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TITLE: MACHINING AND RELATED CHARACTERISTICS OF NEW ZEALAND GROWN DOUGLAS FIR COMPARED WITH RADIATA PINE AND NORTH AMERICAN GROWN DOUGLAS FIR

AUTHOR(S): J.C.P. TURNER, K.F. GILCHRIST **DATE:** MAR. 1995

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DATE: MARCH 1995

KEYWORDS: PLANING, MOULDING, SHAPING, TURNING, MORTICING, CROSSCUTTING, NAILING, NZ DOUGLAS FIR, NZ RADIATA PINE, NORTH AMERICAN GROWN DOUGLAS FIR

ABSTRACT*

Comparisons were made of machining and related properties of NZ Douglas fir, NZ radiata pine and North American Douglas fir.

The tests applied visual assessment of a variety of machining qualities, including planing, turning, shaping, morticing, crosscutting and nailing. The machining and assessment of the timber was based on previous NZFRI research studies.

The comparison showed that radiata was the top performing machining species for the tests applied. North American Douglas fir was marginally lower and the NZ Douglas fir was the poorest performing but was still capable of producing good results in a number of tests.

NZFRI / INDUSTRY DOUGLAS FIR COOPERATIVE

Machining and related characteristics of NZ grown Douglas fir compared with radiata pine and North American grown Douglas fir

SUMMARY

Comparisons were made of machining and related properties of NZ Douglas fir, NZ radiata pine and North American Douglas fir.

The tests applied visual assessment of a variety of machining qualities, including planing, turning, shaping, morticing, crosscutting and nailing. The machining and assessment of the timber was based on previous NZFRI research studies.

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INTRODUCTION

Douglas fir is New Zealand's second most important exotic plantation species although the current planted area at about 65,000 ha. only represents some 5% of the total exotic plantation resource. The allocation of research effort to this important structural species has been limited and often fragmented when compared to radiata pine. A number of studies however, investigating wood quality aspects in particular wood density and sawing studies, linking log characteristics to timber grade recovery and conversion have been undertaken. A comprehensive review of Douglas fir in New Zealand was carried out in 1974 culminating in FRI symposium No.15, (James 1975 & 1978). Whiteside *et.al.* 1977 and McConchie *et.al.* 1990 added to the available data linking silviculture to timber quality.

Previous research effort has established a wide range of silvicultural regimes in trials throughout the country. These trials and the older Douglas fir stands are now reachig maturity and have been or are due to be scheduled for felling in the near future . For this reason there has been a resurgence of interest in Douglas fir research and the establishment of a Douglas fir Research Cooperative and the current contract with the U.S. Stand Management Cooperative has provided the opportunity to again review past research and focus current and future research to meet industry requirements.

Old growth Douglas fir is renowned for the quality of the clear and high strength timber and in the US has been a major source of structural lumber and plywood and also an important source of appearance and finishing grades. However, second growth stands of Douglas fir will contain a higher proportion of juvenile wood and yield negligible amounts of clear wood when harvested at ages below about 150 years (Middleton and Monroe, 1989).

A component of the current contract with the U.S. Stand Management Cooperative which is designed to relate site and silviculture to the yield and value of Douglas fir required the evaluation of a sample of pruned logs. The pruned logs were assessed by two methods, cross-sectional analysis and by a sawing study. The sawing study involved the selection of 10 logs across the diameter range at each of two stands aged 33 and 59 years. The 20 pruned logs were sawn at the TITC sawmill in Rotorua and the clearwood recovered was dried by a range of methods,(Simpson *et.al.*). Clearwood lengths were selected from this dry timber for the machining evaluation presented in this report.

OBJECTIVE

To examine a range of machining and related applications of NZ Douglas fir and compare these with data for radiata pine and US- grown Douglas fir.

RESEARCH METHOD

Study design

The study was designed to examine the planing, turning, shaping, crosscutting, mortising and resistance to nail splitting.

The procedures adopted have been well documented in previous NZFRI project records (Young 1985, P.R. No. 904 & 1283), However for completeness of this report they are briefly described.

