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Machine Stress Grading of Alpine Ash

BY

D. J. GRANT and G. WEIR



FORESTRY COMMISSION OF NEW SOUTH WALES

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INTRODUCTION

The process of machine stress grading is recognized as a normal part of softwood timber production in Australia. The distinctive, colour marked timber, can be seen in many applications throughout the country particularly in house frames and roof trusses. The Forestry Commission of New South Wales, the original inventor and promoter of the Computermatic stress grading machine, has had a continuous involvement in the development and expansion of machine grading in Australia since the early 1960's and has actively promoted the expansion of the concept to the grading of hardwood species.

As part of the promotion the Forestry Commission of New South Wales, in collaboration with various sectors of the timber industry, has undertaken a number of research projects aimed at the development of trial machine grading programs for various hardwood species native to the States of New South Wales, Victoria, Tasmania and Western Australia. The research has shown that hardwood species can be successfully machine stress graded. The researched species include the following:

- Regrowth mountain ash (*Eucalyptus regnans*).
- Tasmanian Oak (a mixture of *E. regnans*, *E. delegatensis* and *E. obliqua*).
- Silvertop ash (*E. sieberi*) and yellow stringybark (*E. muellerana*) mix.
- Jarrah (*E. marginata*).
- Karri (*E. diversicolor*).

Despite the research efforts there has been no commercial production of machine stress graded hardwood in Australia. Reasons for this are many with three of the most important being (a) the high cost of setting up the equipment to perform the task, (b) the nature of much of the hardwood industry i.e. small unit production of many cross-sections and (c) the fact that a significant proportion of the hardwood timber resource is relatively easily visually graded.

However, in spite of the failure of the industry to adopt the machine stress grading of hardwoods, the results from this project have a good chance of being applied commercially because the company involved in the project operates a mill processing both softwood and hardwood and possesses a Computermatic stress grading machine which is currently only being used for the grading of softwood timber. Thus there is spare capacity for the machine grading of hardwood. Also, residual logs produced from a high quality ash resource contains significant defect due to large branches and generally these produce timber only suitable for scantling applications. It is expected that machine grading will provide better recoveries than the normal method of visual grading because of the presence of large knots in the sawn timber.

AIM AND POTENTIAL BENEFITS

The current project was aimed at the development of machine grading programs for seasoned alpine ash (*Eucalyptus delegatensis*) based on the testing of scantling in the common cross-sections of 90 mm x 35 mm and 90 mm x 45 mm.

It is expected that, for alpine ash, machine grading will improve grade recoveries of seasoned, dressed, structural material and improve the acceptability of the product in the structural timber engineering market.

Although marginal improvement in the utilization from the current quality alpine ash quota can be expected, it is hoped that the potential for the Forestry Commission of New South Wales to market low grade logs will be enhanced. This material, currently wasted where pulpwood integration is unviable, has the scope to increase resource availability to processors who could look forward to subsequently improved efficiencies of scale.

Increased resource availability can be expected to assist in justification of processing plant for value added work, where scale is the current limitation as regards necessary capital equipment provision.

METHOD

1. Preparation of Trial Machine Grading Programs

Trial machine stress grading programs¹ were prepared using the results of previous in-grade testing work on regrowth mountain ash from Victoria (Forestry Commission of New South Wales Project TE639). It was expected that the trial programs would be a good first approximation because alpine ash and mountain ash have similar strength groups and other characteristics of importance for structural end uses. The trial grading programs are given in Table 1.

Two programs were necessary because of the two timber thicknesses to be graded. Small differences in Ep limits for the same grades are due to the discrete nature of the transducers in the Computermatic machine.

The trial programs were initially designed to separate the following stress grades: F22, F17, F11 and F8. These grades were called machine grades until they could be verified as having the required mechanical properties by in-grade testing and were given a designation of 1, 2, 3 and 4 respectively (Table 1).

