Radiata pine wood and kraft pulp quality relationships

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SUMMARY

The influence of chip basic density and pulp fibre length on radiata pine kraft handsheet tear, burst and tensile index, and apparent density is determined. The pulps were prepared from two sets of samples.

1. The central North Island set consisting of 55 chip samples prepared from whole tree thinnings, and old and new crop slabwood and corewood. The overall chip basic density range of the 55 chip samples was 288 to 540 kg/m^3.
2. The commercial set consisting of 18 chip samples collected from throughout New Zealand and representative of both slabwood and pulpwood material. The chip basic density range of the 18 samples was 320 to 500 kg/m^3.

The correlations of chip basic density with the selected handsheet characteristics were highly statistically significant. Furthermore the slopes and intercepts of the regression equations for the two sets of samples were remarkably similar.

Kraft pulp quality was determined by chip basic density alone. Seventy to 95 per cent of the variation in handsheet tear and burst index, and apparent density was accounted for by chip basic density. Correlations were generally lower (r^2 = 0.62) for the tensile index/chip density relationship. Co-efficients of determination for the 18 pulps of the commercial chip sample were consistently higher than for the 55 individual-tree pulps of the central North Island sample.

Effects of including pulp fibre length in the various chip density/handsheet relationships were negligible.

Interrelations between the wood, fibre and kraft pulp properties of the corewood and slabwood of unmanaged and untended old crop, and intensively managed new crop radiata pine stands, and new crop radiata pine thinnings, grown in the New Zealand central North Island region, have been described in detail elsewhere(1-4). In these studies wood basic density was found to account for 70 to 90 per cent of the variation in kraft handsheet tear and burst indexes, and apparent density. Such values were sometimes further increased by up to 10 per cent when fibre length was included in the analyses. Results indicated that basic density is the most important wood variable affecting pulp quality. A general review on previous studies of the effects of radiata pine wood quality variation on kraft pulping and paper properties has been presented elsewhere(5).

The data base of these previous studies has been used in the present paper to formulate kraft pulp predictive models for the central North Island radiata pine resource. The second phase of the study considers the validity of these models with reference to kraft pulps prepared from commercial chips collected from a variety of New Zealand geographic locations, and representative of a wide range of radiata pine densities and of chips prepared from both pulp logs and sawmill residues (mainly slabwood).

MATERIALS AND METHODS

Wood Selection and preparation

Central North Island wood samples: For the preliminary studies three sets of radiata pine wood samples were examined.

Nine 52 year old unmanaged old crop trees were selected to represent a range of wood basic densities. For each tree, corewood billets were taken from the 15th internode (roundwood containing 15 growth layers) and slabwood material from the outer 20 of 40 growth layers in the 40th internode from the top of the tree(1).

Nine 24 year old, intensively managed, new crop trees were selected to represent a range of wood basic densities. For each tree, top corewood (roundwood billets containing 15 growth layers), butt corewood (roundwood billets containing 15 growth layers from the pith from inside the pruned butt log), and slabwood (wood outside the butt corewood) samples were collected(2).

Nine 12 year old trees from an intensively managed, new crop stand. These nine trees were also selected to represent a range of wood basic densities. A tenth tree, 14 year old, and a progeny of a low density and average density parent (clones 55 x 121) was selected because of its extremely fast growth and high volume production, and low density(3). Whole tree logs to 10 cm small end diameter were included in the overall sample for each tree(3).

The total number of wood samples was 55. Nine old crop corewood and slabwood, nine new crop top corewood, butt corewood and slabwood, and ten new crop thinnings. Each sample was chipped in a conventional laboratory chipper. Chips used in the study passed through a 32 mm screen and were retained on a 19 mm screen. A round hole Santasalo chip screen was used.

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Commercial wood chips from throughout New Zealand: Eighteen samples of radiata pine chips were collected from commercial installations throughout New Zealand. The samples were selected to give a representative range of wood basic densities from each of the four regions; North Auckland/Coromandel, Rotorua, Nelson/Marlborough and Southland/Otago (Table 1). Chips which passed through the 32 mm screen and retained on the 19 or 16 mm screen (Table 1) were used in the study. In three instances it was necessary to include in the sample those chips retained on the 16 mm screen since these samples consisted of higher than normal proportions of small chips.

Pulping

Kraft pulps with Kappa numbers of 27 ± 2 (old crop samples), 30 ± 2 (new crop samples), and 26 to 29 (commercial samples) were prepared by conventional procedures. The following conditions were used: active alkali charge on o.d. wood 18 or 20 per cent Na_2O; liquor to wood ratio 4:1; sulphidity 23 per cent; time from room temperature to maximum temperature (170°C) 90 min. Time at temperature was varied from pulp to pulp to attain the required Kappa number.