Unlike physical, chemical and mechanical properties, machining properties are difficult to assess by quantitative means. The methods employed by the ASTM-Standard (ASTM D 1666. 1987) which describes methods for conducting machining tests on wood, use subjective visual assessments based on a numerical grading scale from 1 to 5 where:

1- A perfect result (excellent)
2- Slight defects which could be removed with light rumbling (good)
3- Slightly greater defect, but still able to be removed with sandpaper. (average)
4- Deeper and larger defects, difficult to rectify. (poor)
5- Severe defects limiting use. (reject)

This method of assessing machining test samples has been adopted by NZFRI. In addition where some machining related tests were not covered in the ASTM standard, the procedures described by Davis (1962) have been used.

Defects encountered with each test are similar but not always the same or even present, and are dependent on the actual test. The particular defects encountered for each test are described, along with the actual test equipment and procedures, in separate sections of this report.

It should be kept in mind when viewing these machining study results that they represent a single set of conditions for comparative purposes only. These may not be appropriate for the three species tested, and with optimum conditions results might well be improved.

Davis (1962) summarised this approach well by commenting;
"The study (includes) as far as practical the influence of some of the factors within the wood and in the various machines that affect machining results. Since such factors can be combined in literally hundreds of ways, it was impracticable to explore the possibilities of all combinations; instead, one or more sets of fairly representative working conditions were selected for each operation and applied uniformly to all work. These, of course , could not be optimum for all woods, but the results show rather what actually happens under the specified conditions."

DEFINITION OF DEFECTS

CHIP OUT - Chip out is a chipped surface where particles are broken out below the line of cut. Typically, chipped grain is associated with grain deviation in the timber and occurs at spots where the knives are cutting against the grain. Where the slope of grain is wholly in one direction, chip out may be avoided by feeding the board, such that the knives cut with the grain.

TEAR OUT - tear out is the condition where bundles of fibre's have been torn out rather than chipped. This distinction has been introduced especially for turning, shaping, morticing, and drilling, where the fibre's appear to be torn out rather than chipped out. The severity of this defect is similar to chip out in that the defect produces a depression below the surface of cut.

FUZZY GRAIN - Fuzzy grain consists of small particles or groups of fibres, that do not sever cleanly in machining, but stand up above the general level of the surface. Frequently fuzzy grain is associated with reaction wood.

RAISED GRAIN - Raised grain is a roughened condition of the surface of lumber in which part of the annual ring is raised above the general surface, but not torn loose from it.
Considerable pressure is exerted by rollers and the cutting action of the knives as timber passes through a planer. The softer parts (spring wood) can be compressed and then expand once passed through the machine and the pressure is removed producing the raised grain effect.

MATERIALS

New Zealand Douglas fir:

The Douglas fir clearwood samples came from four stands in Kaingaroa forest containing 33 years old and 59 years old trees. The samples were selected from timber sawn and dried in the sawing and drying study section of this research programme. Sizes obtained were 140mm by 24mm and 1.9m in length.

New Zealand Radiata:

The radiata samples also came from a previous sawing and drying study where 30-35 year old radiata representing timber of an age likely to be used in the future was selected. It had been blanked to 100mm by 32 mm and was 2.4m long.

North American Douglas fir:

The US. D. fir was obtained from US lumber merchants as part of a range of North American species imported for a previous comparative machining trial with NZ radiata. The results of this previous study have been used for the comparison in this study.

All of the species, had been conditioned in a laboratory workshop with a climate providing an equilibrium moisture content of approximately 8%.

Table 1 presents the mean and range of moisture content and density at test, for the samples used in this study.

Table 1 - Moisture Content and Density of Species.

