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Plywood Properties Related to Veneer Properties of *Pinus radiata* [*1]

라디에타 소나무의 단판특성에 따른 합판의 성질[*1]

吳 承 源[*2]

Seung-Won Oh[*2]

요 약

4군데의 임반에서 선발된 라디에타 소나무를 공시목으로 두께 2.6mm와 1.4mm의 단판을 제작하였다. 단판을 조합하여 만들어진 합판의 크기는 1200mm×2400mm×12.5mm이었다. 단판의 등급과 합판의 강도적 성질은 원목의 성질과 깊은 관계가 있으며, 원목의 밀도는 합판의 성질을 결정하는 중요한 인자가 되었다.

Keywords : Plywood, radiata pine, veneer, strength, density

1. INTRODUCTION

Radiata pine logs can be rotary peeled to provide plywood for building, formwork, boatbuilding and joinery and furniture. Because of its medium density, even texture and low resin content in outerwood, the wood is easy to peel and slice with minimum pretreatment.

Being a relatively fast-grown plantation pine species, New Zealand radiata pine is largely sapwood with low natural durability. However, it is relatively easy to dry, or season, and it is very permeable to wood preservatives making it suitable for a full range of end uses. New Zealand radiata pine plywood is used for exterior and interior sheathing and panels, box and web beam construction, treated lumber frame foundation, flooring pallets, bins. New Zealand radiata pine is easily peeled for plywood manufacture, the veneer grade depending on log grade.

STANDPAK is a suite of computer programs that models the growth, properties and processing of radiata pine from site to end product. The model is by no means complete. For plywood the prediction stops at estimating the recovery of veneer grades from logs but gives no structural properties for that veneer. It is desirable that a module be added to this model which will enable the structural properties of radiata pine plywood to be predicted from the properties of peeler logs. To evaluate a given log resource for plywood the relationship between

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[*2] 전북대학교 농과대학 College of Agriculture, Chonbuk National University, Chonju 560-756, Korea

panel density and peeler log must be quantified.

The computer model referred to is that described by Ward(1987a) and is part of a suite of programs known as STANDPAK. This model in turn draws on studies done and relationships developed by Ward(1987b), Park(1987), Ward et al (1987), and Johnston and Ward(1987).

The model estimates the quantity and grades of veneer obtainable from logs of given grade Which, in turn, can be predicted from other modules within the STANDPAK suite. A study by Bier(1986), established relationships that predict plywood panel density, bending strength and modulus of elasticity from peeler log density and veneer grade. This study seeks to verify the relationships determined by Bier and to add the variable of log grade into the prediction.

2. MATERIALS & METHODS

2.1 Selection of trees

Four trees were obtained from Matahina forest as part of a study that was being done for Tasman Forestry in 1994. They came from stand 1 of compartment 392 which was planted in 1964 and has a site index value of 35. The management history of that stand is : First prune to 2m at age 6. Second prune to 4m at age 7. First extraction thinning to 347 sph at age 16.

Mid rotation inventory at age 26 showed total stocking 347 sph, pruned trees 247 sph, basal area 54.1 m^2/ha, mean crop height 37.9m, mean top height 38.4m, mean DBH 45.8cm.

2.2 Log descriptions

The trees were indentified with the numbers 102, 114, 121 and 126 and were crosscut into 5.4 m long log with discs taken at the butt, top and between each log. Measurements of diameter, bark thickness, heartwood percentage, corewood percentage, compression wood percentage, pith eccentricity, ovality and density were made. Table 1, 2 gives the data obtained. The logs were labelled A, B, C etc up the tree. A total of 20 logs were obtained. On the logs, measurements were made of diameter, internode length, and branch diameters. From these data log density and branch index values were calculated. Table 3 gives the log form data so obtained.