Pulp processing and evaluation

Pulps were refined in a PFI mill at 10 per cent stock concentration with an applied load of 1.77 N/mm. Each pulp was refined for 1000 or 2000, 4000, 8000, 16000 rev in the PFI mill.

Handsheet property values used in the multiple regression analyses were determined at 1000 rev using the relationship:

Handsheet property = a [$1n$(rev)] + c; which was derived from the four beating point values determined for each pulp.

Tear index, burst, bulk, and air resistance were obtained from 60 ± 2 g/cm² handsheets using Appita standard methods. Tensile index, stretch, tensile energy per unit area, and Young's modulus were determined with a table model Instron instrument. Determinations were made using 15 mm wide strips of gauge length 100 mm and an extension rate of 10 mm/min. Scattering coefficient was determined from 60 ± 2 g/m² handsheets by the SCAN procedure using an Elrepho reflectance meter.

Physical evaluation data for the Central North Island samples have been presented previously(1,2,3) whereas those for the commercial material are presented in the Appendix.

Wood and fibre properties

Basic density: Chip basic density was measured by water immersion and oven drying of individual samples. The chips were immersed within a wire basket of a predetermined immersed volume(6). Basic densities of unextracted chips only were recorded.

Pulp fibre length: Fibre length was estimated by tracing projected fibre images and recording their length with a measuring wheel. Trials showed that about 300 fibres had to be measured to obtain mean length confidence limits of about ±0.1 mm at the 95 per cent level. For each pulp, 50 fibres on each of six microscope slides were measured. Samples were coded and examined in a randomized order to eliminate observer bias. The shortest 'intact' fibre included in the length measurements was 0.2 mm. 'Intact' fibre fragments were defined as shortened fibres with definite or collapsed lumens. Thus split fibre fragments or fibrillar debris were not included in the fibre length analyses.

The weighted average fibre length was defined as:
$\Sigma l^2_i n_i / \Sigma l_i n_i$
where l_i was the length of any one fibre in the sample, and n_i the number of fibres of length l_i.

RESULTS

Central North Island chip resource

The tear and burst indexes, and apparent density of kraft handsheets have previously been correlated one to another for a large number of new and old crop wood samples representative of individual trees or parts of individual trees(1,2,3). The range of chip basic densities for these 55 samples was 288 to 540 kg/m³.

For all samples combined, chip basic density accounts for 75.7, 82.8 and 73.6 per cent of the variation in handsheet burst index, apparent density and tear index respectively (Table 2, Fig. 1, 2, 3). Pulp fibre length is the only other fibre or wood property measured (1,2,3) which further influenced any of these handsheet characteristics, and this is confined to apparent density only (Table 2). The inclusion of pulp fibre length in the sheet apparent density/chip basic density regression increased the coefficient of determination from 82.8 to 92.3 per cent. Individual regression equations or 'predictive models' for these three handsheet properties, based on individual tree data, are listed in Table 2. Ten-

Table 1
Origin and wood and pulp characteristics of commercial chip samples

Sample number	Chip region	Source: forest or sawmill	Chip description	Screen mesh mm	Chip basic density kg/m³	Chip extractive content %	Kraft pulp Kappa No.	Weighted average pulp fibre length mm
1	South Auckland	Maramarua Forest	Slabwood	19	500	2.17	26.1	3.58
2	South Auckland	Tairua Forest	Slabwood	19	483	1.83	28.9	3.45
3	Southland	Beamont Forest	Slabwood	19	480	1.56	27.7	3.27
4	Nelson	Rai Valley Forest	Slabwood	19	468	1.36	26.4	3.28
5	Rotorua	Waipa Sawmill	Slabwood	19	444	2.28	27.5	3.60
6	Rotorua	Kinleith Sawmill	Slabwood	16	443	1.26	26.0	3.53
7	North Auckland	Aupouri Forest	Slabwood	19	434	1.80	26.7	3.05
8	North Auckland	Woodhill Forest	Slabwood	16	430	1.83	28.0	2.93
9	Nelson	Golden Downs Forest	Slabwood	19	427	1.53	29.3	3.12
10	Nelson	Baigents Sawmill	Slabwood	19	409	1.88	27.4	3.11
11	Nelson	Harakeke Forest	Pulpwood	19	407	2.89	26.3	2.72
12	Southland	Berwick Forest	Slabwood	16	399	0.87	27.7	2.60
13	Southland	Otago Coast Forest	Pulpwood	19	385	1.22	27.8	2.63
14	North Auckland	Aupouri Forest	Pulpwood	19	382	2.20	27.0	2.58
15	Rotorua	Kinleith Sawmill	Pulpwood	19	372	2.66	27.8	2.38
16	Rotorua	Tarawera Forest	Pulpwood	19	348	1.34	27.8	2.30
17	Southland	Berwick Forest	Pulpwood	19	331	0.84	28.7	2.03
18	Rotorua	Tarawera Forest	Pulpwood	19	320	1.34	27.7	2.35

sile index/chip basic density correlations are significantly lower than for corresponding tear and burst index relationships (Fig. 4).