Species	Douglas Fir	Radiata pine	US. Douglas Fir
Moisture Content at test (%)			
Mean	8	7	10
Max	9	8	10
Min	7	7	9
Density at Test (kg/m³)			
Mean	549	453	444
Max	630	603	509
Min	473	327	364
Range	157	275	145

PLANING AND MOULDING

Planing and moulding was carried out at the Timber Industry Training Centre (TITC) machining-shop. A Wadkin XJ 220 planer (with knife angle of 25° on the bottom-head and 20° on the top-head, a standard feed speed of 12.5m/min, and with a single knife cutting) was used. The profile was dressed top and bottom with a bull nose moulding on the side head. The boards were fed into the machine randomly (ie with no selection for feeding with or against the grain)

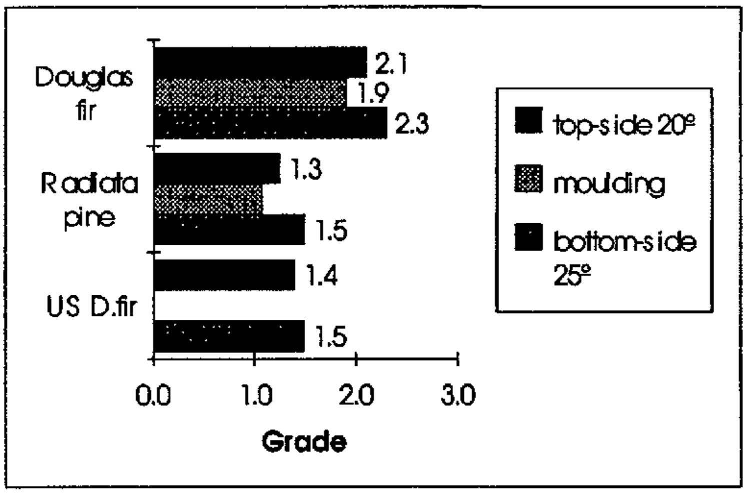
To assess the quality of planing and moulding the three features of each board, top face, bottom face and moulding were considered. Each feature was graded visually on the 1-5 scale.

The various types of defects caused by planing are described in some detail by Davis (1962); these being raised grain, fuzzy grain, chip out and chip marking. Chip-marking was ignored as a defect in this study as it was considered a defect of the machine-extraction system.

RESULTS AND DISCUSSION - PLANING AND MOULDING

The grade for each surface, top, bottom and bullnose moulding for each board were averaged to produce an overall view of the comparative performance of each species for the different knife angles. This is shown graphically in Figure 1.

Figure 1 - Comparison of the average grades for planing, for two knife angles, and moulding by species.

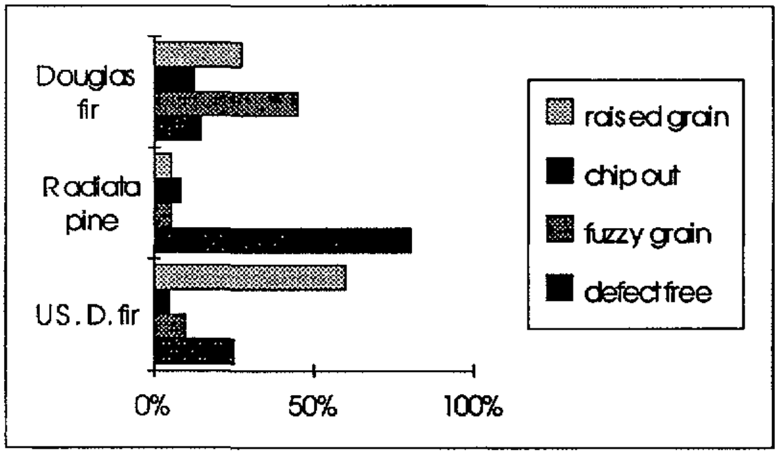


From the figure it can be seen that the lower knife angle (20°) produced marginally better results for all the species.

These results are somewhat surprising, lower knife angle around 20° are generally recommended for hardwoods (high density) and 30° for softwoods. The actual differences are small and are probably a result of the subjective nature of the assessment.

To illustrate the distribution of defects present, and provide a comparison of the general relationship of defect type to species, the % of defect types that occurred (considering all surfaces) is shown in Figure 2. Radiata shows up as a high performance timber, that will plane well to a surface not requiring additional treatment. Fuzzy and raised grain were the major degrades in the Douglas fir and would require light sanding to be suitable for stain or paint.