2.3 Peeling

The logs were transported to HT Plywood Ltd at Mt Maunganui and further crosscut to 2.7m bolts for peeling to 2.6mm thick veneer on the 2.4m lathe. Bolts were labelled 1 for the butt end and 2 for the top end. Bolts with a small end diameter less than mm were further cut in half(labelled A and B) for peeling to 1.5mm thick veneer on the 1.2m lathe.

During peeling and immediately after the clipper, the sheets of veneer were each labelled with the tree/log/bolt number and numbered according to the sequence in which they came off the bolt.(eg. 114A1-1 for the first sheet off the butt-end bolt off the butt log tree 114). A continuous crayon mark was also drawn on the ribbon of veneer as it came off the lathe before clipping. After drying they were transported to FRI where they were resorted into correct sequence using the sequence numbers but checking these by means of the crayon mark, defect patterns, and the distance between repeating defects across the grain. This measurement gave the bolt circumference at that point. A total of 493 sheets of 2.6mm veneer and 274 sheets of 1.5mm veneer were obtained.

2.4 Veneer grading

The dry sheets of veneer were graded to NZ/Australian, Japanese and USA grades using the following standards :

NZ : AS/NZS 2269:1994, Plywood-Structural
Japan : JAS 1516:1989, Japanese Agricultural Standard for Structural Plywood
USA : Product Standard PS 1-83, Construction and Industrial Plywood.

2.5 Veneer MOE

The width and weight of each sheet was measured, also the parallel-to-grain modulus of elasticity using a "Pundit" device. This device has transmitting and receiving transducers which were placed against opposite end-grain edges of the veneer sheets. The Pundit device measured the time for an ultrasonic pulse to be transmitted through the sheet. Modulus of elasticity was calculated from the relationship:

$$E = \rho v^2 (N/m^2)$$

where : ρ = density (kg/m^3), and
v = velocity of the sound wave (m/s)

Density was calculated using the weight and width of each sheet together with an average value for sheet length and thickness which was determined from measurements on 40 sheets, and length=2.540m and thickness=2.651mm for the large sheets, and length=1.288m and thickness=1.437mm for the small sheets. Velocity was calculated from the measured pulse times and the average length of the veneer sheets.

2.6 Plywood manufacture

Five-ply sheets of plywood were made using the veneer sheets in the same sequence as they came off the bolts. Urea-formaldehyde adhesive was used and plywood was made at the HT Plywood plant at Mt. Maunganui. 98 sheets of 12.5mm × 1200mm × 2400mm plywood and 43 sheets of 7.5mm × 1200mm × 1200mm plywood were made.

2.7 Plywood testing

The even-numbered sheets of 12.5mm plywood were tested in bending, tension and compression according the draft standard AS/NZ 2098.9 which requires a specimen of 300mm width. The following formulae were used to calculate the strength properties listed.

(a) Bending strength :

$$\mathrm{MOR} = \frac{P_{max}\,L}{6\,Z_{par}} \qquad \mathrm{MPa}$$

where P_{max} = maximum load, N
L = test span, mm
Z_{par} = section modulus = $\frac{I_{par}}{\bar{y}}$, mm^3
I_{par} = second moment of area, using parallel plies only, mm^4
$\bar{y}$ = dist. form the neutral axis to the outermost veneer, parallel to the span, mm

(b) Bending stiffness :

$$\mathrm{MOE} = \frac{23\,L^3}{1296\,I_{par}}\left(\frac{P'}{\Delta}\right) \qquad \mathrm{GPa}$$

where I'_{par} = second moment of area for stiffness (includes contribution of 0.03 times perpendicular plies), mm^4
$\frac{P'}{\Delta}$ = gradient of the load-deflection curve over the linear portion, N/mm

(c) Compression strength :

$$C = \frac{P_{max}}{b t_{par}} \qquad \mathrm{MPa}$$

where b = width of plywood test picec, mm
t_{par} = thickness of parallel plies only, mm

(d) Tension strength:

$$T = \frac{P_{max}}{b t_{par}} \qquad \mathrm{MPa}$$

3. RESULTS & DISCUSSION

3.1 Log density

From the data in Table 1, 2 the log density value in Table 4 were calculated, showing that No. 102 was the high density tree, No. 114 and

Table 1. Data obtained from discs taken from logs studied.