Data presented in Figures 1, 2, 3 and 4 reflect handsheet values for very lightly refined pulps only (1000 PFI rev with an applied load of 1.77 N/mm). Hence direct comparisons can be made between handsheet and pulp properties, and chip basic density. If other relationships are required such as tear index for given burst values, then the chip density for a given burst can be determined from Figure 1 (or equation 1 of Table 2) and correlated with the tear values of Figure 3 (or equation 4 of Table 2). It is, however, noteworthy that for these essentially unrefined slush pulps it is the slabwood pulps only (and then only 11 out of the 18 slabwood pulps) which have burst values of 5 kPa.m²/g or less.

Table 2
Regression equations relating selected wood, pulp fibre, and handsheet properties for the central North Island pulps

Equation number	Regression equation*	Co-efficient of determination $r^2 \times 100$
1	Tear index = 0.120 (CD) − 26.4	73.6
2	Tear index = 0.102 (CD) + 3.46 (FL) − 29.2	74.9
3	Burst index = −0.019 (CD) + 13.5	75.7
4	Burst index = −0.019 (CD) + 0.089 (FL) + 13.4	75.7
5	Tensile index = −0.118 (CD) + 119.2	34.8
6	Tensile index = −0.20 (CD) + 16.0 (FL) + 106.2	48.1
7	Apparent density = −0.973 (CD) + 1011.5	82.8
8	Apparent density = −0.611 (CD) − 70.7 (FL) + 1068.3	92.3

* CD: Chip basic density (unextracted)
FL: Weighted average pulp fibre length

A number of further comments can be made concerning the regressions of Figures 1, 2, 3 and 4.

1. The data presented refer to pulps prepared from the wood of individual trees or parts of individual trees. Variability due to between-tree differences can be expected to be high(1,2,3).
2. The burst index/chip basic density data of Figure 1 are in general evenly distributed about the regression. Individual regressions for the six wood types are drawn in Figure 5.
3. For apparent density/chip basic density relationships the new crop thinnings data are clearly separate from those of the other samples (Fig. 2, 6). The fibre lengths of the thinnings pulps have been shown to account for this deviation(3).
4. The tear index/chip basic density regression of Figure 3, although relatively highly correlated, is clearly affected by the somewhat low and erratic old crop corewood data (Fig. 7), and the three thinnings data at chip basic densities below 300 kg/m³. Also, the highly significant correlation coefficient (*r*) value (0.87) over the wide density range is associated with a high standard error of regression which is not entirely due to individual tree variation (Fig. 3, 6).

At basic density values of about 300 kg/m³ tear index minima are apparently reached and relationships tend to become non-linear in accordance with known behaviour of radiata pine kraft pulps(7). The very

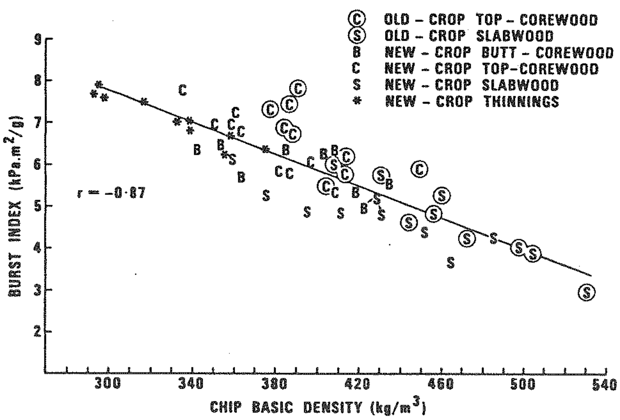

Fig. 1 — Central North Island pulps — burst index and chip basic density at 1000 PFI rev.

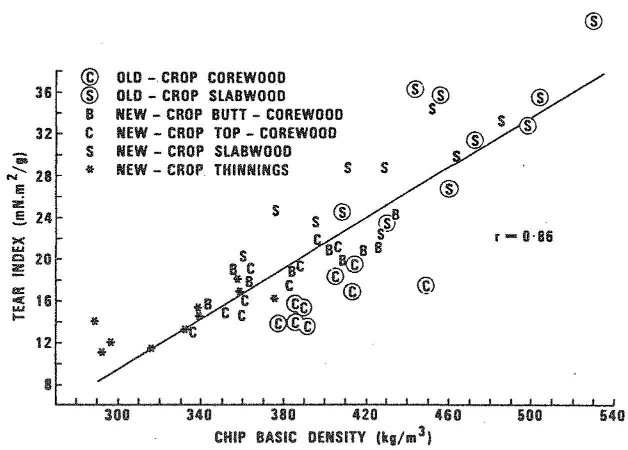

Fig. 3 — Central North Island pulps — tear index and chip basic density at 1000 PFI rev.