2. Sampling of the Parent Material

Alpine ash logs from Bago State Forest in the Batlow/Tumbarumba District of New South Wales were sawn and dried using low temperature kiln drying techniques. The logs were of low quality i.e. normally not acceptable for milling purposes. They were in the 20 cm to 40 cm diameter range and consisted of a mixture of thinning stock and limb defective head material.

The seasoned, dressed timber was processed through the grading machine with the Ep limits set in accordance with the trial programs (Table 1). Two main samplings and two minor samplings were undertaken over a period of six months. The aim of the sampling was to provide sufficient

material in each of the proposed grades for the evaluation of bending strength and stiffness. The sample sticks were sprayed along their full length to indicate the machine grade and were sampled in an unbiased manner.

Table 1. Trial machine grading programs for alpine ash using the Computermatic Mk PIVa and PIV stress grading machines.

(a) 35mm thick timber.

Force in Newtons to be applied by the grading machine is as follows: 15.90 x the timber width. Extreme fibre stress = 17.8 MPa.

Machine Grade	Program limit (Units)	Ep Range (GPa)
1	26	14.31 - max.
2	31	12.00 - 14.88
3	37	10.05 - 12.40
4	42	8.86 - 10.33

(b) 45mm thick timber.

Force in Newtons to be applied by the grading machine is as follows: 28.66 x the timber width. Extreme fibre stress = 19.4 MPa.

Machine Grade	Program limit (Units)	Ep Range (GPa)
1	22	14.35 - max.
2	26	12.14 - 15.03
3	31	10.18 - 12.62
4	35	9.02 - 10.52

Note 1. Units are increments of machine measurement equal to 0.19 mm.

2. The Ep ranges for 45 mm thick timber were estimated from data on 35 mm thick timber.

¹ In preparing a machine grading program, the objective is to determine machine grades which will have required or specified basic working stress in bending (f) and mean modulus of elasticity as a joist (Ej) values. Each machine grade is defined by a minimum modulus of elasticity as a plank (Ep) value, and except for the highest grade in a grading program, by a maximum Ep value also (NZS 1984).

3. Test Procedures for Full-size Specimens

a) *Modulus of elasticity as a joist.* Each full-length sample stick was tested at mid-point, on edge, in third point bending over a span of 18 times the nominal width for the evaluation of modulus of elasticity as a joist (E_j). This value is expected to be equivalent to that obtained by random selection of the test position and therefore suitable as the basis for the calculation of the nominal average stiffness for design purposes as described in the Draft Australian Standard Methods for Evaluation of Strength and Stiffness of Graded Timber (SAA, 1989).

b) *Within-stick location of test specimens.* Specimens, 1800 mm in length, were cut from the sample sticks so that the middle region of each specimen contained the lowest grade zone i.e. they were cut in accordance with Clause 8.2 (a) (iv) of Australian Standard AS 1749 (SAA, 1978).

A second specimen was also taken if a further significant defect was present in the remaining material. This increased sample size by 10%.

The specimens were weighed and measured for the determination of air-dry density.

4. Modulus of Elasticity as a Plank and Modulus of Rupture

Apparent modulus of elasticity as a plank (E_p) and modulus of rupture (R) were determined for each specimen in general accordance with AS1749 Appendix A (SAA 1978) i.e. E_p was determined with the specimen loaded at mid-span simply supported as a plank over a 914 mm span with the defective section at mid-point. R was determined with the specimen loaded as a joist in four-point bending with the subjectively worst strength reducing defect at mid-span and on the tension side.

Span to depth ratio was about 18 to 1 as specified in SAA (1989) for the rupture test not 14 to 1 as specified in AS 1749. SAA (1989) indicates that if the shorter span had been used the R values would have been slightly higher.

5. Test Procedures for Small Clear Specimens

In addition to the tests on full-sized samples, tests were conducted on small clear specimens to establish strength groups and joint groups for the various stress grades. Test procedures were based on standard methods described by Mack (1979).

Moisture content, using the oven-dry method, was determined for all clear specimen test pieces. Air-dry density was also determined for the bending test pieces.

