STRUCTURAL PROPERTIES OF TIMBER FROM TWO POPLAR VARIETIES

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ABSTRACT

For two poplar varieties, **Populus deltoides** Marsh and **P.** 'Androscoggin', moduli of rupture and elasticity were determined from bending tests on 181 specimens of 100 × 50-mm and 60 specimens of 150 × 50-mm timber. For material graded to Building A grade there was no significant difference in strength between the two sizes or the two varieties. A 10% lower modulus of elasticity for the **P. deltoides** was not considered of practical significance. From analysis of the near minimum strengths and other limited data it was concluded that Building A grade poplar could have the same basic working stresses in design as No. 1 Framing grade **Pinus radiata** D. Don provided that nail loads, bolt loads, and stress perpendicular to the grain should be reduced by 30%. Problems in the utilisation of poplar are unlikely to be related to strength considerations.

Keywords: **Populus deltoides**; **Populus** 'Androscoggin'; bending; stresses; strength; stiffness; in-grade testing.

INTRODUCTION

The Forest Research Institute has in recent months received a number of requests from industry regarding the strength properties of poplar. Interest in the species is particularly strong in Canterbury where *P. radiata* structural timber of good quality is presently difficult to obtain. While there is not a large resource of poplar there are significant quantities growing in Canterbury and Otago. The South Canterbury Catchment Board has planted many thousands of hectares in riverbeds for flood control, and potentially more than 10 000 ha will be planted in their region alone. From their own investigations (A. S. D. Evans, pers. comm.) the Board has concluded that the material is salable but they lack information on its strength properties. If the material is to be used for structurally engineered components such as roof trusses there is a need for a wider knowledge of its properties in structural sizes.

Studies to date (Williams *et al.* in prep.) show that, although the timber is not difficult to saw, there are considerable problems with drying, namely distortion (generally associated with tension wood), collapse, and differences in drying time for pieces containing pathological black heart. Some of the early test material was, however, obtained from poorly grown multi-stemmed trees of an unidentified black poplar clone with a high proportion of tension wood. These trees well illustrated the problems, but are not representative of other perhaps more suitable varieties such as *Populus deltoides* (A. G. Wilkinson, pers. comm.). The timber is not naturally durable but may be treated satisfactorily by boron diffusion for internal structural use. Multisalt pressure treatment after drying is not recommended since, in spite of satisfactory fluid retentions in the treatment charge, untreated zones are present in most pieces.

Our present knowledge of its strength is derived from limited tests on small clear specimens of six clones – five balsam poplar hybrids from Rotoehu Forest tested in 1961 (Bier 1982) and one black poplar from McLean's Island in Christchurch (Table 1). Bending tests on five pieces of 100 × 50-mm material (also from McLean's Island) gave an average modulus of rupture of 33.8 MPa and modulus of elasticity of 6.6 MPa. The mean basic density for this (green) timber was 302 kg/m^3. These data indicate that poplar is a low-density hardwood with a clear strength and stiffness lower than *Pinus radiata,* but with in-grade strength that may be equivalent to No. 1 Framing grade *P. radiata.* It was decided to investigate the in-grade strength more thoroughly to establish reliable design data.

TEST MATERIAL

Two species of poplar were investigated. Sixty pieces of 100 × 50-mm *Populus deltoides,* 3 m long, were supplied from a Napier site (by courtesy Soil Conservation Centre, Aokautere, Palmerston North). Sixty pieces each of 100 × 50-mm and 150 × 50-mm *P.* 'Androscoggin', 3 m long, were obtained from the South Canterbury Catchment Board. It was desired to test material with a range of defect sizes to assess the properties of structural timber of different quality. Timber was selected as follows.

Allen Road, Napier: These clones were planted in 1969 as 1-year-old rooted cuttings at a spacing of 5.5 × 5.5 m. The trees were pruned to 2.1–2.6 m in 1970, and to 2.6–4.5 m in 1972. The timber was sawn in 1984 from the basal 4- to 5-m clear-pruned logs of three trees each of four clones of *P. deltoides.* Clonal means for diameter at 1.4 m and total height are given in Table 2.

Canterbury: The timber was sawn from trees of *P.* 'Androscoggin' planted between 1964 and 1966 in the berm land of the Opihi River bed at Arowhenua, 2 km upstream of State Highway 1. The specimens were randomly selected from four unpruned trees in a stand grown at 3 × 8-m spacing.

