/NZS 2269.0:2008. Plywood – Structural, Part 0: Specifications. (Standard Australia, 2008), except for one sample, which met next lowest class of E₁ (see Appendix for test data).

The formaldehyde limits appropriate to each emission class specified in Australian and New Zealand Standard AS/NZS 2269.0:2008. Plywood – Structural, Part 0: Specifications. (Standard Australia, 2008), are as follows:

\[ E₀ = 0.5 \text{ mg/L max.} \]
E₁ = 1.0 mg/L max.
E₂ = 2.0 mg/L max.
E₃ = above 2.0 mg/L

In this study, there were significant differences in formaldehyde emissions in the panels between species in the 34 year old trial, and also between ages in the E. dunnii age trial. Mean emission level ranged from 0.082 mg/L for E. saligna to 0.267 mg/L for E. pilularis (see Figure 9).

Formaldehyde emission appears to be significantly affected by wood age. Higher emission levels were recorded for 12 year old E. dunnii (0.357 mg/L) than the older 17 year old (0.297 mg/L) or 34 year old E. dunnii (0.233 mg/L).

The finding that there were more glue failures in the 12 year-old panels than the 17 year-old and 34 year-old panels (see Section 3.5) raises an interesting question: Assuming formaldehyde is a function of the glue and not wood, is there a relationship between the emission level and glue bond failure?

Figure 9  Formaldehyde emission from plywood. Error bars indicate +/- 1 std dev.
3.5 Glue bond quality

Results of the glue bond tests by EWPAA are summarised in Table 4, which shows the number and proportion of plywood that passed or failed the Type B bond test. For a glue bond to be acceptable (i.e., pass), the gluelines in a single test piece, prepared from each sample, shall have a bond quality score in any single glueline of not less than 2 and an average of not less than 5 when assessed in accordance with Australian and New Zealand Standard AS/NZS 2098.2:2006. Methods of test for veneer and plywood - Bond quality of plywood (chisel test) (Standard Australia, 2006).

The 34 year-old *E. dunnii* and *E. grandis* performed well with 100% of the samples having acceptable Type B bond, followed by *E. agglomerata* (88%), *E. saligna* (83%) and *E. pilularis* (78%). The results were of some concern for younger *E. dunnii* with only a low 27% (12 year-old) of the samples satisfying Type B bond quality. A re-test of the *E. dunnii* population confirmed the poor results, although there was a marked improvement in the pass rate (from 27% to 60%) for the 12 year-old material, but a small decline for the 17 year-old material (from 80% to 70%). The bond quality for re-tested 34 year-old *E. dunnii* plywood was unchanged with 100% pass. The results for *E. dunnii* suggests there is an age effect on bond quality and further work is needed to fully understand the factors involved and for suitable glues to be developed.

Figure 10 shows the overall bond score (mean of individual sample average) for all the samples tested. There was a noticeable trend of increasing bond quality (score) with age for *E. dunnii*. 
Table 4  Summary of glue bond tests (Type B) by EWPAA, showing the number of individuals that passed or failed.

<table>
<thead>
<tr>
<th>Species</th>
<th>Age (yr)</th>
<th>Results for Type B bond test</th>
<th>Fail (count)</th>
<th>Pass (count)</th>
<th>% Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. agglomerata</td>
<td>34</td>
<td></td>
<td>1</td>
<td>7</td>
<td>88</td>
</tr>
<tr>
<td>E. dunnii</td>
<td>12</td>
<td></td>
<td>8</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td></td>
<td>2</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td></td>
<td>-</td>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>E. grandis</td>
<td>34</td>
<td></td>
<td>-</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>E. pilularis</td>
<td>34</td>
<td></td>
<td>2</td>
<td>7</td>
<td>78</td>
</tr>
<tr>
<td>E. saligna</td>
<td>34</td>
<td></td>
<td>2</td>
<td>10</td>
<td>83</td>
</tr>
</tbody>
</table>

(Additional tests)

| E. dunnii       | 12       |                               | 4            | 6            | 60     |
|                 | 17       |                               | 3            | 7            | 70     |
|                 | 34       |                               | -            | 10           | 100    |