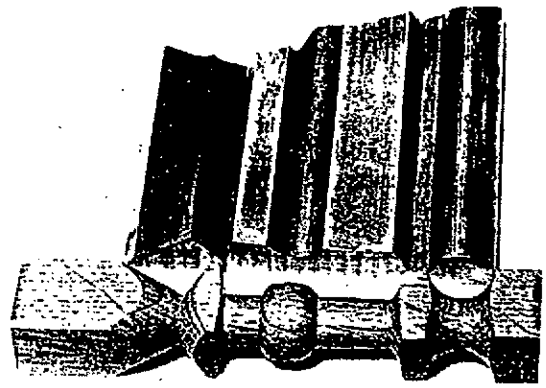
Figure 2 Percentage of each defect type assessed on planing and moulding for each species



ASTM-TURNING

The ASTM turning was done on a CALPE M 1200-H lathe at Kaimanawa Wood Products, Rotorua, using a well sharpened back knife in the shape of the ASTM-profile illustrated in Figure 3.
The milled-to-pattern knife produces a small turning with considerable detail. The turning contains a bead, a cove and fillet (dowel) together with cuts at various angles to the grain.

Figure 3 - Turning Knife and Sample

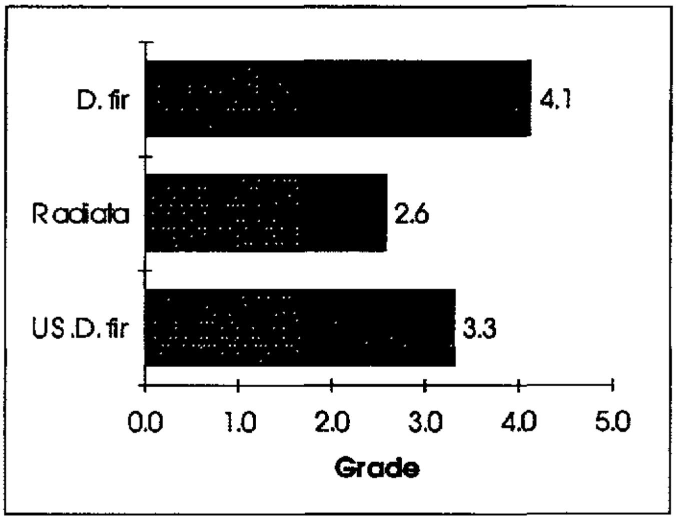


The samples were prepared to a size of 19mm by 19mm and a length of 127mm. 20 samples of each species were prepared. The spindle speed used was 3000rpm as the closest speed to the recommendation of the standard (3200rpm).

RESULTS AND DISCUSSION - ASTM TURNING

The average grades for each ASTM sample by species is shown in Figure 4. Only one grade is assigned to each turning and is based on the worst grade defect encountered. The NZ Douglas Fir demonstrated the poorest turning properties with major chip out and shattering of the piece in the lathe. This was a direct result of the pronounced ring density variation between earlywood and latewood. Previous study reports on Larch (Young 1991 P.R.No. 2894 & P.R.No. 1997) found similar problems. The knife digs into the soft earlywood and then suddenly hits the higher density latewood, resulting in severe chip out, or breakage. Results for the US D.fir were also poor although chip out with the tighter rings was less severe.

Figure 4 - Comparison of the average grades for the ASTM- Turnings



SHAPING (ROUTING)

The primary object of this test was to compare and rank the species by subjective measurement of the shaping or routing qualities of the wood.

Shaping was performed at a commercial operation in Auckland at the Avenue Furniture Company, Veronica St, New Lynn.

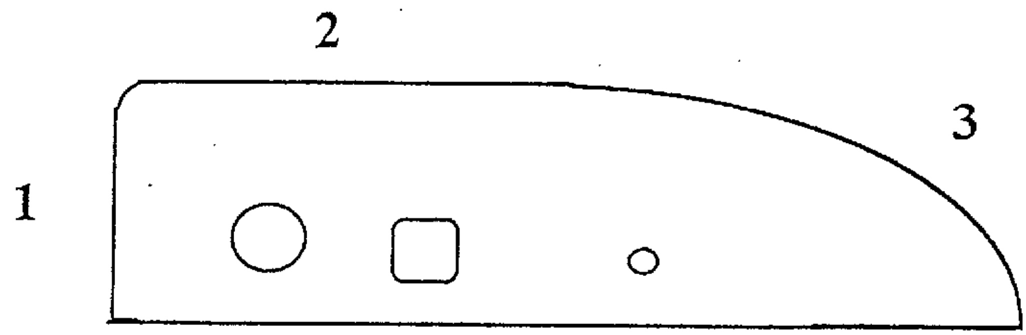
The machine used was a CNC shaping machine CMS NC PF 1 from Italy manufactured in 1991. It was equipped with an 8-tool-rotor head which permitted selection and operation of any of the 8 tools without repositioning of the sample.