Tree No.	Disc No.	No. of Rings	Diam. OB (mm)	Diam. IB (mm)	Bark (mm)	Heart-wood (mm)	Core-wood (mm)	Heart-wood (%)	Core-wood (%)	Comp. wood (%)	Pith off centre (mm)	Ovality* (mm)	Diameters	
													Min (mm)	Max (mm)
102	0	31	473	415	29.0	220	230	28	31	5	40	40	380	420
	1	25	414	382	16.0	210	235	30	38	5	15	35	355	390
	2	24	349	327	11.0	195	220	36	45	5	5	25	310	335
	3	21	310	291	9.5	155	200	28	47	5	15	10	280	290
	4	18	298	287	5.5	105	205	13	51	5	12	10	270	280
	5	15	223	212	5.5	75	170	13	64	10	6	10	205	215
114	0	31	670	620	25.0	235	280	14	20	5	45	80	550	630
	1	28	575	527	24.0	230	270	19	26	10	15	30	500	530
	2	25	515	484	15.5	230	275	23	32	5	12	0	470	470
	3	23	474	447	13.5	200	280	20	39	5	22	15	430	445
	4	18	415	388	13.5	170	262	19	46	5	10	30	365	395
	5	17	350	330	10.0	110	230	11	49	5	15	15	315	330
	6	14	271	255	8.0	70	190	8	56	0	5	20	240	260
121	0	30	485	426	29.5	180	230	18	29	5	25	25	405	430
	1	28	388	369	9.5	200	220	29	36	5	20	0	370	370
	2	24	365	347	9.0	210	220	37	40	5	15	0	340	340
	3	21	330	315	7.5	195	220	38	49	5	18	5	310	315
	4	20	298	285	6.5	155	205	30	52	5	5	5	280	285
	5	17	261	247	7.0	90	180	13	53	0	10	25	230	255
126	0	31	502	422	40.0	230	240	30	32	10	30	40	380	420
	1	27	391	367	12.0	215	220	34	36	5	32	30	350	380
	2	24	352	335	8.5	204	223	37	44	5	6	8	332	340
	3	21	346	331	7.5	195	225	35	46	10	16	21	310	331
	4	19	298	283	7.5	162	212	33	56	5	5	4	280	284

* Difference between maximum and minimum diameters.

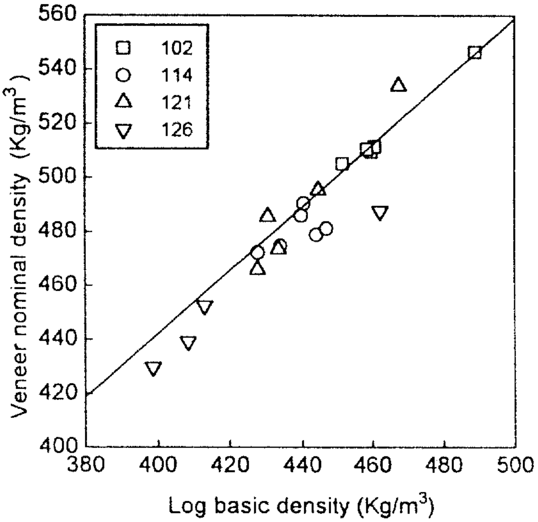

Fig. 1. Relationship of average veneer density to log density.