Figure 10  Overall bond score for all samples combined within each species and age. Error bars indicate +/- 1 std dev.
3.6 Moisture content

Moisture content was within the limits specified in Australian and New Zealand Standard AS/NZS 2269.1:2008. Plywood – Structural, Part 1: Determination of structural properties – Test methods. (Standard Australia, 2008) of being between 6% and 15%, except for one panel which was had a low value of 4.5%. Mean values for the 34 year-old species material ranged from 7.8% (E. dunnii) to 9.2% (E. agglomerata) (Figure 11). The mean moisture content of the 12 and 17 year-old E. dunnii panels was similar at around 9.5%; this being significantly higher than the older 34 year-old E. dunnii panels.

![Figure 11 Moisture content of plywood. Error bars indicate +/- 1 std dev.](image)

3.7 Grade recovery

Appendix A3 gives the individual stress grades of the panels based on MOE as measured on a test piece from each panel. The proportion of panels recovered in each grade is summarised in Table 5 according to species.

Stress grades ranged from F11 to F34 in increasing order of quality. The industry benchmark for high grade plywood is F27. For the 34 year-old material, grade recovery was similar for E. pilularis, E. agglomerata and E. dunnii with at least 76% of the recovered plywood panels making F27 or better. Recovery of the same grades for E. grandis and E. saligna was disappointingly low at around 30% - a result most likely attributed to the high presence of injury related gum.
pockets and borer attack in this study. The majority of the *E. grandis* or *E saligna* panels were rated F17 or F22. The results from the age effect study for *E. dunnii* produced some surprising and favourable outcomes. The 17 year-old *E. dunnii* gave 80% recovery of F27 or better, whilst the 12 year-old material gave 68% for the same grades. These results were encouraging, particularly when *E. dunnii* is not widely regarded by the timber industry. It is however a species of importance for planting in NSW. The potential to produce high grade plywood from a species at such an early age is undoubtedly economically beneficial to forest growers.

### Table 5 Stress grades recovered from each species

<table>
<thead>
<tr>
<th>Species</th>
<th>Age (yr)</th>
<th>Stress Grade</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. agglomerata</em></td>
<td>34</td>
<td>F17</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>21.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>65.2</td>
</tr>
<tr>
<td><em>E. dunnii</em></td>
<td>12</td>
<td>F14</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F17</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>43.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>F14</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F17</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>15.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>40.7</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>F14</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F17</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>42.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>34.0</td>
</tr>
<tr>
<td><em>E. grandis</em></td>
<td>34</td>
<td>F11</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F14</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F17</td>
<td>28.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>12.0</td>
</tr>
<tr>
<td><em>E. pilularis</em></td>
<td>34</td>
<td>F14</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F17</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>54.5</td>
</tr>
<tr>
<td><em>E. saligna</em></td>
<td>34</td>
<td>F14</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F17</td>
<td>26.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F22</td>
<td>26.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F27</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F34</td>
<td>26.8</td>
</tr>
</tbody>
</table>
3.8 MOR & MOE results

Individual panel results for MOR and MOE are given in Appendix A3 and summarised in Table 6. Overall species and plantation age but not billet position influenced MOE or MOR.

Plywood manufactured from 34 year-old *E.agglomerata* and *E.pilularis* had high MOR and MOE (of approximately 110 MPa for MOR and 23000 MPa for MOE). These results were similar to, albeit slightly higher than results for 34 year old *E. dunnii*. (NB. There was no statistical difference between *E. agglomerata*, *E. pilularis* and *E. dunnii*). MOR and MOE of panels produced from 34 year-old *E. grandis* and *E. saligna* were significantly lower (at approximately 18000 MPa for MOE and 90 MPa and for MOR). The result for *E. saligna* is somewhat unexpected, considering the clearwood properties for that species would normally be comparable with *E. agglomerata* or *E. pilularis* (cf. Bootle, 1983). *E. grandis* had the lowest MOR and MOE relative to the other four species.

MOR and MOE of the younger *E. dunnii* (12 and 17 year-old) were only slightly lower than of the 34 year-old material. There was no significant difference in MOR and MOE amongst the 12, 17 and 34 year-old *E. dunnii*.

