COMBINED VISUAL AND MECHANICAL GRADING OF PINUS RADIATA

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ABSTRACT

In New Zealand, grading machines are programmed to produce grades of **Pinus radiata D. Don** (radiata pine) with properties equivalent to existing visual grades. However, because (a) mechanically sorted timber can contain larger defects than visually sorted timber of similar strength, and (b) the increase in strength on drying is less in timber containing larger defects than in timber containing smaller defects, it has been necessary to impose visual grading requirements on radiata pine that is mechanically graded while green.

A study of the in-grade properties of radiata pine showed that combined visual and mechanical grading gives a better prediction of strength than either method alone, but the prediction of stiffness is not significantly improved by visual in addition to mechanical grading.

INTRODUCTION

In New Zealand about 90% of the timber used for the structural framing of houses is green radiata pine graded visually as either No. 1 or No. 2 Framing according to the National Grading Rules (SANZ 1978a). Although No.1 Framing is specified (SANZ 1975) for the load-bearing members of the framework and No. 2 Framing for the more lightly stressed members, these grades were not formulated as stress grades to which design values should be assigned but rather as utility grades for non-engineering uses. However, it has become necessary to assign stresses to these grades for three reasons:

(1) A structural grade specifically intended for engineer-designed timber structures has never been readily available in New Zealand so designers have tended to specify No. 1 Framing and assign whatever stresses they considered appropriate;

(2) Revision of the code of practice for light timber frame construction (SANZ 1978b), required that the properties of these grades be determined;

(3) In order to determine settings for stress-grading machines to sort material equivalent to existing visually sorted grades, reference strength and stiffness values were required.

DERIVATION OF GRADING MACHINE PROGRAMME

The decision to produce mechanically graded timber in grades equivalent to existing visual grades was based on the reasoning that it was easier to supply an existing market than to create a new one. Also, it was necessary that producers who do not possess grading machines should not be commercially disadvantaged.

The reference values characterising the visually graded timber were taken to be the five percentile modulus of rupture (MOR) and the mean modulus of elasticity (MOE). It is necessary, for a valid comparison, that these quantities be determined in the same manner for both visually and mechanically graded timber – i.e., it is not possible to compare properties for mechanically graded timber from a relationship between strength and stiffness with properties for visually graded timber derived from data from small clear specimens, grading rules, and strength ratios. Data from in-grade tests were therefore used as the basis of a comparison which produced the information given in Table 1.

TABLE 1—Comparison of visually and mechanically graded 100 × 50-mm radiata pine

	Grade					
	Engineering	F11	No. 1 Framing	F6	No. 2 Framing	F4
(a) Graded green – tested green						
MOR (mean MPa)	34.65	36.68	23.00	22.65	17.91	17.01
MOR (5 percentile MPa)	19.57	21.77	12.10	11.59	9.55	8.89
MOE (mean GPa)	8.05	9.29	6.53	6.38	5.68	4.24
(b) Graded dry – tested dry						
MOR (mean MPa)	51.5	55.14	31.7	32.44	25.18	20.04
MOR (5 percentile MPa)	22.15	25.19	12.05	12.81	7.94	4.56
MOE (mean GPa)	10.5	11.82	8.01	8.30	7.45	5.72
(c) Graded green – tested dry						
MOR (mean MPa)		58.54		30.97		
MOR (5 percentile MPa)		25.22		10.81		
MOE (mean GPa)		12.00		8.29		
(d) Graded green with visual regrade of F6 – tested dry						
MOR (mean MPa)				31.70 (1.024)*		
MOR (5 percentile MPa)				12.56 (1.162)		
MOE (mean GPa)				8.46 (1.021)		

* Values in parentheses show the improvement obtained over those given in (c)

The particular values of modulus of elasticity as a plank (EP) which defined the machine grade boundaries were determined by trial and error. The programme finally chosen aims to maximise the recovery of a grade equivalent to No. 1 Framing and produce a small amount of a "super" grade intended for special engineered applications. With this approach, however, machine-sorted grades with properties equivalent to the visually sorted No. 2 Framing or Engineering grades were not obtained.