6. Data Analysis

Data for the two cross-sections were pooled and then separated into groups based on the stress grade of the sample stick as defined by the individual stick's E_p value. The analysis was performed on these data groups.

Estimates of the lower percentiles of R were made using three different techniques:

Estimate 1 - The ordered array technique eg ASTM D2915 (ASTM, 1974).

Estimate 2 - The Pearson technique described by Johnson *et al.*, (1963).

Estimate 3 - The Weibull technique described by Pierce (1976).

RESULTS

1. Data from Full-size Sample Tests

a) *General.* Total sample stick size was 386 with approximately equal representation from the two cross-section size groups. A total of 423 specimens were cut from the sample sticks.

The frequency distribution of E_p for all specimens is given in Table 2. This illustrates the broad range of values included in the sampling and the reasonable number of specimens below the grade 4 lower limit of 8.86 GPa. This gives some assurance that the lower limit has not been significantly affected by a decrease in data frequency at the low end.

b) *Density and moisture content.* Air-dry density results are given in Table 3. The general trend toward a reduction in density as grade decreases is an expected result with machine graded timber because density has a significant effect on E_p which is the parameter measured during machine grading (Grant *et al.*, 1984). As a matter of interest the mean air-dry density value for alpine ash given in the Draft Australian Standard for Timber Properties (SAA, 1988) is 663 kg/m^3 .

Table 2. Observed frequencies of E_p for all specimens (GPa).

From	To Below	Frequency	
		No.	%
2	3	1	0.2
3	4	2	0.5
4	5	0	0.0
5	6	1	0.2
6	7	10	2.4
7	8	26	6.2
8	9	26	6.2
9	10	36	8.6
10	11	36	8.6
11	12	47	11.2
12	13	39	9.3
13	14	49	11.6
14	15	37	8.8
15	16	41	9.7
16	17	33	7.8
17	18	18	4.3
18	19	13	3.1
19	20	4	1.0
20	21	1	0.2
21	22	1	0.2

All samples were kiln dried as part of normal production. Moisture content was estimated using the oven dry method by selecting a portion of some specimens after testing. Moisture content was found to have a mean value of approximately 12%.

Table 3. Air-dry density (kg/m^3).

Machine Grade	No.	Mean	C.V. %
1	138	683	5.8
2	119	649	6.7
3	99	630	8.4
4	47	618	10.0

c) *Modulus of elasticity on edge.* E_j statistics for the various stress grades are given in Table 4 and indicate that mean E_j decreases as grade (ie E_p range) decreases. This is an expected result because of the good correlation between E_p and E_j ($R^2 = 0.61$) and is consistent with previous work eg, Grant *et al.*, (1984), Leicester *et al.*, (1988).

Table 4 also shows that the average nominal modulus of elasticity as calculated using SAA (1989) was found to be adequate for all proposed grades when compared to the design values given in AS 1720. Interestingly, the average nominal modulus of elasticity was more than 30% better than the design value for grades 3 and 4 respectively. Since stiffness is the critical parameter for many types of structural elements, the test results indicate that there is a considerable potential for improving the efficiency of the structural use of these two grades.

Table 4. Modulus of elasticity as a joist for the proposed grades. Also shown are the nominal modulus of elasticity calculated using SAA (1989), and the design values from AS1720 for the proposed stress grades. Units are GPa.

Machine Grade	No.	Mean E_j	C.V. (%)	$E_{0.05}$	Calculated Nominal Average E	Proposed Stress Grade	Design Value from AS1720
1	131	16.9	9.9	14.5	16.8	F22	16.0
2	108	14.6	9.3	12.4	14.5	F17	14.0
3	82	13.8	13.8	11.1	13.7	F11	10.5
4	43	12.5	18.2	9.5	12.2	F8	9.1

$E_{0.05}$ = 5-percentile value of E_j

d) *Modulus of rupture.* Results are given in Table 5. The working stress ratio is the parameter used here to test if the lower percentile R is adequate for the particular grade. A value of 2.0 based on $R_{0.025}$ is normally considered adequate for structural purposes (Anton, 1981).