The average MOR and MOE values according to species and stress grades are given in Table 7 and Table 8. As would be expected, MOR and MOE increased with grade, irrespective of species. In general there was little difference in MOR or MOE between species of the same grade; demonstrating that by segregating plywood on the basis MOE is also effective in segregating for MOR. Any differences in MOR or MOE between species of the same grade may have been attributed to differences in sample size tested within each grade, and/or differences in relationship between MOR and MOE between species. Technically, there should be no difference in MOR or MOE between species of the same grade. The reason being, according to the Australian grading system, there should only be one set of design properties for each grade with no distinction between species.
Table 6  
Species mean MOR and MOE for plywood panels. Std dev given in brackets.

<table>
<thead>
<tr>
<th>Species</th>
<th>Age (yrs)</th>
<th>No. tested</th>
<th>MOR (MPa)</th>
<th>MOE (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. agglomerata</td>
<td>34</td>
<td>46</td>
<td>110.4 (21.2)</td>
<td>23109 (4564)</td>
</tr>
<tr>
<td>E. dunnii</td>
<td>12</td>
<td>57</td>
<td>98.1 (21.1)</td>
<td>19474 (3208)</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>59</td>
<td>98.3 (20.9)</td>
<td>21062 (3339)</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>47</td>
<td>103.6 (28.6)</td>
<td>21283 (4448)</td>
</tr>
<tr>
<td>E. grandis</td>
<td>34</td>
<td>50</td>
<td>88.0 (19.0)</td>
<td>17403 (3400)</td>
</tr>
<tr>
<td>E. pilularis</td>
<td>34</td>
<td>66</td>
<td>109.2 (24.0)</td>
<td>22293 (4358)</td>
</tr>
<tr>
<td>E. saligna</td>
<td>34</td>
<td>41</td>
<td>90.3 (23.5)</td>
<td>18313 (4628)</td>
</tr>
</tbody>
</table>

Table 7  
Mean MOR of plywood panels according to species and grade.

<table>
<thead>
<tr>
<th>Species</th>
<th>Age (yrs)</th>
<th>Mean MOR of panels according to stress grade (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F11</td>
</tr>
<tr>
<td>E. agglomerata</td>
<td>34</td>
<td>70.2</td>
</tr>
<tr>
<td>E. dunnii</td>
<td>12</td>
<td>56.5</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>51.7</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>80.0</td>
</tr>
<tr>
<td>E. grandis</td>
<td>34</td>
<td>54.2</td>
</tr>
<tr>
<td>E. pilularis</td>
<td>34</td>
<td>61.6</td>
</tr>
<tr>
<td>E. saligna</td>
<td>34</td>
<td>63.4</td>
</tr>
</tbody>
</table>
Table 8  
Mean MOE of plywood panels according to species and grade.

<table>
<thead>
<tr>
<th>Species</th>
<th>Age (yrs)</th>
<th>Mean MOE of panels according to stress grade (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F11</td>
</tr>
<tr>
<td>E. agglomerata</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>E. dunnii</td>
<td>12</td>
<td>15941</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>E. grandis</td>
<td>34</td>
<td>11365</td>
</tr>
<tr>
<td>E. pilularis</td>
<td>34</td>
<td>13747</td>
</tr>
<tr>
<td>E. saligna</td>
<td>34</td>
<td>12997</td>
</tr>
</tbody>
</table>

3.9 In-grade evaluation of design properties

An essential part of any timber grading is an assurance that the graded product does indeed meet or exceed the product specification, which includes design properties. For plywood, the design properties for each stress grade are contained in Australian Standard AS 1720.1-1997. *Timber structures - Design methods.* (Standard Australia, 1997).

In this study it was possible only to undertake a limited evaluation of the design properties, as the minimum number of test samples was not achieved for all species and grade. According to Australian and New Zealand Standard AS/NZS AS/NZ 2269.1:2008. *Plywood – Structural, Part 1: Determination of structural properties – Test methods.* (Standard Australia, 2008) the minimum sample needs to be at least 30 for strength (MOR) and 20 for stiffness for a given grade and product type.


