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WOOD MACHINING PROPERTIES OF AUSTRALIAN PLANTATION-GROWN EUCALYPTS

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ABSTRACT

This study assessed the moulding, drilling, turning, sanding, and routing properties of seven plantation-grown hardwood species from southeast Australia to evaluate their potential as a resource for the manufacture of high quality furniture and furnishings. *Eucalyptus grandis*, *Eucalyptus saligna*, *Corymbia maculata*, *Eucalyptus camaldulensis*, *Eucalyptus sideroxylon*, *Eucalyptus cladocalyx*, and *Eucalyptus globulus* were machined using different tools, and the surface quality obtained was visually graded. A sanding sequence of 100-150 grit produced satisfactory surfaces for furniture manufacturing for most studied species. Usually, a feeding direction against the rotational direction of the tool showed best results and reduced incidence of corner breakout when routing. Overall, high-density plantation-grown Australian hardwood species performed well during machining trials with the use of appropriate parameters and cutting tools allowing overcoming some typical processing difficulties for some species. The data obtained within this study will allow optimising the machining process of plantation-grown wood in Australia and increase value from the current plantation resource.

Keywords: *Eucalyptus*, machining, plantation, surface quality, wood.

INTRODUCTION

Most of the furniture manufactured in Australia is made from eucalypt timber species (Ozarska 1997). The decline in Australia's native forest log harvests is closely linked with increases in log harvests from plantation estate and decreased availability of tropical rainforest timber species (Ozarska 2009). Extensive research has been conducted so far on growing eucalypts in plantations and primary processing but secondary processing of Australian plantation hardwoods for high value wood products has received little attention. It is widely accepted that wood species vary greatly in their behaviour under cutting tools (Porankiewicz and Goli 2014). The properties of wood produced from intensively managed trees associated with short-rotation harvest are also quite different from wood produced in natural stands (Bendtsen 1978). Those properties are important in order to assess the ability in processing raw material into products of different shapes and dimensions, with good quality surfaces. The present project was designed to evaluate the potential of seven Australian plantation-grown eucalypts as a resource for the manufacture of high quality furniture and furnishings and to optimise the processing methods. Following planing trials (Belleville *et al.* 2016), the machining trial focused on moulding, drilling, sanding, turning and routing properties of seven young eucalypts growing under short rotation planting conditions with a view to provide recommendations on how these species should be machined to obtain high quality machining performance.

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MATERIALS AND METHODS

Seven species ranging from 15 to 40 years in age were selected from a variety of locations in southeast Australia (Table 1). 60 years of age mature Victorian ash (*Eucalyptus regnans/delegatensis*) was included for comparison purposes. All specimens were prepared from pieces obtained following a planing trial (Belleville *et al.* 2016). The timber was selected from the butt log of the tree, and was cut from the heartwood at a location midway between the bark and pith. Testing methods were based on surface quality protocol developed by CSIRO/Holmesglen Institute which is based on the worst affected area of the machined surface (Waugh and Rozsa 1991). Two people using sight and touch method graded the planed surface. The defects checked for were torn grain (torn and chipped grain are referred to as torn grain), raised grain and chip marks. A score was assigned to the worst defect of each type: 5) Unacceptable with defect a lot beyond repair; 4) Unacceptable with defect just beyond repair; 3) Acceptable with heavy sanding but undesirable; 2) Acceptable with moderate sanding but undesirable; 1) Acceptable with light sanding; 0) No defect present. Moulding, routing and drilling trials were conducted at the Leitz tooling Company in Oberkochen, Germany. Turning and sanding trials were conducted at Holmesglen Institute in Victoria, Australia.

Table 1. Species included in the machining trial.