Note that the Australian Standard for machine grading (SAA, 1978) specifies the 2.5-percentile modulus of rupture ($R_{0.025}$) as the basis for decisions related to the adequacy of bending strength in any particular stress grade. However, the 5-percentile modulus of rupture ($R_{0.05}$) is now regarded as standard in most countries for this purpose so it was also used for the determination of working stress ratios.

The working stress ratios in Table 5 indicate that bending strength is adequate for grades 1 and 2 but potentially inadequate for grades 3 and 4 because

the estimates based on $R_{0.025}$ are all below 2.0 for the lower two grades. This means that the trial program lower limits on E_p need to be increased to achieve an adequate bending strength for grades 3 and 4.

An alternative to doing this would be to combine grades 3 and 4 thus leaving only one grade below grades 1 and 2. A check could then be made on the new grade to see if the working stress ratio was adequate for it to meet the F8 requirement. This approach would have the advantage of optimising the recovery of F8 material, an important financial consideration in this instance.

Table 6 shows the bending strength results after grades 3 and 4 were combined. Note that all working stress ratios can now be considered adequate. The final grading programs were therefore designed to discriminate F22, F17 and F8.

Table 5. Modulus of rupture statistics and working stress ratios for the original proposed grades.

Machine Grade	Proposed Stress Grade	No.	Mean R (MPa)	C.V. (%)	Working Stress Ratio*					
					$R_{0.025}/f$			$R_{0.05}/f$		
					Est.1	Est.2	Est.3	Est.1	Est.2	Est.3
1	F22	138	88.5	19.8	2.1	2.2	2.2	2.4	2.7	2.5
2	F17	119	74.9	23.8	2.2	2.3	2.2	2.4	2.6	2.5
3	F11	99	54.5	37.7	1.6	1.9	1.7	2.0	2.1	2.1
4	F8	47	42.4	42.7	1.9	-	1.9	2.0	-	2.1

* The working stress ratio is determined by dividing the lower percentile R (either $R_{0.025}$ or $R_{0.05}$) by the basic working stress in bending (f). Three estimates were obtained for each lower percentile R (see text).

Table 6. Modulus of rupture statistics and working stress ratios for the revised grades.

Machine Grade	Proposed Stress Grade	No.	Mean R (MPa)	C.V. (%)	Working Stress Ratio*					
					$R_{0.025}/f$			$R_{0.05}/f$		
					Est.1	Est.2	Est.3	Est.1	Est.2	Est.3
1	F22	138	88.5	19.8	2.1	2.2	2.2	2.4	2.7	2.5
2	F17	119	74.9	23.8	2.2	2.3	2.2	2.4	2.6	2.5
3	F8	137	50.6	41.0	2.0	2.2	2.0	2.2	2.4	2.4

* The working stress ratio is determined by dividing the lower percentile R (either $R_{0.025}$ or $R_{0.05}$) by the basic working stress in bending (f). Three estimates were obtained for each lower percentile R (see text).

Table 7. Modulus of elasticity as a joist for the revised grades. Also shown are the nominal modulus of elasticity calculated using SAA (1989), and the design values from AS1720 for the revised stress grades. Units are GPa.

Stress Grade	No.	Mean E_j	C.V. (%)	$E_{0.05}$	Calculated Nominal Average E	Design Value from AS1720
F22	131	16.9	9.9	14.5	16.8	16.0
F17	108	14.6	9.3	12.4	14.5	14.0
F8	82	13.8	13.8	11.1	13.2	9.1

$E_{0.05}$ = 5-percentile value of E_j .

Results of the E_j analysis for the modified E_p ranges are given in Table 7. Again all grades had a nominal average stiffness greater than the design value. It is worth noting that the new F8 grade was found to have a mean test MOE 45% greater than the design value.

e) *Final grading programs.* The final grading programs for alpine ash scantling in the 35 mm to 45 mm thickness range are given in Table 8. The programs are suitable for use in the Computermatic MkPIVa and MkPV machines and are designed to discriminate F22, F17 and F8 stress grades.