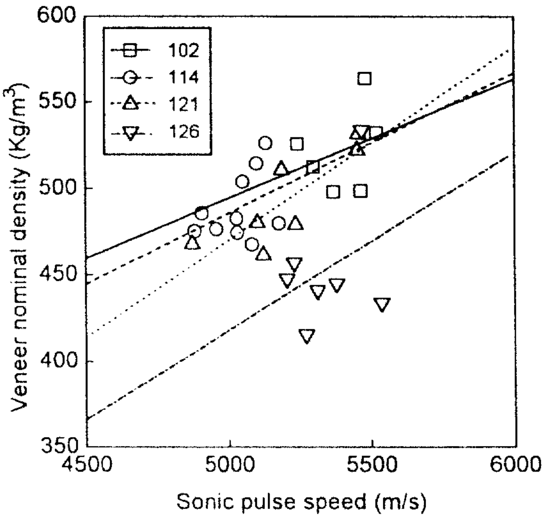

Fig. 2. Veneer density vs sonic pulse speed.

Table 2. Within-tree density data.

Tree	Disc No.	5Ring Group	Basic Density (kg/m³)	Tree	Disc No.	5Ring Group	Basic Density (kg/m³)	Tree	Disc No.	5Ring Group	Basic Density (kg/m³)	Tree	Disc No.	5Ring Group	Basic Density (kg/m³)
102	0	1	468	114	0	1	416	121	0	1	392	126	0	1	456
		2	480			2	401			2	430			2	468
		3	511			3	443			3	475			3	468
		4	519			4	453			4	497			4	517
		5	530			5	476			5	529			5	538
		6	530			6	494			6	525			6	547
	1	1	371		1	1	356		1	1	338		1	1	306
		2	451			2	370			2	416			2	371
		3	488			3	423			3	465			3	440
		4	499			4	452			4	507			4	482
		5	500			5	475			5	517			5	489
						6	474			6	519				
	2	1	375		2	1	332		2	1	358		2	1	321
		2	428			2	391			2	420			2	361
		3	472			3	431			3	463			3	427
		4	509			4	458			4	505			4	494
		5	509			5	495			5	505			5	494
	3	1	387		3	1	366		3	1	362		3	1	337
		2	423			2	402			2	397			2	383
		3	503			3	441			3	444			3	464
		4	510			4	489			4	485			4	463
						5	486								
	4	1	388		4	1	411		4	1	364		4	1	347
		2	441			2	428			2	409			2	353
		3	515			3	457			3	466			3	441
		4	528			4	492			4	469			4	441
	5	1	379		5	1	420		5	1	376				
		2	412			2	422			2	413				
		3	492			3	470			3	461				
					6	1	386								
						2	415								
						3	463								

121 were the average density trees and No. 126 was the low density tree.

3.2 Log to veneer density relationship

Fig. 1 compares the mean nominal density of the sheets of veneer from each log with the basic density of that log. The regression equation describing the relationship is

$$D_{n,v} = 1.288D_{b,l} - 82.7 \text{ kg/m}^3$$

where $D_{n,v}$ = Nominal density of the veneer,

and $D_{b,l}$ = Basic density of the log

The standard error of the estimated veneer density is 9.15kg/m³.

3.3 Relationship of pulse speed to density

The measured speed of the sonic pulse through the sheet can be used to sort sheets for density and/or modulus of elasticity. Such a device is marketed by Metriguard Inc. as their "Ultrasonic veneer tester model 2600" which used to grade veneer. Fig. 2 shows the relationships between nominal density of the veneer sheets and the average speed of the sonic pulse

Table 3. Log from data.