Species	Origin	Age	Air dry density ($kg\ m^{-3}$)	Mature wood [b] ($kg\ m^{-3}$)
Eucalyptus grandis (flooded or rose gum)	Macksville	28	691 (11,6) [a]	804
	Mildura[e]	17	656 (13,4)	
	Shepparton[e]	22	721 (15,4)	
Eucalyptus saligna (Sydney blue gum)	Shepparton[e]	25	779 (10,4)	806
	Mildura	18	774 (12,4)	
Corymbia maculata (spotted gum)	Lake Hume	40	871 (5,5)	969
	Shepparton[e]	25	888 (3,4)	
	Mildura[cde]	18	798 (6,8)	
Eucalyptus camaldulensis (river red gum)	Mildura	17	696 (13,6)	854
Eucalyptus sideroxylon (red ironbark)	Lake Hume	40	925 (6,8)	1060
Eucalyptus cladocalyx (sugar gum)	Lake Hume	40	1032 (4,4)	1035
Eucalyptus globulus (southern Tasmanian blue gum)	Oxley	16	728 (10,5)	843
	Alexandria[de]	15	703 (6,1)	
	Thurgoona[cef]	16	662 (7,1)	

[a] Coefficient of variation or Ratio of the standard deviation to the mean (%); [b] Air dry density of mature wood at 12% MC according to Kingston and Risdon (1961); [c] Not available for drilling; [d] Not available for turning; [e] Not available for sanding; [f] Not available for routing.

Moulding or shaping

Moulding trial was carried out on 80 specimens 35 mm thick, 40 mm wide, and 2,0 m long with a moisture content (MC) of 10% using a Weinig Hydromat 23 moulder (Oberkochen, Germany) under two different conditions. Condition 1 used high-speed steel (HSS) bolection style mould profile cutters with a diameter of between 123 and 162 mm (Figure 1). Cutting angle was between 15° and 20° depending upon the distance of the cutting edge from the centre of the cutter block. Clearance angle was 20°. Two cutters were used in the cutter block but with a one cutter finish.

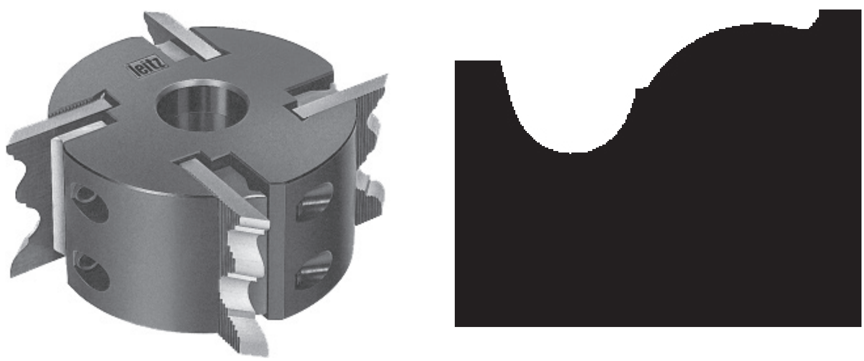


Figure 1. Tool used (left) and profile (right) for moulding trial in condition 1 (adapted from Leitz, 1997).

Condition 2 used a hydro clamped aluminium body system tool with a diameter of 200 mm, a spindle diameter of 40 mm and a width of 80 mm (Figure 2). The tool had a 1,5 mm built in chip-breaker. Average cutting angle was 15° and dependent upon the distance of the cutting edge from the centre of the cutter block. The profile cut using this tool involved a deep cut-out with a flat base and a curved section.

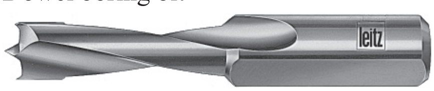
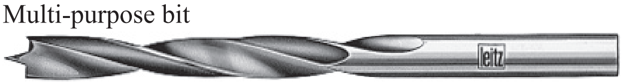
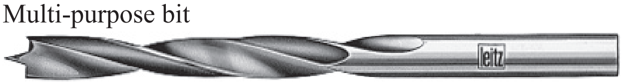
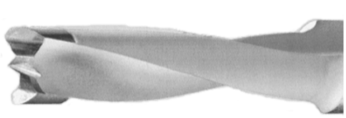
Figure 2. Tool used for moulding in Condition 2 (adapted from Leitz 1997).

Spindle speed was set at 6000 rpm for both conditions. The specimens were fed through the machine in order alternating through the species and graded. Two people using sight and touch method graded the planed surface. A score was assigned to the worst defect of each type: 5) Unacceptable with defect a lot beyond repair; 4) Unacceptable with defect just beyond repair; 3) Fair with heavy sanding but undesirable; 2) Good with moderate sanding but undesirable; 1) Very good with light sanding or no defect present. The pieces scoring between 1 and 3 were considered acceptable.