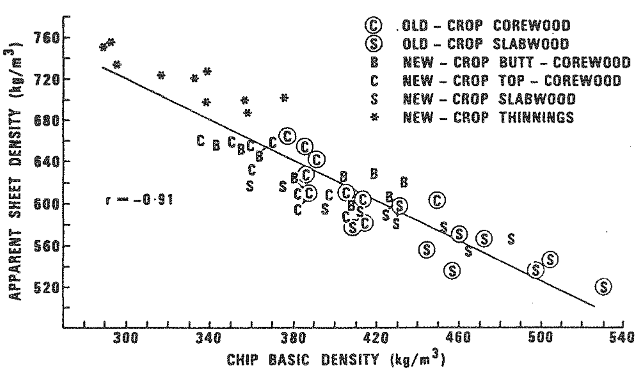

Fig. 2 — Central North Island pulps — apparent density and chip basic density at 1000 PFI rev.

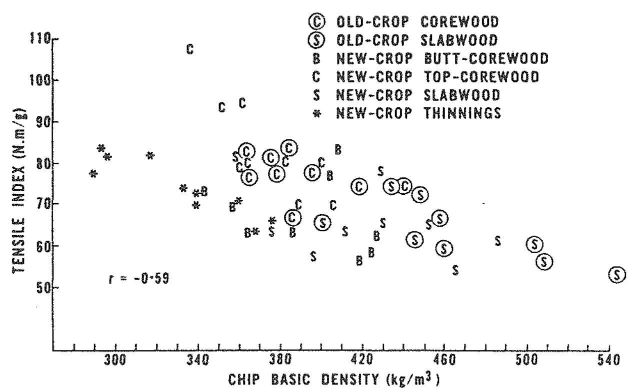

Fig. 4 — Central North Island pulps — tensile index and chip basic density at 1000 PFI rev.

high tear index of about 43 mN.m²/g noted at a chip density of 531 kg/m³ is realistic for the situation of Figure 3 since it was determined by the extrapolation of refining data. In practice such high tear indexes do not occur since for such high density pulps, tear index first increases to a maximum and then decreases with refining.

5. The low chip basic density/tensile index correlation can be accounted for by the strong deviation of the top corewood data from those of the other wood types (Fig. 4). No explanation is given for this effect although it could be related to previously discussed differences between new crop, top and butt corewood pulps(2).

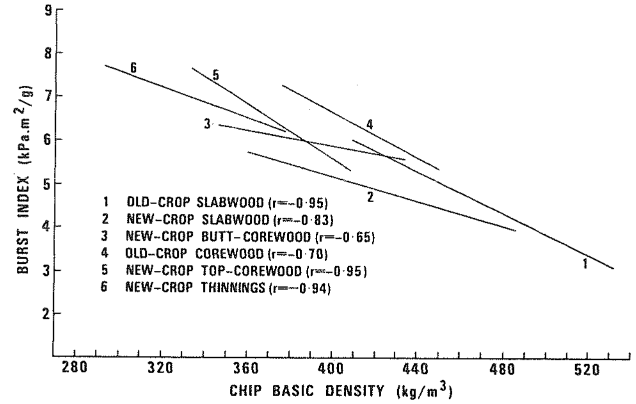

Fig. 5 — Chip basic density and burst index for central North Island Wood types at 1000 PFI rev.

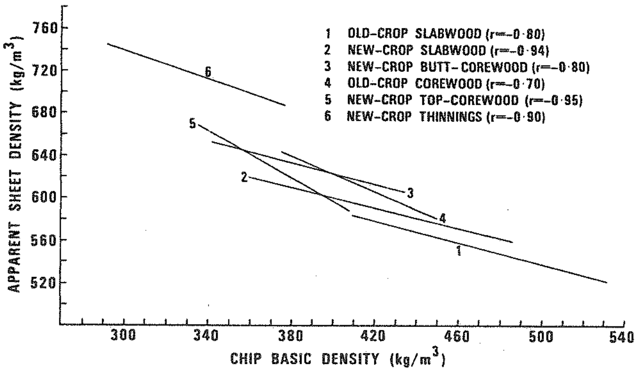

Fig. 6 — Chip basic density and apparent density for central North Island wood types at 1000 PFI rev.