The test blanks were 305mm long, 75mm wide, and 19mm thick. Moisture contents were as shown in Table 1. Vacuum pressure was used to hold each sample onto one of two plywood jigs during shaping.

The basic shape was outlined with a "GUHDO" turnblade shaping hogger with Carbide replacement knives. The diameter of this hogger was 35mm and maximum depth of cut was 65mm. The spindle speed for the hogger was 18000rpm and it cut the pieces in direction of the feed. For the finishing cut a spindle shaper was used and it turned anti clockwise around the piece to cut the profile. The spindle speed of the shaping blade was 9000rpm and the feed rate 2.5m/min.

The profiled edge surface was assessed in 3 sections, the end grain, parallel to the grain, and the diagonal curve across the grain (see figure 5).

Figure 5 - Shaping Sample With Sections 1-3

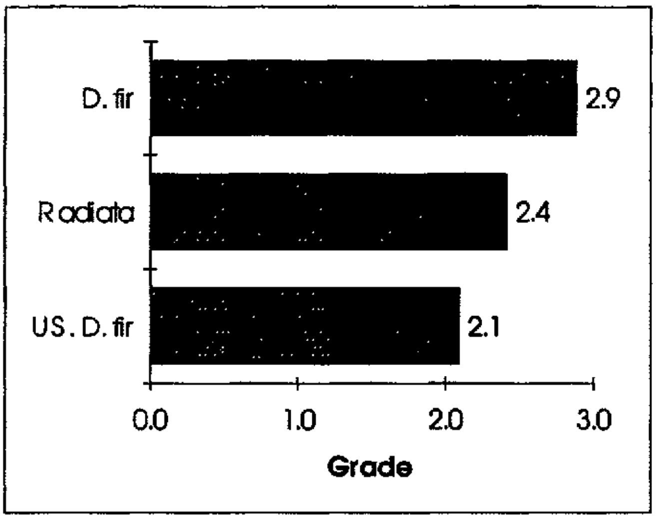


All sections were individually graded on the scale from 1 to 5 , with the following defect types:
F - fuzzy grain ; C - chip out ; R - raised grain ; T - tear out

RESULTS AND DISCUSSION - SHAPING (ROUTING)

The poorest grade for the three sections within each sample, have been averaged to provide an overall comparative performance for shaping by species. Figure 6 shows these results.

Figure 6 - Comparison of the Average Grade for Shaping by Species



The US. D.fir showed the best performance with about 90% of the samples being good to excellent. Radiata had 68% (in the 1&2 grade) and NZ D. fir (37%) again produced the poorest grades, with tear-out in the end grain sections (1 and 3) as the worst grade reducing defect.

Cuts made in a direction parallel to the grain or in a diagonal direction were consistently and noticeably better than cuts at a right angle to the grain. A light fuzziness was noted, on the curved section (3), in radiata pine due to the coarser grain of radiata. Frequently a light fraying or fuzziness on the top edge of the profile was noted with all species. This would easily be removed with light sanding.

MORTICING

Although the ASTM standard requires the use of manual boring for morticing, advantage was taken of the CNC 8 tool head, to assess the machining qualities of the router bit for morticing. The router bit had a diameter of 10mm and the spindle speed was 8000rpm. It was used to make a square mortice hole about 22mm across and a 10mm drill hole. The feed rate vertically was 2.5 m/min and horizontally 1.25m/min.

Additionally the manual hollow-chisel type was used following procedures described by Davis (1962). The tool head, consisted of a hardened steel square section, with the centre hollowed out to contain an auger. The inner faces of the chisel are sharpened to form four cutting edges while the auger cuts out the bulk of the material removed.

The tool was used on a hand operated drill press.