When the timber from both sites arrived at FRI it was fillet stacked under weights and air dried for about 6 months. Many of the pieces distorted badly in the direction which was not restrained by weights. The woolly appearance of the sawn surface in some pieces indicated the presence of tension wood.

The timber was graded in the laboratory to the Group III rules for Building A grade (SANZ 1978), with clear material being identified on the premise that this would be used for other than structural purposes. The resulting distribution of grades was as shown in Table 3.

TABLE 1—Small clear strength properties of poplar

Clone name and parentage	Moisture condition	Density (kg/m³)	Static bending: Modulus of rupture (MPa)	Static bending: Modulus of elasticity (MPa)	Compression strength parallel to grain (MPa)	Origin and quantity of test material	FRI shipment No.
'Androscoggin'	Green	363	39.1	5680		Rotoehu	128
(**maximowiczii** × **trichocarpa**)	12%	391	61.2	7150		5 tests	(1961)
'Oxford'	Green	345	34.4	5560		Rotoehu	
(**maximowiczii** × **berolinensis**)	12%	384	64.1	6870		7 tests	
'Roxbury'	Green	328	40.3	5000		Rotoehu	
(**nigra** × **trichocarpa**)	12%	349	61.2	6240		4 tests	
'Rumford'	Green	347	42.5	5660		Rotoehu	
(**nigra** × **laurifolia**)						2 tests	
'Strathglass'	Green	340	41.2	5500		Rotoehu	
(**nigra** × **laurifolia**)	12%	354	64.1	6390		3 tests	
						Christchurch	677
nigra 'Italica'	Green	305	36.1	5410	15.6	10 tests	(1983)
(syn. Lombardy poplar)	12%	326	61.5	6750	33.9	9 tests	

TABLE 2—Mean total height and diameter at 1.4 m for **Populus deltoides** from Napier

Clone No.	1972		1974		1984 (16 seasons' growth	
	Diameter (cm)	Height (m)	Diameter (cm)	Height (m)	Diameter (cm)	Height (m)
'G3'	13.4	9.9	23.2	17.7	49.5	28.8
'ANU 60/106'	13.1	9.8	24.1	18.0	46.5	28.2
'ANU 60/125'	11.7	8.7	22.4	15.7	46.6	28.7
'ANU 60/129'	9.4	7.2	21.2	14.4	50.2	24.5

TABLE 3—Grades of test material

Source and size	No. of sticks of each grade		
	Clear	Building A	Commons
Napier 100 × 50-mm	30	25	5
Canterbury 100 × 50-mm	6	27	27
Canterbury 150 × 50-mm	1	40	19

METHOD

For a span to depth ratio of 18 only one test was possible in each of the 3-m lengths of 150 × 50-mm material. Each stick of 100 × 50 mm was marked at 1.9 m from each end and labelled (a) and (b), yielding two potential test pieces. Each piece was regraded to obtain the grade of the test piece.

Modulus of elasticity as plank

Each piece was tested on the flat over a span of 914 mm by applying a central preload of 222 N at the worst defect in the piece. A dial gauge at midspan was set to zero at this point and a further 888-N load applied with readings taken at 444 N and 888 N. The test was repeated if the second deflection was more than 0.1 mm different from twice the first reading.

The modulus of elasticity as a plank (EP) was computed from:

$$EP = \frac{P\ 914^3}{4\ \delta\ b^3 d}$$

where δ was the midspan deflection for an 888-N load P, d was the width of the plank, and b was the thickness of the plank (millimetre units).

Bending as a joist

A ramp third-point load was applied with the worst edge of the piece in tension and with the grade-determining defect between load heads. Span for the 100-mm-deep pieces was 1800 mm, and 2700 mm for the 150-mm-deep pieces. For the 100-mm-deep sticks, piece (a) was tested first. If failure was outside the line marking piece (b), a second test was possible. Failure load was recorded for each test and deflection was measured using an LVDT connected to an X-Y plotter to give a load deflection curve. The duration of each test was about 3 minutes.

Modulus of elasticity as a joist (EJ) was determined from:

$$EJ = \frac{23}{108} \frac{W}{\Delta} \frac{span^3}{b\ d^3}$$

Where W/Δ was the slope of the load deflection curve up to the elastic limit.