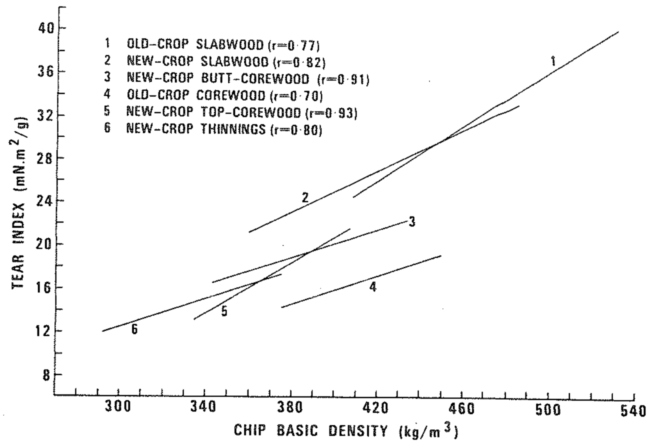

Fig. 7 — Chip basic density and tear index for central North Island wood types at 1000 PFI rev.

New Zealand chip resource

Chip basic density: For the 18 chip samples studied (Table 1), chip basic density is strongly correlated with handsheet tear, burst and tensile index, and apparent density. Chip basic density accounts for 81.0, 79.0, 62.1 and 92.4 per cent of the variation in tear, burst and tensile indexes and apparent density (Table 3, Fig. 8, 9, 10). The influence of weighted average pulp fibre length on these relationships is negligible in all cases (Table 3).

Two regression lines are presented in each of Figures 8, 9, and 10. This indicates the overall influence of the apparent deviation from the general trend of burst and tear index values for chip basic densities below 370 kg/m³. Relationships for the basic density range 370 to 500 kg/m³ could be of most relevance to pulp and paper manufacturers in New Zealand.

The 18 chip samples represent wood of different ages grown on a wide variety of sites throughout New Zealand (Table 1). Irrespective of site it is clearly evident that chip basic density determines the handsheet strength characteristics of kraft pulps. Sample numbers of Table 1 correspond with those given in Figures 8, 9 and 10.

Table 3
Influence of chip basic density, and pulp fibre length, on the handsheet strength properties of commercial chip samples

Equation number	Chip basic density range kg/m³	Regression equation*		Co-efficient of determination $r^2 \times 100$
1	320 to 500	Tear index	= 0.125 (CD) − 31.4	81.0
2	320 to 500	Tear index	= 0.071 (CD) + 6.29 (FL) − 27.4	83.7
3	320 to 500	Burst index	= −0.018 (CD) + 13.69	79.0
4	320 to 500	Burst index	= −0.017 (CD) − 0.14 (FL) + 13.6	79.1
5	320 to 500	Tensile index	= −0.129 (CD) + 123.9	62.1
6	320 to 500	Tensile index	= −0.171 (CD) + 4.90 (FL) + 127.0	63.4
7	320 to 500	Apparent density	= −1.015 (CD) + 1055.5	92.4
8	320 to 500	Apparent density	= −0.683 (CD) − 38.64 (FL) + 1030.6	94.3
9	370 to 500	Tear index	= 0.162 (CD) − 47.8	83.1
10	370 to 500	Tear index	= 0.107 (CD) + 6.15 (FL) − 42.9	86.1
11	370 to 500	Burst index	= −0.025 (CD) + 16.5	84.6
12	370 to 500	Burst index	= −0.025 (CD) + .02 (FL) + 16.5	84.6
13	370 to 500	Tensile index	= −0.182 (CD) + 147.1	68.1
14	370 to 500	Tensile index	= −0.224 (CD) + 4.81 (FL) + 150.8	69.4
15	370 to 500	Apparent density	= −0.914 (CD) + 1010.3	86.6
16	370 to 500	Apparent density	= −0.600 (CD) − 35.2 (FL) + 982.9	89.9

* CD: Chip basic density (unextracted)
FL: Weighted average pulp fibre length

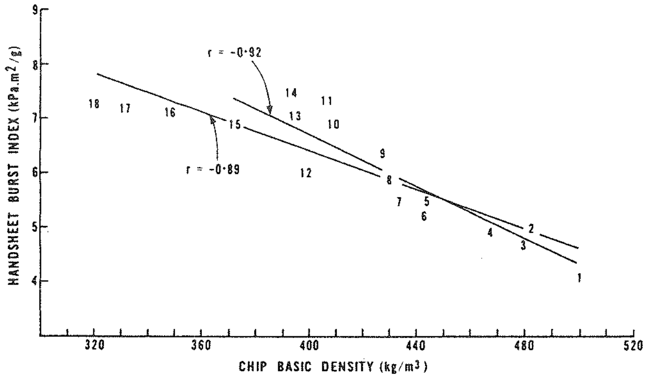

Fig. 8 — Commercial chip samples — burst index and chip basic density at 1000 PFI rev.