Drilling

Twenty-six samples 100 mm square and 20 to 35 mm thick were drilled using a numerically controlled machining centre (Maka CNC-222 T, Germany). Five rows of ten holes were bored in the face of each sample using six different drill bits were supplied by the Leitz Company, Germany (Table 2). Blind holes were drilled to a depth of 15 mm. The drills were set at 3000 rpm and feed rate was 2 m min^{-1}. The holes were then graded: 1) Excellent with no chipping; 2) Good with very slight chipping; 3) Fair with some chipping but acceptable; 4) Poor with more serious chipping and unacceptable for seen surface; 5) Very poor with severe chipping and unacceptable.

Table 2. Drill bits used in the drilling trials.

Bit #	Description	Diameter (mm)	Spiral angle	Material
1	Levin bit for blind/through hole 	5	38°	HSS
2	Through drill 	4	15°	HW
3	Dowel boring bit 	5	15°	HW
4	Multi-purpose bit 	5	25°	HSS
5	Multi-purpose bit 	5	15°	HW
6	Marathon precision tear free dowel bit 	5	15°	HW

HSS: high-speed steel; HW: tungsten carbide. Images adapted from Leitz (1997).

Turning

Turning trial was performed on 61 specimens 600 mm long and 40 mm square using an automatic lathe (Barker, Australia). The cutter-head had six sides and profile was cut with 16 profile knives. Cutter-head was 360 mm in diameter and periphery speed was 3330 m min^{-1}. The wood material was conditioned at 23°C and 65% relative humidity until constant mass prior testing. After turning, each piece was examined and graded: 1) Excellent with no defects and a smooth surface; 2) Very good with no defects such as torn or raised grain; 3) Fair, slight torn or raised grain accepted but product suitable for sale after sanding; 4) Unacceptable, deep torn grain and product unacceptable even after sanding; 5) Unacceptable, severe chips or removed timber. Pieces scoring 1 to 3 were considered commercially acceptable.

Sanding

Sanding trial was performed on a two-head wide-belt sanding machine (DMC Europa 110, Italy). Twenty-eight specimens 19 mm thick, 40 mm wide, and 1,8 mm long were prepared from pieces used for planing trial. Aluminium oxide sandpaper (Adalox H211 series, Norton abrasives, Australia) was used for all species. An initial pass was performed with 80-grit sandpaper to calibrate all specimens to the same thickness and determine the belt clogging potential of each species. The belt speed on this head was 18 m sec^{-1}. The machine was set-up to run at 6 m min^{-1} with a depth of cut of 0,5 mm. Each of the species was sanded three times, removing 0,5 mm each time. The belt was removed after the first and the third sanding pass and examined for the presence of clogging (Table 3). The surface finish achieved was then evaluated using five different belt grit sizes: 80, 100, 120, 150 and 180. Two sanding programs were then tested: 100-150-180 and 80-120-180. Depth of cut was set at 0,5 mm for 80 grit, 0,2 mm for 100 grit sandpaper and at 0.1 mm for 150- and 180-grit sandpapers. Feeding was carried out at 6 m min^{-1} feed speed. The surface finish and the level of fuzzing of the worst specimen from each set of four per species were each graded from 1 to 5 after each sanding program (Table 4). A specimen graded 1 for surface finish and 2 or better for fuzzing would be considered acceptable.

Table 3. Relative clogging potential of plantation eucalypts.

Species	After one pass	After three passes
Corymbia maculata	Slight clogging	Medium clogging
Eucalyptus grandis	Medium clogging	No change
Eucalyptus globulus	Slight clogging	No change
Eucalyptus saligna	Medium clogging	No change
Eucalyptus sideroxylon	Medium clogging	No change
Eucalyptus cladocalyx	Very slight clogging	No change

**Eucalyptus camaldulensis* test pieces were not assessed.

Table 4. Grading and description of surface finish following sanding program.