Modulus of rupture (RJ) was computed from:

$$RJ = \frac{W_{max} \cdot span}{b\ d^2}$$

After testing, a disc was cut from near the fracture zone to determine moisture content (MC), ring width (RW), and nominal density (DN) (oven-dry weight/volume at test).

A diagram of the projected area of knots in the failure zone was drawn for each failed piece (*see* Fig. 1). From these the knot area ratio (KAR) was calculated as the area of knots divided by the area of the cross-section and the margin knot area ratios (tension TKR, and compression CKR) calculated as the area of knots in the margin divided by the area of each margin (1/4 of the total area). The width of the largest knot (LK) was also measured.

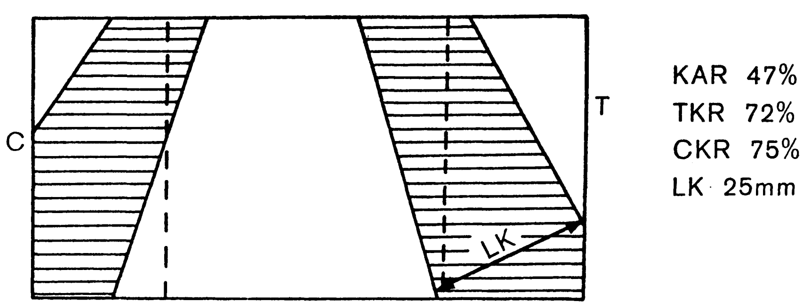

FIG. 1—Sample knot diagram.

RESULTS

The results are summarised in Table 4, and those for Building A grade only in Table 5.

Concomitance of properties

Regression analyses were carried out to assess the effects of defects on the strength and stiffness of the material. Figure 2 shows little if any correlation between stiffness and density for Building A grade. In fact, the Napier 100 × 50-mm material has a lower modulus of elasticity in spite of its higher density (Table 3). A stepwise regression analysis of EJ on DN, RW, MC, for the clear pieces revealed that none of these variables appeared to have any effect on stiffness.

Regressions of RJ on TKR and KAR for all the data are:

$$RJ = 42.4 - 0.35 \text{ KAR} \qquad r^2 = 0.21$$

$$RJ = 42.3 - 0.19 \text{ TKR} \qquad r^2 = 0.23$$

These are both significant trends at the 1% level (Fig. 3 and 4).

TABLE 4—Summary of results of tests on poplar

Measured property*	Canterbury 100 × 50 mm (92 specimens)		Canterbury 150 × 50 mm (60 specimens)		Napier 100 × 50 mm (89 specimens)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
DN (kg/m³)	356	21.7	364	26.4	392	31.8
RW (mm)	15.0	3.0	15.4	2.8	16.6	5.0
MC (%)	14.0	0.5	13.9	0.4	14.3	0.8
KAR (%)	14	15.3	15	15.4	5	10.3
CKR (%)	4	11.8	7	16.9	1	3.0
TKR (%)	26	31.2	25	30.1	9	18.8
LK (mm)	15	14.7	18	16.0	6	11.5
EP (GPa)	6.9	1.0	6.4	1.0	6.3	1.4
EJ (GPa)	7.9	1.2	7.9	1.2	7.5	1.5
RJ (MPa)	36.5	10.8	36.2	10.2	42.2	10.7

* DN – nominal density
RW – ring width
MC – moisture content
KAR – knot area ratio
CKR – KAR for compression margin
TKR – KAR for tension margin
LK – width of largest knot
EP – modulus of elasticity as a plank
EJ – modulus of elasticity as a joist
RJ – modulus of rupture

TABLE 5—Summary of results for Building A grade poplar

Measured property*	Canterbury 100 × 50 mm (54 specimens)		Canterbury 150 × 50 mm (40 specimens)		Napier 100 × 50 mm (36 specimens)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
DN (kg/m^3)	353	22.9	362	25.6	372	33.4
RW (mm)	15.4	3.0	15.5	2.8	18.2	4.6
MC (%)	14.0	0.5	13.9	0.4	14.4	0.7
KAR (%)	9	10.0	9	9.4	11	13.3
CKR (%)	5	14.0	6	13.9	1	4.6
TKR (%)	13	16.8	14	20.9	18	22.2
LK (mm)	10	9.3	12	10.8	13	13.9
EP (GPa)	6.9	1.0	6.4	1.0	6.3	1.4
EJ (GPa)	8.0	1.1	7.9	1.2	7.2	1.3
RP (MPa)	37.5	9.9	37.9	10.5	36.6	10.1
5-%ile RJ (MPa) (from Equation (1))	13.6		18.5		12.6	

* For explanation of abbreviations, see Table 4.