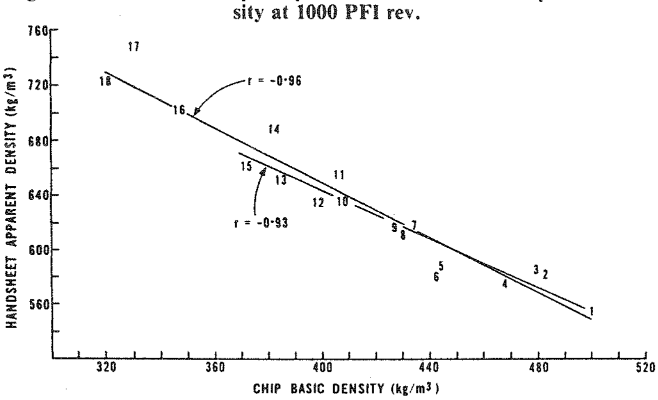

Fig. 9 — Commercial chip samples — apparent density and chip basic density at 1000 PFI rev.

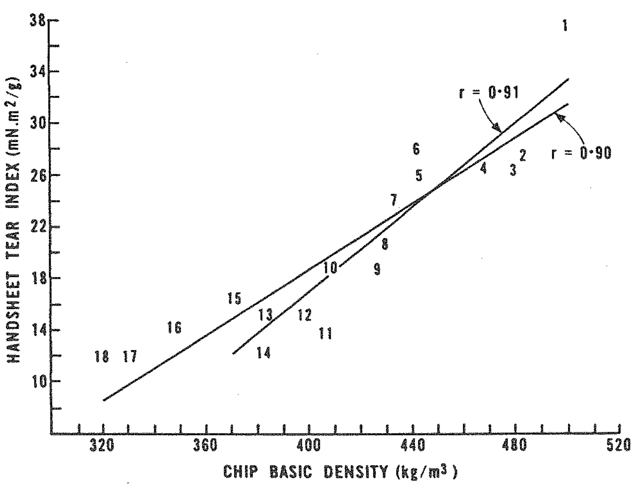

Fig. 10 — Commercial chip samples — tear index and chip basic density at 1000 PFI rev.

Table 4
Influence of weighted average pulp fibre length on handsheet strength properties for commercial chip samples

Equation number	Chip basic density range kg/m³	Regression equation*		Co-efficient of determination $r^2 \times 100$
1	320 to 500	Tear index	= 13.26 (FL) − 18.2	79.6
2	320 to 500	Burst index	= − 1.80 (FL) + 11.4	68.1
3	320 to 500	Tensile index	= − 11.89 (FL) + 104.9	46.0
4	320 to 500	Apparent density	= − 105.51 (FL) + 942.5	87.6
5	370 to 500	Tear index	= 15.25 (FL) − 24.6	77.2
6	370 to 500	Burst index	= − 2.09 (FL) + 12.3	63.7
7	370 to 500	Tensile index	= − 14.27 (FL) + 112.4	44.0
8	370 to 500	Apparent density	= − 86.26 (FL) + 880.2	80.8

* FL: Weighted average pulp fibre length

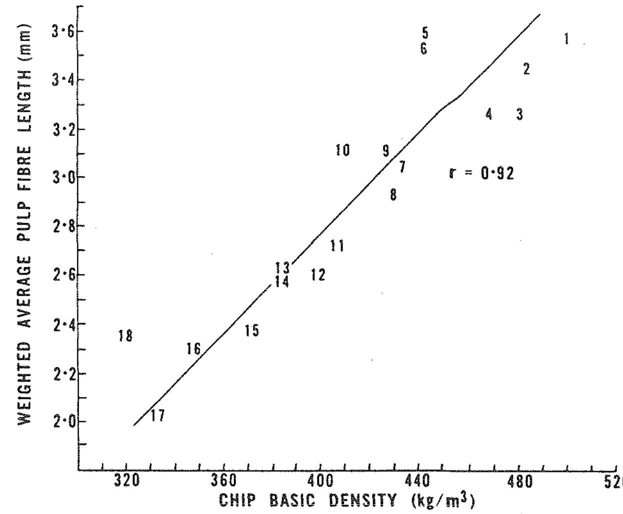

Fig. 11 — Chip basic density and weighted average pulp fibre length for commercial chip samples.

Weighted average pulp fibre length: Pulp fibre length is itself strongly correlated with handsheet tear, burst and tensile indexes, and apparent density, but to a lesser extent than chip basic density (Tables 3 and 4). A positive relationship exists between chip basic density and weighted average pulp fibre length for the wide range of densities examined (Fig. 11). For the 55 pulps of Figures 1, 2 and 3 the corresponding correlation coefficient (*r*) of the chip density/fibre length regression is 0.74.