The results showed in all cases plywood stiffness far exceeded AS1720 requirements, ie, \( E_k > E \). On the other hand, strength was marginal compared to AS1720 requirements, albeit only slightly less, ie., \( R_{k,norm} < f_b \). Nevertheless, the
results were encouraging given the relatively small number of panels tested, and indicated plantation eucalypts have the potential to produce high value veneer products.

Table 9  Comparison of evaluated in-grade MOR and MOE properties with AS1720.1.1997 design properties.

<table>
<thead>
<tr>
<th>Species</th>
<th>Grade</th>
<th>No of tests</th>
<th>$R_{k,norm}$ (MPa)</th>
<th>$E_k$ (MPa)</th>
<th>AS1720 $f'_b$ (MPa)</th>
<th>AS1720 $E$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. pilularis</em></td>
<td>F34</td>
<td>36</td>
<td>99.1</td>
<td>25327</td>
<td>100</td>
<td>21500</td>
</tr>
<tr>
<td><em>E. agglomerata</em></td>
<td>F34</td>
<td>30</td>
<td>96.5</td>
<td>25400</td>
<td>100</td>
<td>21500</td>
</tr>
<tr>
<td><em>E. dunnii</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 yrs</td>
<td>F27</td>
<td>25</td>
<td>**</td>
<td>19941</td>
<td>80</td>
<td>18500</td>
</tr>
<tr>
<td>17 yrs</td>
<td>F27</td>
<td>23</td>
<td>**</td>
<td>19806</td>
<td>80</td>
<td>18500</td>
</tr>
<tr>
<td>17 yrs</td>
<td>F34</td>
<td>24</td>
<td>**</td>
<td>24128</td>
<td>100</td>
<td>21500</td>
</tr>
<tr>
<td>34 yrs</td>
<td>F27</td>
<td>20</td>
<td>**</td>
<td>19981</td>
<td>80</td>
<td>18500</td>
</tr>
</tbody>
</table>

** no of tests <30

3.10 Relationship between calculated and measured MOE

MOE of test plywood pieces was better able to be predicted from Director HM200 acoustic resonance than Fakopp acoustic velocity (Figure 12). The relationship between MOE$_{Dir}$ and MOE of test panels of different aged *E. dunnii* had a correlation coefficient between 0.4 and 0.5 depending on plantation, and the relationship was similar for plywood panels manufactured from logs sourced from the two younger aged plantations than from the 34 year-old plantation. The finding that Director HM200 can predict test panel MOE is interesting as it indicates the potential that logs could be segregated into those that will produce veneer that meets particular grades of plywood panels.

In contrast the relationships derived from the five species aged 34 years showed MOE of test panels did not have a significant relationship with MOE calculated from either Fakopp or Director HM200. Clearly the use of acoustic tools to predict MOE of finished products requires further attention.
Figure 12  MOE calculated from acoustic velocity of trees and logs, as a function of MOE measured on plywood panels manufactured from this material.
3.11 Hardness (Janka)

The results of the hardness (Janka) tests conducted on the plywood samples are summarized in Table 10. These results provide an indication of the potential for plywood manufactured from plantation-grown eucalypts to be utilized as a flooring product such as T&G flooring.

There was significant difference in hardness between species in the 34 year old species trial. *E. agglomerata* had the highest hardness overall, followed equally by *E. pilularis* and *E. saligna*, then *E. dunnii* and *E. grandis* (Table 10). This trend closely mirrors that of basic density (Table 2), which is probably not surprising given that it is generally known that density correlates well with hardness. *E. agglomerata* performed exceptional well with a mean hardness of 9.7 kN compared to 7.5 kN for solid wood (Bootle, 1983). The hardness of 34 year old *E. dunnii* plywood also compared favorably with that for solid wood. Both *E. pilularis* and *E. saligna* hardness were comparable, albeit slightly lower, to that given by Bootle (1983) for solid wood. *E. grandis* was the only species with a hardness (5.4 kN) much lower than for solid wood (7.5 kN). However, it should be noted that the values given by Bootle (1983) have been obtained from tests on wood sourced from more mature native forests stands.