Tree No.	Log	SED (mm)	LED (mm)	Length (m)	Sweep (mm)	Largest branch per quartile 1	2	3	4	Branch index (mm)	Internodes 〉60cm				Internode index
102	A	370	405	5.4	80										
	B	320	360	5.4	0	30	40	30	30	32.50					0.00
	C	285	310	5.5	40	40	45	40	30	41.25	0.63	0.62			0.23
	D	280	285	5.4	20	50	40	40	45	43.75	0.81				0.15
	E	210	270	6.0	35	35	25	30	45	33.75	0.60	0.78			0.23
114	A	510	585	5.5	40										
	B	480	525	5.4	10	60	53	40	50	50.75	1.00	0.85			0.34
	C	435	475	5.4	25	60	45	50	45	50.00	0.64				0.32
	D	370	445	5.4	0	60	70	65	65	65.00					0.00
	E	325	345	5.5	25	65	65	65	55	62.50					0.00
	F	255	325	5.4	30	65	70	65	45	31.25					0.00
121	A	345	420	5.4	30										
	B	345	365	5.5	40	25	25	30	25	26.25					0.00
	C	305	345	5.4	50	30	30	25	40	31.25	1.70				0.31
	D	275	310	5.5	30	30	40	30	35	33.75	1.50	0.80			0.42
	E	250	280	5.4	35	25	30	40	25	30.00	0.87				0.16
126	A	365	405	5.5	35										
	B	325	350	5.5	15	35	50	45	40	42.50	0.75	0.86	1.13	0.73	0.63
	C	320	335	5.4	50	40	35	45	55	43.75	1.03	1.40	0.71		0.58
	D	275	325	5.4	58	70	40	40	30	45.00	1.662	1.35			0.55
	E	245	275	2.9											0.00

Table 4. Log basic densities, taper, volume and diameters.

Tree No.	Log height class	SED under bark (mm)	LED (mm)	Taper (mm/m)	Volume (m^3)	Log density (kg/m^3)	Heart-wood (%)	Core-wood (%)
102	Butt	382	415	7	0.612	489	29	34
	2nd	327	382	11	0.487	460	32	41
	3rd	291	327	7	0.369	452	32	46
	4th	287	291	1	0.321	461	21	49
	5th	212	287	15	0.245	459	13	56
	Tree				2.034	467		
114	Butt	527	620	19	1.274	440	16	23
	2nd	484	527	9	0.985	428	21	29
	3rd	447	484	8	0.835	434	21	35
	4th	388	447	12	0.674	444	20	42
	5th	330	388	12	0.499	447	16	47
	6th	255	330	15	0.335	441	10	51
	Tree				4.603	438		
121	But	369	426	12	0.611	467	23	32
	2nd	347	369	4	0.497	445	33	38
	3rd	315	347	7	0.432	434	37	44
	4th	285	315	6	0.347	428	34	50
	5th	247	285	8	0.274	431	23	52
	Tree				2.148	444		
126	Butt	367	422	11	0.602	462	32	34
	2nd	335	367	7	0.475	413	36	40
	3rd	331	335	1	0.427	408	36	45
	4th	283	331	10	0.365	399	34	50
	Tree				1.869	425		

Table 5. Correlation matrix of plywood strength and predictive properties.

	Predictive parameters				Plywood properties							
	ND_{ven}	Speed	E_{ven}	Circ.	R_{parl}	E_{parl}	R_{perp}	E_{perp}	C_{parl}	C_{perp}	T_{parl}	T_{perp}
ND_{ven}	1											
S_{peed}	0.699	1										
E_{ven}	0.912	0.927	1									
Circ.	0.436	0.316	0.381	1								
R_{parl}	0.623	0.525	0.624	0.432	1							
E_{parl}	0.665	0.734	0.764	0.386	0.845	1						
R_{perp}	0.337	0.457	0.441	0.474	0.367	0.452	1					
E_{perp}	0.516	0.673	0.659	0.327	0.471	0.575	0.610	1				
C_{parl}	0.625	0.582	0.660	0.251	0.465	0.505	0.260	0.549	1			
C_{perp}	0.723	0.591	0.714	0.362	0.392	0.488	0.487	0.407	0.574	1		
T_{parl}	0.466	0.455	0.508	0.353	0.413	0.408	0.374	0.466	0.629	0.501	1	
T_{perp}	0.448	0.286	0.395	0.507	0.369	0.275	0.427	0.374	0.481	0.454	0.467	1

Table 6. Regression statistics for the prediction of plywood properties from veneer density in kg/m^3, according to NZ grade.