Decreases in pulp fibre length are associated with corresponding decreases in chip basic density (Fig. 11); there is no evidence that effects of pulp fibre length and chip basic density on the measured handsheet properties are additive (Tables 3 and 4).

DISCUSSION

Chip basic density

The consistent and strong influence of chip basic density on handsheet strength properties for a very wide range of pulp samples is technically important (Fig. 1-4, 8-10). This influence of chip basic density holds not only for within tree and between tree chip samples, but also for composite commercial chip samples. Furthermore the relationship obtained holds for radiata pine wood grown on virtually all sites in New Zealand.

Regression equations with generally similar slope and intercept are obtained for the central North Island and commercial sets of chip samples when chip basic density is correlated with handsheet burst, tensile and tear indexes, and apparent density (Tables 2 and 3). These relationships are, however, also dependent on the range of chip basic densities involved as well as the wood age and wood property composition of the samples (Fig. 5-7). Differences associated with between tree and within tree sample differences can be significant when compared with those of composite material made up of chips from a number of trees or parts of trees (Fig. 1-9).

The predictive models of Tables 2 and 3 show emphatically that chip basic density can be used to predict kraft pulp quality. For commercial operations the relationships of Table 3 for the chip basic density range 370 to 500 kg/m³ are considered to be the most meaningful. It is important to note that these relationships apply only to slush and very lightly refined kraft pulps in the 26 to 30 Kappa number range only.

For a wide range of chip basic densities it has been shown previously that it can be misleading to compare or relate wood and pulp qualities at, say, given handsheet density or burst values(1). For the 18 pulps of this earlier study(1). which were prepared from chips in the basic density range 380 to 540 kg/m³, burst indexes common to all pulps lay between 8 and 9 kPa.m²/g only (see Fig. 7 of reference 1). Furthermore comparision of pulps at specific burst values ignores the very different degrees of refining given each pulp and, therefore, direct comparison with wood characteristics such as chip basic density is questionable.

It is necessary to compare wood and handsheet qualities at low levels of pulp refining when wide ranges of chip basic density are involved. Pulp refining normally causes handsheet tear index to decrease, and burst and tensile indexes, and apparent density to increase(7). For pulps prepared from low density chips, however, these trends are not always obtained since minimum or maximum strength values can develop with refining. This is particularly true for tear index(7). When comparing or relating the wood and pulp qualities of radiata pine chips of densities below about 320 kg/m³ it is, therefore, necessary to minimize effects of pulp refining.

The data of Figures 8, 9, 10 show that although radiata pine growth rates, wood basic density and tracheid lengths may vary with geographic location(5,8), overall kraft pulp quality can be predicted in terms of wood basic density alone. Kraft pulps prepared from Southland old and new crop, slabwood and pulpwood, clearly fit the same regressions as those prepared from corresponding wood grown in South and North Auckland. Samples from Southland are numbered 3, 12, 13, and 17 and from Auckland 1, 2, 7, 8, and 14 (Table 1).

Pulp fibre length

The strong correlation between chip basic density and weighted average pulp fibre length shown in Figure 11 requires comment.

1. Chip basic density is a wood property whereas weighted average pulp fibre length reflects a mean length of a population of fibres, a pulp property.
2. Correlations between chip density and pulp fibre length can be expected for wide ranges of chip basic density since it has been shown that this parameter and wood tracheid length both increase within radiata pine stems from pith to bark(9), and generally decrease with increasing latitudes and altitudes of forest growing sites in New Zealand(5,8). Thus, for the wide range of chip basic densities examined (Figure 11), the strong correlations obtained between these two wood and pulp properties is not unexpected. For narrower ranges of chip basic density and for non-composite chip samples, chip density and pulp fibre length correlations are low(1,2). Wood tracheid length and pulp fibre length have been shown to be correlated(2,3,4).
3. Although chip basic density and pulp fibre length are correlated one to another (Figure 11), and appear to have roughly parallel roles in the determination of handsheet properties (Tables 3 and 4), the apparent effect of fibre length should be interpreted with caution. Chip basic density is always more strongly correlated with the handsheet properties of tear, burst and tensile index, and apparent density, than is pulp fibre length (Tables 3 and 4, and references 1, 2, and 3). Furthermore, pulp fibre length must be dependent on wood processing, pulping and pulp processing operations and its values will vary with individual mill equipment and the types of products being produced. Chip basic density on the other hand is independent of wood processing and kraft pulping operations.
4. It should be emphasized that for selected commercial operations pulp fibre length could be used to predict and especially monitor kraft pulp quality where the quality of the wood supply (basic density) and processing operations and equipment are relatively constant and well characterized.