The hand operation meant that it was not always possible to maintain a smooth and even feed rate throughout the cut, especially with the Douglas fir growth ring density changes. However it is unlikely that this had a major influence on results.

Spindle speed was 2700 rpm and the size of the chisel was 1/2 " by 1/2 " . The square holes were made with one side parallel to the grain direction.

Evaluation of the morticing was based on the same defect types and grade scale 1 to 5 as shaping. The edge and inner surface of the hole were assessed.

RESULTS AND DISCUSSION - MORTICING

The performance of the species by CNC-routing is shown in Figure 7 and for manual morticing in figure 8. Radiata produced the best results, with smooth inner surfaces and relatively clean entry edges. The NZ Douglas fir also had good edge grades but slightly rougher interiors. The US Douglas fir showed more tear-out on the edges but had smooth inner surfaces.

Figure 7 - Comparison of average grades for CNC morticing based on worst defect (either edge or inner hole surface)

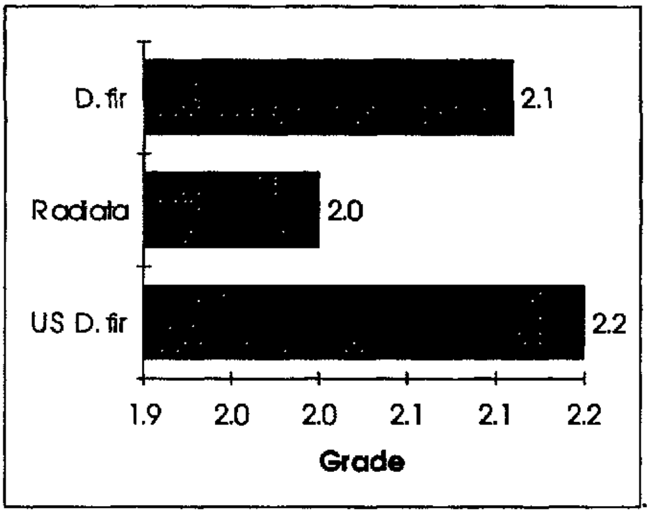
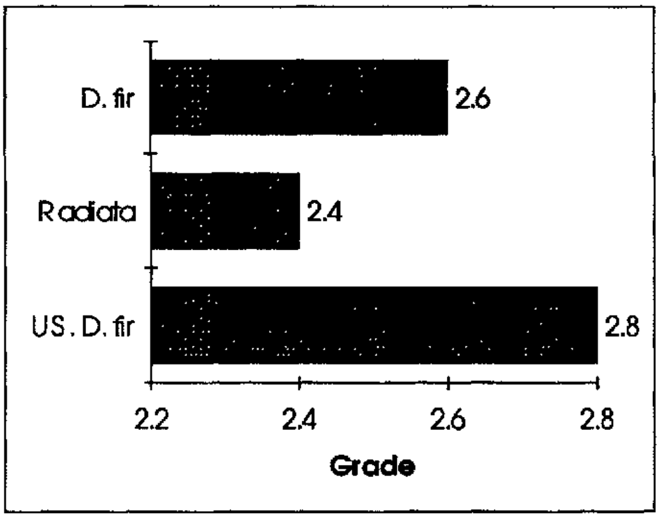


Figure 8 - Comparison of average grades for manual morticing based on worst defect (either edge or inner hole surface).



In the manual mortising two edges of the chisel cut across the grain and simultaneously two cut parallel to the grain. The early wood of the NZ Douglas fir tended to crush and tear out across the grain. Additionally both Douglas fir samples tended to chip out on the entry edge. The more even density of the radiata produced the best results.

CROSSCUTTING

For the US Douglas fir an automatic electronic crosscutting machine, (Paul electronic cross-cutter, operated by "Global Timbers" Rotorua), was used to cut off a 200mm section from a 1m length. The saw had a carbide tipped blade Ø 595mm with 144 teeth, 5mm kerf, and 3500rpm spindle speed.