Properties of Timber Graded Green but Used Dry

As stated previously, the usual building practice in New Zealand is to erect houses with green framing which is not expected to receive its full design dead-plus-live loading before it has dried (equilibrium moisture content is about 16%). Therefore the most relevant data in Table 1 are for timber which is graded green but tested dry. In this case the five percentile MOR of mechanically graded timber in the green F6 grade is too low. On examination of the specimens it was found that the weakest pieces usually were above average density and contained a single large knot which intersected an arris – i.e., appeared on the narrow face of the piece. Therefore, in drafting the New Zealand Standard for mechanically graded timber (SANZ 1979) a clause was added:

> "In F6 grade machine-graded in the green condition, no single knot intersecting an arris shall exceed one-half of the finished cross-section".

The effect of this additional visual grading was to reduce the recovery of F6 grade by about 3%. To achieve the same effect by raising the lower EP grade boundary value would have reduced recovery by about 10%. Thus a practical solution was found to a technical problem but it is pertinent to observe that pieces with such large defects would have to be rejected in any case to obtain customer acceptance.

DISCUSSION

The fact that timber mechanically graded green met the required stress when it was green but not when it was dry indicates that the change in the mechanical properties of structural timber with drying depends on the size of the defects it contains. This may be seen in Table 1 where the ratio of five percentile MOR to mean MOR ranges from 0.51 to 0.59 for timber tested green but from 0.23 to 0.46 for timber tested dry. Table 2 shows the ratio of dry to green MOR and MOE values for several grades of radiata pine. There is a trend of decreasing values of the ratio for the worse grades. Variation of MOR is greater in dry timber than in green, indicating that the increase in strength on drying is not the same for all pieces within a given grade. The above effects are not found in MOE, however.

TABLE 2—Effect of drying on some properties of 100 × 50-mm radiata pine

	Grade (to NZS 3631)			
	Clear	Engineering	No. 1 Framing	No. 2 Framing
(a) Ratio of dry (15% m.c.) to green mean values				
MOR	1.57	1.52	1.38	1.31
MOR	1.32	1.30	1.28	1.27
(b) Coefficient of variation of MOR values (%)				
Green	22	26	33	36
Dry	24	30	37	42
(c) Coefficient of variation of MOE values (%)				
Green	25	22	27	28
Dry	24	20	23	27

The presence of pieces of high density and large knots in the mechanically sorted F6 grades is a result of two factors:

(1) With increasing distance from the pith in radiata pine there is an increase in density and an increase in branch diameter;

(2) The correlation of EP with density (Table 3) is positive while that with defect size (i.e., KAR and MKAR as defined in Table 3) is negative, so that in the mechanical grading process the high density compensates for the presence of the defect.

TABLE 3—Single correlation coefficients relating in-grade properties of radiata pine

	MOR	MOE	EP	D	KAR	MKAR	RW
(a) Green - n = 1347							
MOR	1.0	0.768	0.732	0.474	—0.580	—0.639	—0.358
MOE	0.768	1.0	0.872	0.639	—0.438	—0.360	—0.581
EP	0.732	0.872	1.0	0.666	—0.551	—0.240	—0.615
D	0.474	0.639	0.666	1.0	—0.280	—0.121	—0.527
KAR	—0.580	—0.438	—0.551	—0.280	1.0	0.456	0.198
MKAR	—0.639	—0.360	—0.240	—0.121	—0.456	1.0	0.068
RW	—0.358	—0.581	—0.615	—0.527	0.198	0.068	1.0
(b) Dry (approximately 15% m.c.) - n = 1137 (except EP - n = 797)							
MOR	1.0	0.750	0.708	0.392	—0.526	—0.585	—0.343
MOE	0.750	1.0	0.879	0.602	—0.392	—0.362	—0.565
EP	0.708	0.879	1.0	0.746	—0.492	—0.189	—0.633
D	0.392	0.602	0.746	1.0	—0.209	—0.049	—0.521
KAR	—0.526	—0.392	—0.492	—0.209	1.0	0.454	0.189
MKAR	—0.585	—0.362	—0.189	—0.049	0.454	1.0	0.048
RW	—0.343	—0.565	—0.633	—0.521	0.189	0.048	1.0