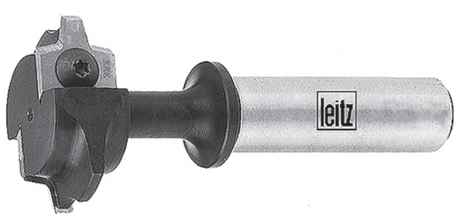
Grade	Surface finish	Level of fuzzing [a]
1	Excellent - very smooth surface with no visible scratches	Excellent - no fuzzing present
2	Good - smooth surface, scratches just visible to the eye (further sanding required)	Good - very little fuzzing
3	Acceptable - visible scratches but cutter marks removed (further sanding required)	Acceptable - fuzzing, but would be removed by further light sanding
4	Poor/unacceptable - scratches and machining defects visible	Poor/unacceptable - excessive fuzzing
5	Extremely poor - cutter marks and defects still showing	Extremely poor - excessive fuzzing, several sanding operations required

[a]Based on Davis (1962).

Routing

Routing trial was conducted using a numerically controlled machining centre (Maka CNC-222 T, Germany). Samples were cut from selected boards and glued together to make thirteen boards 200 mm square, and thickness from 23 to 35 mm. A series of cuts were routed in the edges and face of each sample using four different HW bits (Table 5). Exterior cuts were made on the quarter sawn face. The spindles were set to run at 16000 rpm, and rotated in a clockwise direction (viewed from the spindle). Feeding rate was 5 or 10 m min^{-1} depending on the trial.

Table 5. Bits characteristics for the routing trials.

Cutter #	Description	Diameter (mm)	Spiral angle	Cutting angle	Clearance angle
1	Spiral finishing tool 	20	20°	20°	15°
2	Turnblade cutter, straight 	30	0°	18°	17°
3	Profile cutter, radius tool 	40	0°	15°	20°
4	Turnblade cutter, straight 	18	0°	20°	15°

Images adapted from Leitz (1997).

The trials included:

1. A cut along and across the grain where the cutting action of the tool and the relative feed movement of the workpiece are counter to each other (Tools 1-3, Figure 3).
2. A cut along and across the grain where the cutting action of the tool and the relative feed movement of the workpiece are in the same direction (Tools 1-3, Figure 3).

For all species and tools the depth of cut was 2 mm where the feed speed was 10 and 5 m min^{-1} along and across the grain, respectively. The height of the cut when using bit #2 was 17 mm.

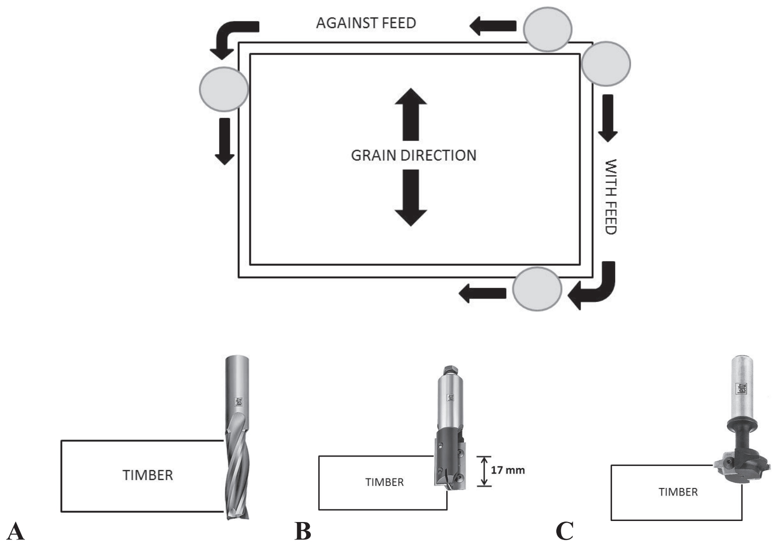


Figure 3. Routing trial for routing bit #1 (A), #2 (B) and #3 (C): 1) a cut along and across the grain where the cutting action of the tool and the feed movement of the workpiece are against each other; 2) a cut along and across the grain where the cutting action of the tool is with feed movement of the workpiece. Cutter rotation was clockwise.

3. A cut through the wood and across the grain (Tool 4, Figure 4). Height of cut for all the test pieces was 17 mm and feed speed was 5 m min^{-1}.