Age had a significant effect on hardness in the *E. dunnii* age effect trial. The hardness of the 34 year old material was significantly greater than those for the 12 and 17 year old material. The older material had a hardness of 7.7 kN compared to the younger material of around 6.0 kN. There was no significant difference in hardness between the 12 and 17 year old wood.

Table 10  Mean hardness (Janka) values according to species and age, and number of test pieces. Std dev given in brackets.

<table>
<thead>
<tr>
<th>Species</th>
<th>Age (yrs)</th>
<th>No. tested</th>
<th>Hardness (Janka) (kN)</th>
<th>Ref. values* (Bootle, 1983)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. agglomerata</em></td>
<td>34</td>
<td>29</td>
<td>9.7 (1.3)</td>
<td>7.5</td>
</tr>
<tr>
<td><em>E. dunnii</em></td>
<td>12</td>
<td>57</td>
<td>5.7 (1.0)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>59</td>
<td>6.0 (1.1)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>44</td>
<td>7.7 (1.7)</td>
<td>7.2</td>
</tr>
<tr>
<td><em>E. grandis</em></td>
<td>34</td>
<td>42</td>
<td>5.4 (1.0)</td>
<td>7.5</td>
</tr>
<tr>
<td><em>E. pilularis</em></td>
<td>34</td>
<td>54</td>
<td>8.5 (1.6)</td>
<td>9.1</td>
</tr>
<tr>
<td><em>E. saligna</em></td>
<td>34</td>
<td>28</td>
<td>8.5 (1.4)</td>
<td>9.0</td>
</tr>
</tbody>
</table>

*Reference values given in Bootle have been derived from tests on mature native hardwood.*
4 Conclusion

Recovery of veneers depended on species and log diameter. The species component was related to a combination of effects including ‘spin out’, splitting, and factors such as decay/kino which would affect the economics of plantation forestry. Plywood grade recovery was similar for *E. pilularis*, *E. agglomerata* and *E. dunnii* with at least 76% of the recovered plywood panels making F27 or better. Recovery of the same grades for *E. grandis* and *E. saligna* was disappointingly low at around 30% - a result most likely attributed to the high presence of injury related gum pockets and borer attack in this study. The 17 year-old *E. dunnii* gave 80% recovery of F27 or better, whilst the 12 year-old material gave 68% for the same grades. These results were encouraging, particularly when *E. dunnii* is not widely regarded by the timber industry. The potential to produce high grade plywood from a species at such an early age is undoubtedly economically beneficial to forest growers. Quality defects in the plywood included poor bond strength in some instances. Poor bond strength were of some concern for younger *E. dunnii* with only a low 27% (12 year-old) and 80% (17 year-old) having acceptable bond strength. A re-test of the *E. dunnii* population confirmed the poor results, although there was a marked improvement in the pass rate (from 27% to 60%) for the 12 year-old material. The results for *E. dunnii* suggests there is an age effect on bond quality and further work is needed to fully understand the factors involved and for suitable glues to be developed. However, bond strength was excellent in the 34 year-old *E. dunnii* and *E. grandis* (100% of the samples having acceptable Type B bond), followed by *E. agglomerata* (88%), *E. saligna* (83%) and *E. pilularis* (78%). Mechanical properties of plywood manufactured from 34 year-old *E. agglomerata* and *E. pilularis* were similar and had the highest MOR and MOE (of approximately 110 MPa and 23000 MPa respectively), which were not significantly higher than results for 34 year old *E. dunnii*. MOR and MOE of panels produced from 34 year-old *E. grandis* and *E. saligna* were significantly lower. Encouragingly MOR and MOE of the younger *E. dunnii* (12 and 17 year-old) were only slightly lower than of the 34 year-old material. There was no significant difference in MOR and MOE amongst the 12, 17 and 34 year-old *E. dunnii*. There were indications that MOE of test plywood pieces was able to be predicted from Director HM200 acoustic resonance on logs suggesting acoustic tools could be employed to segregate logs into different quality classes. Hardness of plywood differed between species with all species except for *E. grandis* compared favourably or reasonably well with hardness values published for solid wood. However, age had a significant effect on hardness with the older (34 year old) *E. dunnii* plywood having a higher hardness value than the younger material with the 12 year-old material being least hard.
5 Acknowledgements

This research would not have been possible without the support of Forests NSW for provision of the logs and considerable technical and scientific support; of Big River Timber for processing the logs, production of plywood and allowing the generous use of equipment and facilities to Forests NSW staff. FWPA contributed financial support for testing the quality of plywood panels.