This machine was not readily available for the other two species which were cut instead using a newly sharpened 80 tooth, Ø350mm carbide tipped crosscut blade, with a rake angle of 4° on a " SCM L'invincible" panelsaw with slide (NZFRI workshop). The saw arbour ran at 3200 rpm, and the highest point of the blade was 11cm above the sawing table. Feed speed was kept as constant as possible by the operator and this was made easier by the use of the "sliding bed " facility on the machine. Samples of each species came from the machining and moulding sample boards.

The cut-off piece (15 cm long) was assessed for the smoothness of cut and the amount of splintering on the bottom and back edge. The grade for the top and front edge was excellent on all samples, so it is not mentioned separately in the analysis.

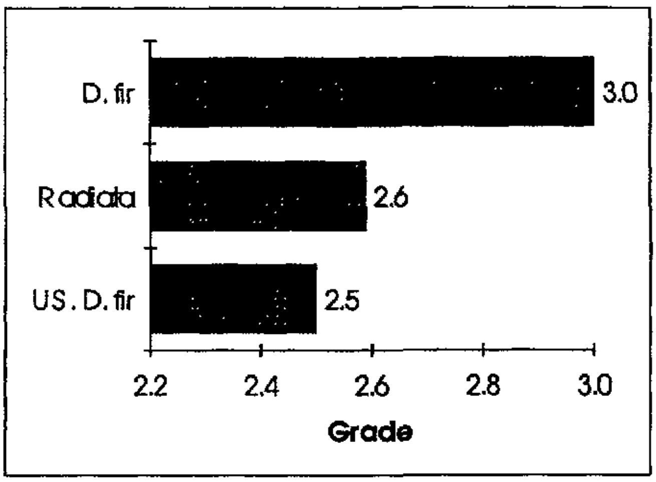
The grades for the back edge and bottom were based on a slightly more objective basis by using the following scale.

1 - Clear
2 - Chip-out less than 1mm along the grain.
3 - Chip-out greater than 1mm along the grain.
4 - Chip-out greater than 1mm in depth.
5 - Chip-out occupying 25% of the bottom surface with type 3 & 4 defect.

RESULTS AND DISCUSSION - CROSSCUTTING

Average grades are presented in Figure 9.

Figure 9 - Comparison of average grades for crosscutting based on worst defect (eitherX-cut surface or back edges.).



The most important criteria of a good cross-cut is a smooth, clean cut with a minimum of fibre break out on the surfaces.

The US. Douglas fir produced the best quality with an average grade of 2.5 for smoothness of the cut-surface. Splintering or break-out on the bottom and back side surface occurred to some extent on all species, with the worst splintering on the NZ Douglas Fir.

Surprisingly the NZ Douglas fir produced the second best cross-cut surface for smoothness, despite the density variation across the growth rings. Radiata was not as good, showing slightly more tear out.

NAILING

With the wide use of nailing in the remanufacturing industry, an indication of the nailing properties of a species is of interest. The ASTM has no standard for nail splitting but Davis (Davis 1962) describes a method which was applied for these studies.

In brief, a nail positioning jig was made up to position 3 nails within 10mm of the sawn end of the sample, equi-distant from the edges. Bright steel jolt-head nails of 3.15mm diameter, 75mm long were driven with a standard carpenters hammer, as evenly as possible.

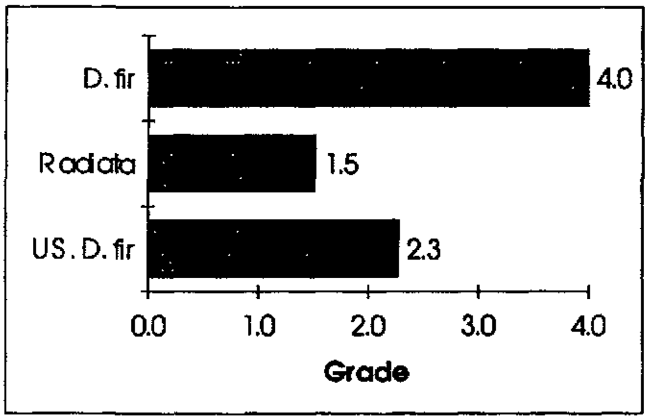
For this test the assessment had an objective basis for grading.