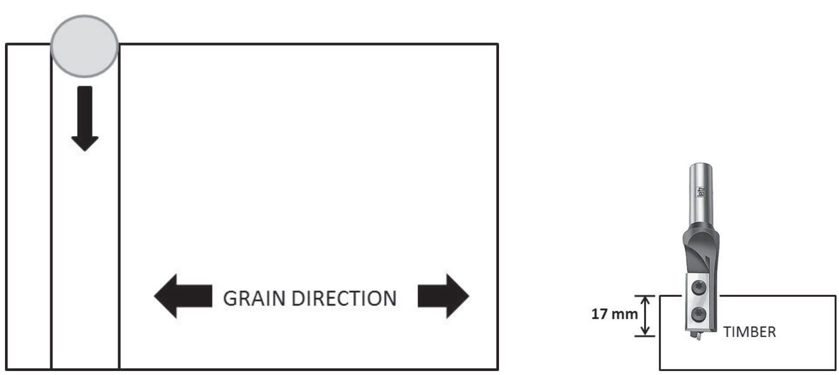


Figure 4. Routing trial for bit #4 with a cut through the wood and across the grain. Cutter rotation was clockwise.

The cuts produced for all trials were allocated a score based on surface produced: 1) Excellent with very smooth surface; 2) Good surface, no tearout and fairly smooth, 3) Acceptable surface, no tearout and could be sanded; 4) Poor, tearout, surface would not be restored by sanding; 5) Severe tearout, very poor surface. In order to standardise the scoring, the system used to score the edges was also used on the corners.

RESULTS AND DISCUSSION

Moulding Properties

The use of a system tool with a 1,5 mm chip-breaker built-in (Condition 2) improved the surfaces produced by moulding for all of the species except *Eucalyptus grandis*, *Eucalyptus camaldulensis* and *Eucalyptus sideroxylon* (Table 6). Part of the improvements was due to the diameter of the system tool used being larger than that for the standard tool. This result demonstrates the potential of a system tool to overcome moulding difficulties for certain Australian species. The grade limiting defect that was most prevalent in every species was torn grain. Hernández *et al.* (2001) also reported torn grain as the principal defect when moulding plantation-grown white spruce (*Picea glauca*). Very little raised grain was produced with either tool. No indication of the defects severity could be attributed to grain orientation. No difference in the amounts of torn or raised grain was observed when samples were moulded with or against the grain.

Table 6. Percentage of defect free pieces following moulding trials.

Species	Condition 1	Condition 2
Eucalyptus regnans	42%	67%
Eucalyptus grandis	37,5%	0%
Eucalyptus saligna	37,5%	50%
Corymbia maculata	23%	100%
Eucalyptus camaldulensis	0%	0%
Eucalyptus sideroxylon	50%	50%
Eucalyptus cladocalyx	14%	50%
Eucalyptus globulus	9%	50%

* Percentage of pieces that did not contain any machining defects (i.e. scoring 1-3).

Drilling Properties

Initial trials revealed that the levin drill (bit #1) caused burning on all studied species and was then excluded from the remainder of the trials. *Eucalyptus cladocalyx* and *Eucalyptus sideroxylon* produced the best results when drilled with a variety of drill bits (Figure 5). Of the remaining species, the order from best to worst was *Corymbia maculata*, *Eucalyptus grandis*, *Eucalyptus saligna*, *Eucalyptus camaldulensis*, and *Eucalyptus globulus*. Examination of the entry of the holes showed that all species produced acceptable holes (i.e. score of 3 or less) with the exception of *Eucalyptus saligna* from one location. As expected, denser species demonstrated better machinability and drilling performances than lighter wood species. This observation is in accordance with results obtained for hybrid poplar clones (*Populus spp*.) (Hernández *et al.* 2011).

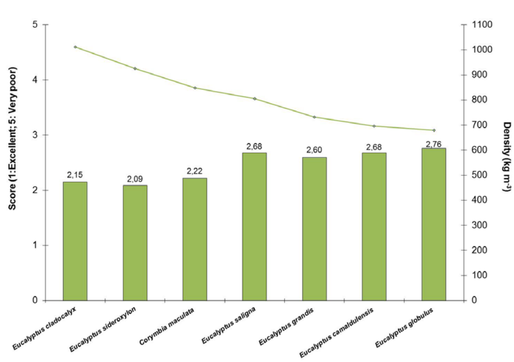


Figure 5. Average drilling score per species for all types of bit.