6 References


7 Appendices

Appendix A1: Formaldehyde emission test results

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Species</th>
<th>Comments</th>
<th>Finish</th>
<th>Absorbance</th>
<th>Emission</th>
<th>E-Class</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-78-1-38</td>
<td>B Bond</td>
<td>Interior</td>
<td>15 mm</td>
<td>6 ply</td>
<td>Other</td>
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<tr>
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<td>B Bond</td>
<td>Interior</td>
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<td>5 ply</td>
<td>Other</td>
<td>Not Finish</td>
<td>0.011</td>
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<td>Interior</td>
<td>15 mm</td>
<td>5 ply</td>
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<td>Not Finish</td>
<td>0.032</td>
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<td>Interior</td>
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<td>5 ply</td>
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<td>B Bond</td>
<td>Interior</td>
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<td>5 ply</td>
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<td>0.086</td>
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<td>B Bond</td>
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<td>Not Finish</td>
<td>0.076</td>
</tr>
<tr>
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<td>15 mm</td>
<td>5 ply</td>
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<td>B Bond</td>
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<td>5 ply</td>
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<td>Comments</td>
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<td>Result</td>
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<td>Other</td>
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</tr>
<tr>
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<td>5 ply</td>
<td>Other</td>
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<td>15 mm</td>
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<td>5 ply</td>
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Testing has been in accordance with methods outlined in the Australian Standard Test Method's AS/NZS2098.11 for Plywood or AS/NZS4357.4 for LVL. Measurement uncertainty is 0.035 mg/L. All LVL, I Beam and Formply samples are Edge Treated prior to testing. This report must not be reproduced except in full. This document is issued in accordance with NATA's accreditation requirements.

Regards

Susie Steiger
Technical Officer
Appendix A2: Glue bond quality results
Part A: Plywood manufactured from veneers sourced from lower billets
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# Results of Plywood Bond Quality Tests of Samples Received 17/09/2008 (Batch 9-79)

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<th>Thickness</th>
<th>Bond Ratings</th>
<th>Avg</th>
<th>Result</th>
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</table>

Total Samples: 66  
Samples Passed: 54  
Batch Bond Quality Average: 5.71

The bond qualities and thicknesses of the above samples were determined in accordance with AS/NZS 2098.2:2006 (except section 8.1) and AS/NZS 2098.4-2006 respectively. Bond quality pass criteria used as per clause 3.0.5, AS/NZS 2269. The minimum and maximum thickness have not been reported. This report must not be reproduced except in full. This document is issued in accordance with NATA’s accreditation requirements.

Regards

Sue Steiger  
Technical Officer

Tuesday, 21 October 2008
Part B: Plywood manufactured from veneers sourced from lower billets
Results of Plywood Bond Quality Tests of Samples Received 4/02/2009 (Batch 2-17)

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Total Samples: 30  Samples Passed: 23  Batch Bond Quality Average: 6.68

The bond qualities and thicknesses of the above samples were determined in accordance with AS/NZS 2086.2:2006 (except section 8.1) and AS/NZS 2086.4:2006 respectively. Bond quality pass criteria used as per clause 3.3C, AS/NZS 2268. The minimum and maximum thickness have not been reported. This report must not be reproduced except in full. This document is issued in accordance with NATA’s accreditation requirements.

Regards

Susie Steiger
Technical Officer
**Appendix A3. In-grade MOR & MOE test results**


Testing Machine: Avery UTM (Grade A)
Test facility: Forests NSW, Sydney
Test type & configuration: 4-point bending test loaded at third points
Test span: 720 mm
Nominal thickness: 15 mm  Nominal width: 300 mm
Plywood construction: 15-30-5

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