Grade		R_l (MPa)	E_l (GPa)	R_p (MPa)	E_p (GPa)	C_l (MPa)	C_p (MPa)	T_l (MPa)	T_p (MPa)
A	Constant	-30.1	-9.9	63.5	-1.12	-18.5	-19.4	-7.9	118.4
(n =11)	Coefficient	0.216	0.044	0.32	0.28	0.126	0.132	0.113	-0.12
	r^2	0.415	0.717	0.007	0.37	0.341	0.751	0.103	0.115
	Std error	7.447	0.899	13.06	1.208	5.749	2.488	10.97	10.77
B		Insufficient data to determine regressions							
C	Constant	-45.6	3.22	35.7	1.00	26.91	21.05	-1.15	64.54
(n =11)	Coefficient	0.222	0.018	0.059	0.024	0.032	0.041	0.085	-0.05
	r^2	0.136	0.089	0.009	0.109	0.046	0.054	0.035	0.026
	Std error	17.42	1.752	19.03	2.12	4.536	5.308	13.86	10.4
D	Constant	-46.7	-2.32	24.5	5.82	15.85	3.891	43.34	3.70
(n =19)	Coefficient	0.213	0.026	0.066	0.012	0.051	0.077	-0.03	0.06
	r^2	0.29	0.282	0.033	0.081	0.128	0.341	0.015	0.043
	Std error	12.97	1.613	14.05	1.575	5.216	4.151	8.075	10.97
R	Constant	13.65	-2.57	194.2	1.07	-47.5	-13.3	3.88	35.69
(n = 6)	Coefficient	0.113	0.031	-0.3	0.024	0.193	0.117	0.061	-0.02
	r^2	0.09	0.289	0.21	0.145	0.649	0.278	0.067	0.009
	Std error	13.32	1.802	21.23	2.116	5.237	6.967	8.449	8.805

* Correlations significant at the 5% level are shown in italics, those significant at the 1% level are shown in bold type.

measured on them for each tree. The data for 2.6mm veneer only have been plotted.

3.4 Correlation between plywood properties

Table 5 gives the correlation matrix between the four predictive properties of the plywood, (veneer nominal density, ultrasonic pulse speed, veneer MOE, and peel circumference or radius), and the strength properties measured on the 48 sheets of 12.5mm plywood.

The best correlation between predictive parameter and strength property has been identified in bold type. Modulus of elasticity of the veneer (E_{ven}) is found to be the best predictor of

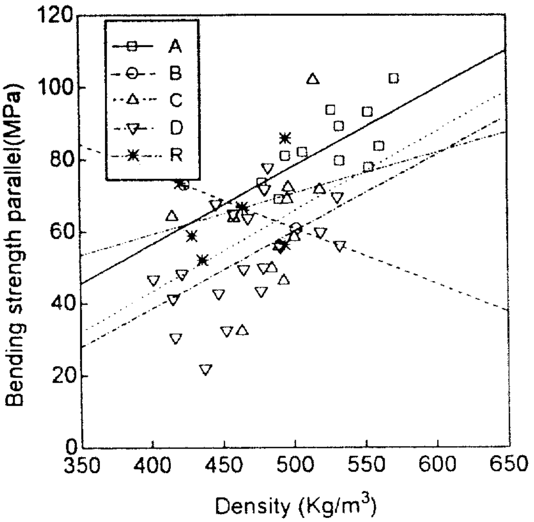

Fig. 3. Regression of bending strength parallel to face grain vs veneer density.

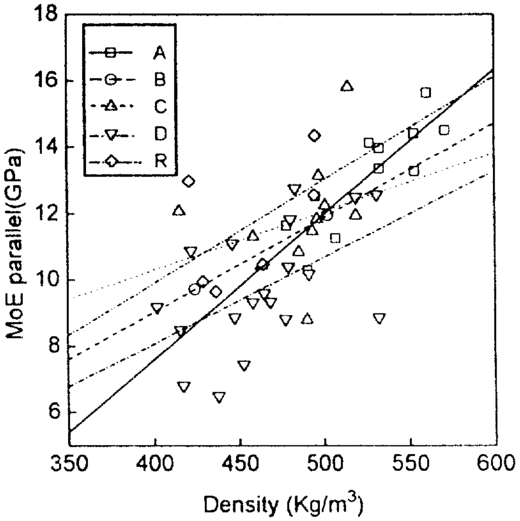

Fig. 4. Regression of MOE parallel to face grain vs veneer density.