The grading was:	1-excellent:	no splitting
	2-good:	splitting ≤ 10mm
	3-average:	splitting 10-25mm
	4-poor:	splitting 26-50mm
	5-reject:	splitting ≥ 50mm

RESULTS AND DISCUSSION - NAILING

The results for nailing are presented in Figure10.

Figure 10 - Average splitting grade of all nails for each species.



There was no discernible difference between the 3 nails in any sample, and the distance to the edge had no influence on splitting. The NZ radiata performed very well showing almost no splitting. US. Douglas fir showed a higher tendency to split, and for the NZ Douglas Fir, nail splitting was quite severe.

For the Douglas fir it is recommended to drill small holes before nailing or avoid nailing to close to a cross cut end.

SUMMARY OF RESULTS AND DISCUSSION

Comparison of the grade results for each test by species is shown in Table 2. The comparisons are based on the percentage of samples that met the grades 1 and 2 or grades 1 to 3 as described in the ASTM standard. These grades are shown in the "Grades included" column in Table 2.

Table 2 - Summary of percentage grade output for each species in each test

TEST	GRADES INCLUDED	NZ DOUGLAS FIR	RADIATA PINE	US. DOUGLAS FIR
Planing 20^{o} knife angle	1 & 2	84%	100%	100%
Turning ASTM	1 to 3	31%	100%	63%
Shaping	1 & 2	37%	68%	90%
Cross-cutting	1 to 3	92%	100%	90%
CNC Mortising	1 & 2	97%	95%	83%
Manual Mortising	1 & 2	61%	82%	35%
Nailing	1 & 2	19%	94%	62%

CONCLUSIONS

It is not easy to provide a meaningful overall assessment of the machining characteristics of species based on grades covering such a range of utilisation options.

A simple way is to rank the species based on the grade percentage scores shown in Table 2. The problem with this kind of ranking is, that although there may not be much difference between the total scores used for ranking, there may have been large differences in quality between the species and this type of analysis masks such facts. This problem of comparison was discussed by Young (1991 P.R.No. 2894). He made up a scoring system based on overall quality and mark. His scoring system used the percentage of samples in grades 1 and 2 where:

85 - 100 %	scored 5
65 - 84 %	scored 4
50 - 64 %	scored 3
35 - 49 %	scored 2
0 - 34 %	scored 1

In this report this score system has been applied to Table 2 and is shown in Table3. Table 3 indicates a similar ranking for the species to Table 2.

Table 3 - Point score (based on Young's scoring system)

TEST	GRADES INCLUDED	NZ DOUGLAS FIR	RADIATA PINE	US. DOUGLAS FIR
Planing 20^{o} knife angle	1 & 2	4	5	5
Turning ASTM	1 to 3	1	5	3
Shaping	1 & 2	2	4	5
Cross-cutting	1 to 3	5	5	5
CNC Mortising	1 & 2	5	5	4
Manual Mortising	1 & 2	3	4	2
Nailing	1 & 2	1	5	3

It would be useful to allocate an overall single score for each species that more closely indicates quality differences. Young (Ref. 3) attempts this by giving individual ratings a specific weighting, based on a perceived importance of the characteristic being tested, and then uses the sum of these weighted ratings as an overall score. Young suggested weighting factors of; planing (x2), turning (x2), shaping (x2). The maximum possible score a species can achieve based on the six tests in this study is 50. The sum of the weighted score for each species, expressed as a percentage of this maximum, is presented in Table 4.

Table 4 - Weighted point score and comparative rating

TEST	GRADES INCLUDED	NZ DOUGLAS FIR	RADIATA PINE	US. DOUGLAS FIR
Planing 20^{o} knife angle	1 & 2	8	10	10
Turning ASTM	1 to 3	2	10	6
Shaping	1 & 2	4	8	10
Cross-cutting	1 to 3	5	5	5
CNC Mortising	1 & 2	5	5	4
Manual Mortising	1 & 2	3	4	2
Nailing	1 & 2	1	5	3
Points total		28	47	40
Max. possible		50	50	50
% after weighting		56%	94%	80%
Comparative ranking		3	1	2

From Table 4 it may be seen that Radiata came out as the top species, just ahead of US. Douglas fir. The NZ Douglas Fir proved the poorest in this run of machining tests.

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