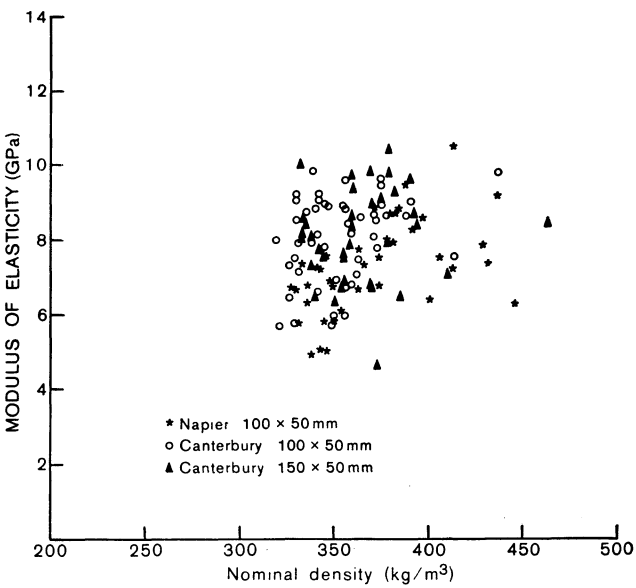

FIG. 2—Modulus of elasticity as a joist (EJ) v. density for Building A grade.

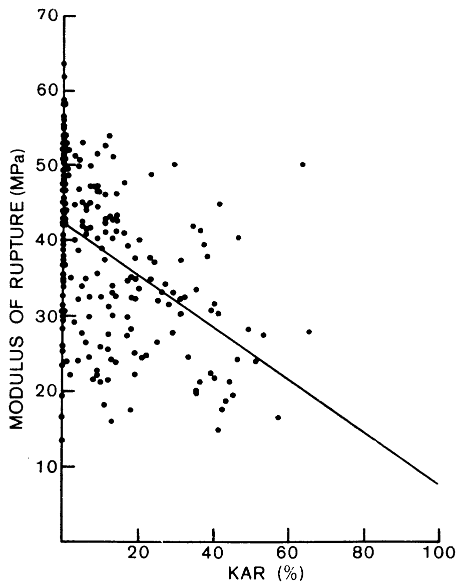

FIG. 3—Effect of knot area ratio (KAR) on strength (RJ).

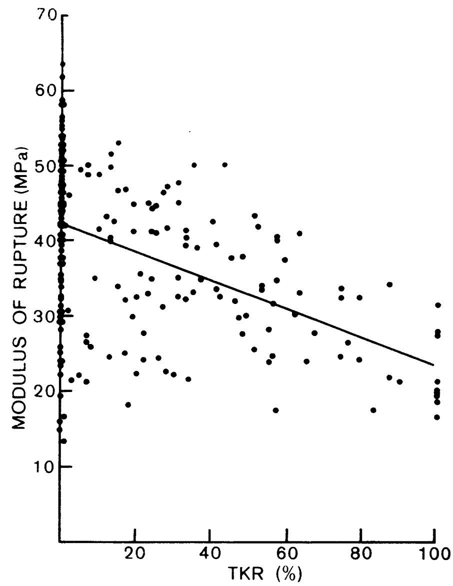

FIG. 4—Effect of KAR for tension margin (TKR) on strength (RJ).

Design values

The modulus of elasticity of the Napier material was significantly lower than that from Canterbury. This is most evident for pieces with a nominal density between 325 kg/m^3 and 375 kg/m^3 (Fig. 2), but the difference (10%) is not of practical concern in design for deflection. The modulus of elasticity (green) of 5.41 GPa in Table 1 was obtained from small clear specimens cut from an earlier shipment of five in-grade pieces from Christchurch. The modulus of elasticity for in-grade material is substantially higher than that of small clear specimens. Consequently, deriving design data from tests on small clear specimens may lead to conservative utilisation of a species.