It is recommended that an evaluation of in-grade tension strength be carried out in the future in order to complete the grade verification.

2. Data from Small Clear Specimen Tests

Approximately 30 to 40 sample stick numbers were selected at random from each stress grade. One 20 x 20 x 300 mm bending test piece and one 20 x 20 x 60 mm compression test piece were machined from a clear section of the remaining material from each selected sample stick.

Results of the tests are given in Table 9 for both the original trial grading program and the revised program. As expected, all the measured properties tended to decrease as the stress grade of the sticks from which the specimens were selected decreased.

Table 8. Machine grading programs for alpine ash scantling using the Computermatic MkPIVa and PV stress grading machines.

(a) 35mm thick timber.

Force in Newtons to be applied by the grading machine is as follows:

15.90 x the timber width. Extreme fibre stress = 17.8 MPa.

Stress Grade	Program Limit (Units)	E_p Range (GPa)
F22	26	14.31 -max.
F17	31	12.00 -14.88
F8	42	8.86 -12.40

(b) 45mm thick timber.

Force in Newtons to be applied by the grading machine is as follows:

28.66 x the timber width. Extreme fibre stress = 19.4 MPa.

Stress Grade	Program Limit (Units)	E_p Range (GPa)
F22	22	14.35 -max.
F17	26	12.14 -15.03
F8	35	9.02- 10.52

Note 1. Units are increments of machine measurement equal to 0.19 mm

2. The E_p ranges for 45 mm thick timber were estimated from data on 35 mm thick timber.

Table 9. Small clear specimen results, apparent strength groups and joint groups. The coefficient of variation expressed as a percentage is shown in brackets under the mean value.

(a) Data separated into grades based on the E_p classes specified in the original trial grading program for 35 mm thick timber.

Machine Grade	Proposed Stress Grade	No.	Mean MOE (GPa)	Mean MOR (MPa)	Mean MCS (MPa)	Apparent Strength Group	Air-dry Density (kg/m ³)	Apparent Joint Group
1	F22	43	17.2 (12)	135 (11)	69.9 (8)	SD3	688 (7)	JD3
2	F17	45	15.5 (12)	126 (11)	67.3 (9)	SD4	651 (7)	JD3
3	F11	36	14.6 (14)	121 (15)	64.9 (10)	SD4	644 (8)	JD3
4	F8	30	13.6 (20)	117 (17)	61.6 (14)	SD5	622 (10)	JD3

(b) Data separated into grades based on the E_p classes specified in the final grading program for 35 mm thick timber.

Stress Grade	No.	Mean MOE (GPa)	Mean MOR (MPa)	Mean MCS (MPa)	Apparent Strength Group	Air-dry Density (kg/m ³)	Apparent Joint Group
F22	43	17.2 (12)	135 (11)	69.9 (8)	SD3	688 (7)	JD3
F17	45	15.5 (12)	126 (11)	67.3 (9)	SD4	651 (7)	JD3
F8	66	14.1 (17)	119 (16)	63.4 (12)	SD4	634 (9)	JD3

The apparent strength groupings were assigned using the method described in AS 2878 (SAA 1986) which allocates a grouping for all stress grades was found to be equal to or better than SD4 except for grade 4 in the original trial program. This had an apparent strength group of SD5.

The density results indicate an apparent joint group of JD3 for all grades using the method described in the Draft AS1720.2 (SAA 1988).

CONCLUSIONS

Programs have been designed for the machine grading of seasoned alpine ash scantling into F22, F17 and F8 stress grades.

All three grades meet the normal bending strength and stiffness requirements required for structural purposes. In addition the F8 grade was found to have a nominal average modulus of elasticity 45% greater than the design value so the potential for improving the efficiency of the structural use of this grade is considerable. It was recommended that an evaluation of in-grade tension strength be carried out to complete the grade verification.

Apparent strength grouping of the material from each stress grade indicates that the standard SD4 rating for alpine ash is equalled or exceeded for all grades. The apparent joint group was found to be JD3 for all stress grades.

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