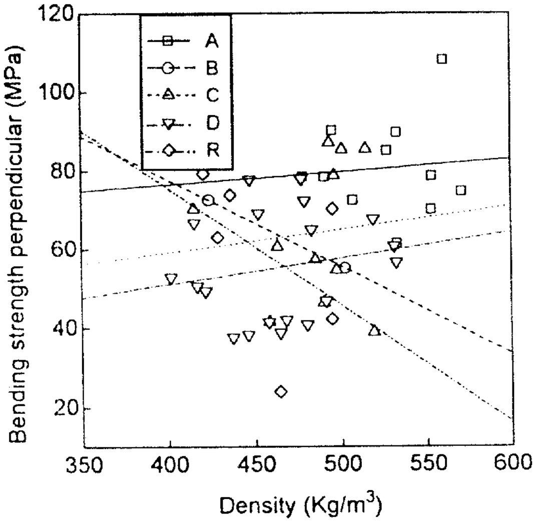

Fig. 5. Regression of bending strength perpendicular to face grain vs veneer density.

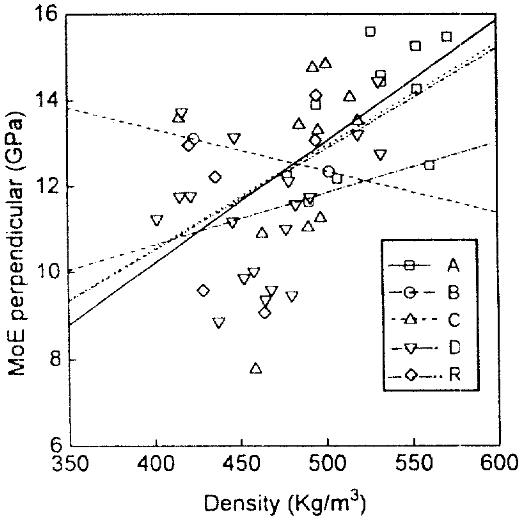

Fig. 6. Regression of MOE perpendicular to face grain vs veneer density.

strength and stiffness in most cases. However this property is calculated from density and pulse speed and so is not measured directly on the veneer. If E_{ven} is ignored, density(ND_{ven}) is the next best predictor but this property, too, is measured indirectly from weight and dimensions. Of the two directly-measured properties, pulse speed(S_{peed}) and peel radius($C_{irc.}$), the better predictor is pulse speed.

3.5 Relationship of strength properties to density

In terms of the STANDPAK model, density and veneer grade are the two parameters available from which to predict plywood properties. Table 6 lists the linear regressions between each strength property and density, by grade to

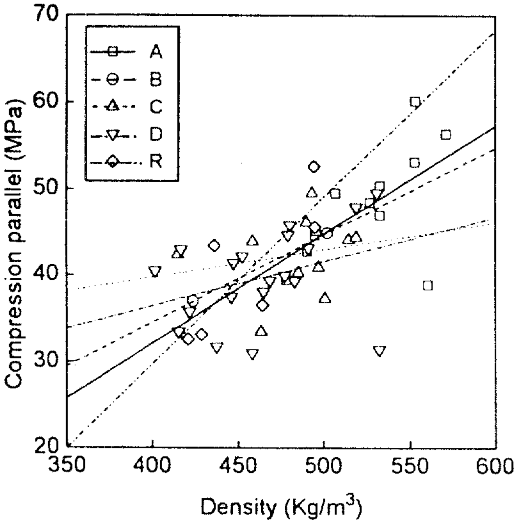

Fig. 7. Regression of compression strength parallel to face grain vs veneer density.