From an analysis of variance of the data for Building A grade there was no significant difference in mean strength for the two sizes or the two sites (Fig. 5). To determine whether differences existed at the near-minimum strengths it was necessary to establish confidence intervals for the fifth percentiles. These were estimated by summing the quantity

$$\sum_i \frac{n\,!}{i\,!\,(n-i)\,!} \times 0.05^i \times 0.95^{n-i} \qquad (1)$$

for i = 0, 1, 2, etc., where n is the sample size and ! denotes Factorial. The fifth percentile determined with 75% confidence was the data value with a rank of i for which the sum was 0.25, and was linearly interpolated between the discrete values of i used in the summation. Likewise the upper and lower 75% confidence limits of the fifth percentile were taken as data values which gave a sum of 0.875 and 0.125.

The fifth percentiles are given in Table 5 and are shown together with the means and confidence intervals in Fig. 5. There was no significant difference between the near-minimum strengths.

Carroty fracture at test indicated that brittleheart was a possible defect, although the strengths at test did not indicate that the brittle fracures were weaker than others. In fact, some pieces which showed extremely brittle fracture had strengths above the mean, and certainly well above the fifth percentile.

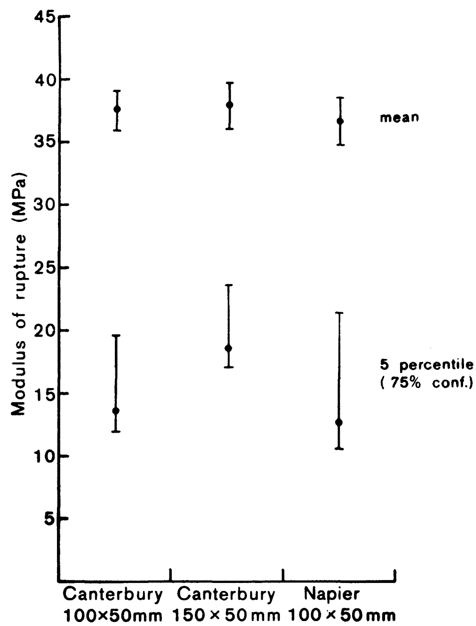

FIG. 5—Mean and fifth percentile strength for two sizes and sites.

Basic working stresses are obtained by multiplying the fifth percentile stresses by a factor for safety (0.8) and load duration (0.56) (Bier 1984). Thus the basic working stresses for Canterbury and Napier 100 × 50-mm timber are respectively 6.12 MPa and 5.67 MPa.

These basic working stresses and in-grade moduli of elasticity are compared with design code values for No. 1 Framing grade *Pinus radiata* in Table 6. The in-grade bending properties of Building A grade poplar are, for practical purposes, similar to those of No. 1 Framing grade *P. radiata.* Because of its lower density, poplar wood is soft. Compression perpendicular to the grain is highly correlated with density and hardness for all wood species, so it is to be expected that fastener loads should be lower for poplar. Nail loads were found to be about 30% below those in *P. radiata* (N. C. Clifton, pers. comm.) in limited tests made by a nail-plate manufacturer in Christchurch. It is suggested that the basic working stress in compression perpendicular to the grain, nail loads, and bolt loads given in NZS3603 (SANZ 1981) for *P. radiata* should be reduced by 30% for poplar.

TABLE 6—Basic working stresses (F'_b) and moduli of elasticity (E) in bending for poplar and **Pinus radiata**

	Poplar Building A 100 × 50 mm		**Pinus radiata** (NZS3603 : 1981) No. 1 Framing
	Canterbury	Napier	
Dry			
F'_b (MPa)	6.12	5.67	6.0
E (GPa)	8.0	7.2	8.0
Green			
E (GPa)	6.6 (5 tests, Christchurch)		6.5

CONCLUSIONS

Poplar of Building A grade can be used in structures with the same basic working stresses as for *P. radiata* No. 1 Framing grade provided that compression perpendicular stresses, nail loads, and bolt loads are reduced by 30%.

Any problems with its utilisation are unlikely to be related to strength considerations. Because of its poor drying characteristics, installing timber green will lead to problems with creep or distortion.

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