All the drill bits have shown to be suitable when drilling blind or dowel holes in plantation eucalypts (Figure 6). When quality of entry was important, only the marathon drill bit #6 produced excellent results for all plantation eucalypts combined. This drill bit worked well on the denser species considering that dense hardwoods are usually difficult to drill using small diameter drill bits. All other drill bits generated at least twice the defects of drill #6. The worst results were obtained with drill #4 and produced unacceptable holes in many pieces. The drill bit #4, with a 25° spiral angle, managed fair results with an average of 3,25 but badly chipped the entry and additional work (e.g. sanding and filling) would be required to produce a seen surface. Surface produced during drilling is not as critical as those produced during planing since the hole is likely to be hidden. However, it may hinder the gluing of the pieces during assembly if large chips are produced. Good results were obtained with drill bits #3 and #5 with an average score of 1,96 and 2,18 respectively.

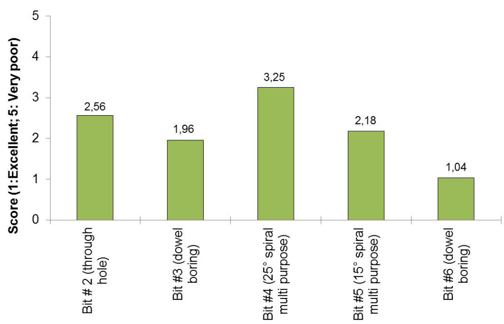


Figure 6. Average drilling score per bit type for all studied species.

Turning Properties

Five of the seven eucalypts were able to be turned well (Table 7). *Eucalyptus sideroxylon* returned an 80% recovery of pieces graded 2 or better. The results were considerably better than for the other species. All other species returned recoveries between 0% and 20% percent for pieced graded 2 or better. These pieces were considered to be excellent, and would need very little reworking such as sanding. *Eucalyptus saligna* from Mildura, *Eucalyptus sideroxylon* from Lake Hume, and *Eucalyptus globulus* from both Oxley and Thurgoona returned 100% of acceptable pieces (Grade 3 or better). *Eucalyptus grandis* from Mildura and *Corymbia maculata* from Lake Hume yielded in excess of 80% recovery. These pieces will require additional work, and are expected to sand to a satisfactory finish. Poor recoveries were obtained from *Corymbia maculata* from Shepparton and *Eucalyptus cladocalyx*. The results for *Eucalyptus camaldulensis* were very poor and no pieces were graded acceptable for the production of furniture components.

There was a difference in performance between wood of the same species, grown at different locations. No relationship could be established between age and turnability. *Eucalyptus grandis* and *Eucalyptus saligna* both returned a greater percentage of good pieces with the younger samples while *Corymbia maculata* returned a greater percentage of good pieces with older samples. All the pieces graded from 2 and 3 were finally hand sanded with 120 and 240 grit cloth backed sand paper. Grade 2 pieces had torn grain completely removed by sanding where grade 3 pieces still showed minor signs of grain tear after the sanding process, still satisfactory for appearance wood products.

Table 7. Recovery and reject percentage per species and origin following turning trial.

Species	Origin	Grade	
		2 or better *	3 or better **
Eucalyptus grandis	Macksville	0	87,5
	Mildura	0	66,7
	Shepparton	20	60
Eucalyptus saligna	Mildura	0	100
	Shepparton	0	75
Corymbia maculata	Lake Hume	12,5	87,5
	Shepparton	16,7	33,3
Eucalyptus camaldulensis	Mildura	0	0
Eucalyptus sideroxylon	Lake Hume	80	100
Eucalyptus cladocalyx	Bandiana	0	42,85
Eucalyptus globulus	Oxley	0	100
	Thurgoona	0	100

* Very good. ** Good.

Sanding Properties

The only grit that left visible scratches on the surface of the timber was the 80 grit. None of the surfaces produced using the 100, 150 or 180 grit belts for any of the seven species showed any visible scratches. The surface finish produced for all pieces was very smooth (grade 1). *Eucalyptus cladocalyx*, *Eucalyptus sideroxylon* and *Corymbia maculata* all scored 3 for surface finish when sanded with 80 grit paper. These species were graded as acceptable. *Eucalyptus globulus* scored 4 (poor). *Eucalyptus grandis* and *Eucalyptus saligna*, scored 5 (extremely poor). These three species all had rough areas.