Note: Two sizes included - 90 × 40 mm and 190 × 40 mm actual green dimension.

MOR = modulus of rupture; third point loading; span/depth = 15 : 1

MOE = modulus of elasticity on edge including shear effects

EP = modulus of elasticity on flat (as a plank); span 914 mm; load and deflection at midspan

D = density; oven dry weight/volume at test

KAR = knot area ratio; projected cross-sectional area of knots in a length equal to the width expressed as a percentage of the gross cross-section

MKAR = margin knot area ratio; as for KAR but only for the quarter of the cross-section on the worst edge

RW = average annual ring width

All tests done with "worst" edge stressed in tension.

Justification for the imposition of visual grading requirements on mechanically graded timber is found in the correlation coefficients in Table 3 and in the multiple linear regression analysis in Table 4 because:

- EP by itself is a better predictor of MOR and especially MOE than is defect size or density or ring width. Including defect size, however, particularly defects in the margin of the piece, gives a significant improvement in the prediction of MOR but not of MOE;
- Visual grading cannot match mechanical grading in predicting MOE but including an assessment of density would give a considerable improvement over that given by defect size alone.

TABLE 4—Multiple linear regression analysis of in-grade data from dry radiata pine beams

(a) Prediction of MOR including EP (e.g., machine grading); n = 797

Constants (MPa)	Coefficients: EP (GPa)	MKAR (%)	RW (mm)		Correlation R^2
—2.36	4.34			No significant	0.50
14.77	3.80	—0.248		contribution	0.71
11.76	3.98	—0.247	0.216	from KAR	0.71
				and D	

(b) Prediction of MOE including EP; n = 797

Constants (GPa)	Coefficients: EP (GPa)	MKAR (%)	KAR (%)	RW (mm)	Correlation R^2
1.717	0.890				0.77
2.935	0.852	—0.018			0.81
1.536	0.929	—0.024	0.032		0.83
2.377	0.880	—0.024	0.056		0.83

(c) Prediction of MOR excluding EP (e.g., visual grading); n = 1137

Constants (MPa)	Coefficients: MKAR (%)	D (kg/m^3)	KAR (%)	RW (mm)	Correlation R^2
46.27	—0.298				0.34
2.17	—0.289	0.097			0.47
14.05	—0.232	0.084	—0.273		0.52
27.59	—0.233	0.064	—0.259	—0.720	0.54

(d) Prediction of MOE excluding EP; n = 1137

Constants (GPa)	Coefficients: D (kg/m^3)	MKAR (%)	RW (mm)	KAR (%)	Correlation R^2
—3.102	0.026				0.36
—1.298	0.025	—0.028			0.47
3.884	0.018	—0.027	—0.263		0.55
4.668	0.017	—0.023	—0.253	—0.022	0.57

CONCLUSIONS

The percentage increase in strength upon drying of radiata pine decreases as the size of the contained knots increases. This indicates that the sloping grain around knots, combined with the different rates of shrinkage along and across the grain, causes stresses and possible damage in these regions.

Subsequent visual grading of mechanically graded timber can produce a significant improvement in design bending stress with only a small loss in recovery, thus utilising the best features of both methods of grading.

Because the stiffness of the timber is tested in the machine grading process, subsequent visual grading of mechanically graded timber does not significantly improve the MOE of mechanically graded timber.

REFERENCES

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