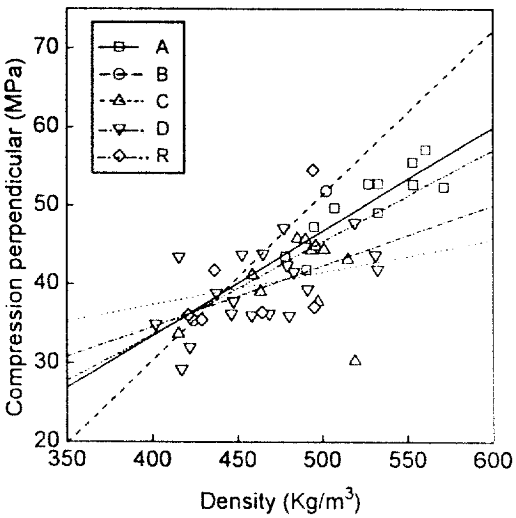

Fig. 8. Regression of compression strength perpendicular to face vs veneer density.

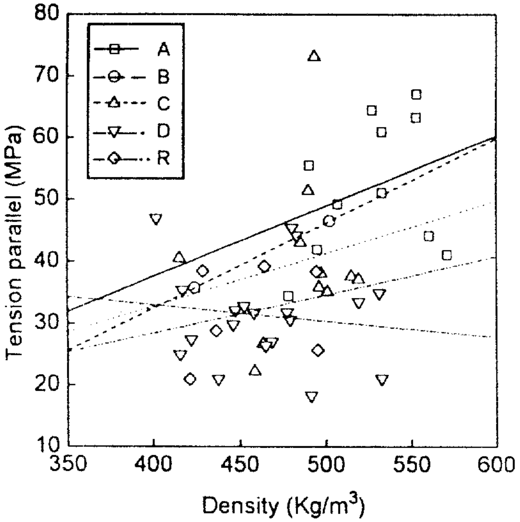

Fig. 9. Regression of tension strength parallel to face grain vs veneer density.

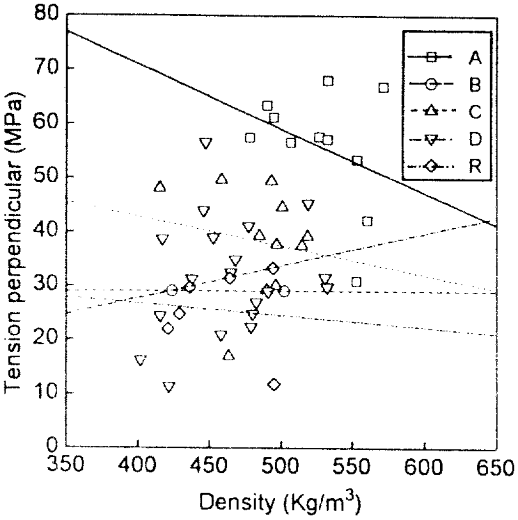

Fig. 10. Regression of tension strength perpendicular to face grain vs veneer density.

AS/NZS 2269. The relationships are shown in fig. 3 to 10. In qualitative terms, these plots show that density and grade affect properties as follows:

Property	Effect of density	Effect of grade
Bending strength parallel	yes	yes
MoE parallel	yes	no
Bending perpendicular	no	yes
MoE perpendicular	yes	no
Compression strength parallel	yes	no
Compression strength perpendicular	yes	no
Tension strength parallel	yes	yes
Tension strength perpendicular	no	yes

4. CONCLUSIONS

1. Modulus of elasticity of the veneer, veneer density, peel radius and ultrasonic pulse speed all give significant correlations with plywood strength.
2. The most practical predictor is density as it is known before peeling commences. After peeling, MOE of the veneer is the best predictor but cannot be measured directly on sheets.
3. Log density and veneer grade together give a better prediction of plywood strength than does either property alone.

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