No improvement in the fuzzing of the surface for *Eucalyptus grandis* past the 100 sanding grits. The remaining species scored 2 or better for fuzzing using the 180 grit paper, indicating that all of the surfaces were acceptable for finishing. For many species a sanding sequence of 100-150 grit produced good enough surfaces to be finished during furniture manufacturing. The only species that would benefit from sanding with a 180 grit paper were *Eucalyptus sideroxylon* and *Eucalyptus camaldulensis*.

Sanding using a 100 grit belt would prepare the timber surface ready for sanding with the finer belts. One pass would not produce a surface that would be acceptable for the finishing of furniture. The critical factor here was whether the timber surfaces produced using the 150 grit belt is satisfactory for finishing, or whether a further pass using the 180 grit belt is necessary.

Routing Properties

There was a definite trend towards a feeding direction against the rotational direction of the tool to produce the best finish. There was also a reduced incidence of corner breakout using this method. The results of this trial indicated that there is no reason to cut with the tool rotating in the same direction as the feed.

Edge finish

A good surface was produced when cutting along the grain on all species, and the results produced were comparable to mature *Eucalyptus regnans*. A little improvement in edge quality could be observed when cutting against the feed of the work instead of cutting with the feed, with most of the tools. When tool #3 was used to cut along the grain, good surfaces were usually produced on all of the species. *Eucalyptus saligna*, *Corymbia maculata*, *Eucalyptus globulus*, *Eucalyptus sideroxylon*, and *Eucalyptus cladocalyx* all had a perfect grade when cut in either direction. When the same tool was used to cut across the grain, all species produced an acceptable surface. When cutting with the feed, all species performed better than *Eucalyptus regnans*. When tool #1 and #2 were used to cut along the grain, all species produced good surface, with tool #2 performing marginally better. *Corymbia maculata* and *Eucalyptus globulus* performed best.

Corner finish

The surface produced when cutting across the grain was not as good as cutting along the grain, but still graded as acceptable. When cutting against the direction of the feed of the wood, the edge finish was marginally better than for cutting with the feed. Cutting this way also resulted in half as many corner breakout defects. When tool #1 was used to cut across the grain with the feed, only *Corymbia maculata* from Lake Hume, *Eucalyptus sideroxylon*, and *Eucalyptus cladocalyx* produced acceptable corners with all other eucalypts returning unacceptable grade. The results for tool #2 were marginally worse. When tool #1 was used to cut across the grain against the feed, the results were better. All species except *Corymbia maculata* from Shepparton and *Eucalyptus globulus* from Oxley produced acceptable corners. Again, results for tool #2 were usually worse.

Groove and breakout

When machining grooves across the grain, breakout was a problem at the start and at the end with an average grade of 3,5 and 4,5 respectively. The only samples to produce acceptable entry and exit breakout figures were *Eucalyptus cladocalyx* and *Eucalyptus grandis* from Shepparton. The scores for mature *Eucalyptus regnans* were worse than the average for the plantation species. Where possible, it would be recommended that grooves across the grain be machined before any external cuts are made. On manually fed routing machines, the breakout at the ends of the groove can be minimised by the use of supporting (backing) pieces.

CONCLUSIONS

This research confirmed that high-density plantation-grown Australian hardwoods can perform well during moulding, drilling, sanding, and routing processes when the appropriate tools and parameters are used, as demonstrated during the moulding and drilling trials. However, turning trials showed to be difficult for *Eucalyptus cladocalyx*, *Eucalyptus camaldulensis* and *Corymbia maculata* from one location. For most species a sanding sequence of 100-150 grit produced satisfactory surfaces for furniture manufacturing where *Eucalyptus sideroxylon* and *Eucalyptus camaldulensis* could benefit from sanding with a 180 grit paper. A feeding direction against the rotational direction of the tool usually produced the best finish when routing which also reduced incidence of corner breakout. The results of this trial indicated that there is no reason to cut with the tool rotating in the same direction as the feed. This project provides the technical information on machining of a number of potential hardwood species which have met tree growth and primary processing requirements regarding their potential for high quality furniture and furnishing products. The data obtained within this study will allow optimising the machining process of plantation-grown wood in Australia and increase value from the current plantation resource.

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