Previous studies have shown an additive effect of pulp fibre length on handsheet property/chip basic density relations(1,2,3). These effects were inconsistent and increased the amount of variation in handsheet tear and burst indexes, and apparent density accounted for by chip basic density alone by from 0 to 10 per cent. These studies were concerned with limited numbers of pulps made from selected trees and parts of trees. The present studies have shown (Tables 2 and 3) that such an additive effect of pulp fibre length is fortuitous and that kraft pulp quality can be predicted from chip basic density alone.

CONCLUSIONS

The radiata pine kraft pulp properties of handsheet tear, burst and tensile indexes, and apparent density can be predicted from chip basic density alone.

Effects of including pulp fibre length in the handsheet property/chip basic density predicting relationships are negligible.

The chip basic density/handsheet property predictive models hold for whole trees (thinnings), parts of trees (corewood and slabwood), and commercial pulpwood and sawmill residue slabwood chips obtained from a wide range of forests located throughout New Zealand.

Pulp fibre length and chip basic density can be strongly correlated one to another, particularly when the range of chip densities included in the overall sample is high. When such correlations exist, the influence of these pulp (fibre length) and wood (density) property parameters on selected handsheet characteristics are generally similar one to another. Chip basic density is, however, more highly correlated (than pulp fibre length) with kraft pulp quality and is entirely independent of wood processing and pulping operations.

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APPENDIX

Physical evaluation data for commercial chip samples

Chip sample No.	Beating	Freeness	Tear index	Burst index	Apparent density	Air resistance	Tensile index	Stretch	Tensile energy index	Light scattering co-efficient
	rev	CSF	$mN.m^2/g$	$kPa.m^2/g$	kg/m^3	s/100 ml	Nm/g	%	J/kg	o.d. m^2/kg
1	2000	730	34.6	5.0	576	0	61	2.45	965	17.8
	4000	710	27.4	6.2	600	1	72	2.78	1266	15.8
	8000	590	24.3	7.1	621	4	76	2.97	1435	14.2
	16000	300	21.5	7.9	642	47	86	3.25	1746	13.6
2	2000	725	25.5	5.8	595	1	62	2.45	1012	17.4
	4000	695	21.3	6.7	622	2	75	2.94	1448	15.7
	8000	585	18.1	7.9	640	6	86	3.43	1902	13.7
	16000	290	17.3	8.2	645	34	90	3.37	1952	13.5
3	2000	735	24.7	5.5	608	1	68	2.72	1229	17.7
	4000	720	20.6	6.7	627	1	78	2.95	1455	15.6
	8000	595	18.7	7.9	651	4	88	3.45	1886	13.7
	16000	315	16.8	8.4	673	18	92	3.47	1993	12.3
4	2000	760	24.7	5.9	598	1	70	2.34	1200	16.3
	4000	700	20.1	6.7	623	1	80	2.88	1472	14.5
	8000	590	18.0	7.7	640	5	89	3.27	1851	13.2
	16000	310	15.7	8.5	669	63	94	3.50	2089	12.1
5	2000	730	24.2	6.3	609	1	71	2.72	1288	17.1
	4000	710	21.0	6.9	628	1	83	3.12	1677	15.8
	8000	595	19.1	7.7	645	5	87	3.34	1851	14.3
	16000	320	16.6	8.6	669	50	90	3.39	1965	13.0
6	2000	740	25.3	6.2	608	1	72	2.90	1358	17.0
	4000	700	23.3	7.1	622	1	81	2.85	1465	15.8
	8000	611	20.8	8.1	646	5	88	3.21	1801	14.4
	16000	310	17.6	9.1	676	70	94	3.36	2001	13.2
7	2000	730	23.5	6.3	632	2	70	3.31	1562	16.6
	4000	690	20.7	6.8	654	4	74	3.58	1772	15.0
	8000	595	20.2	7.7	672	6	83	3.81	2103	13.6
	16000	360	19.3	8.3	679	55	87	3.78	2178	11.9
8	2000	705	19.1	6.6	631	3	74	3.13	1536	17.9
	4000	650	18.4	7.2	652	4	83	3.31	1811	15.8
	8000	540	15.4	7.9	667	15	88	3.62	2059	14.6
	16000	315	15.0	8.6	689	115	93	3.80	2298	13.2
9	2000	710	18.1	7.1	643	3	80	3.06	1593	17.4
	4000	680	15.8	8.0	659	5	87	3.62	2024	16.0
	8000	560	14.3	8.4	686	15	95	3.79	2306	14.1
	16000	340	13.9	9.4	706	120	97	3.89	2572	12.4
10	2000	720	18.3	7.1	654	2	81	3.17	1653	16.9
	4000	670	16.0	8.1	669	5	89	3.36	1902	15.2
	8000	570	15.3	8.5	686	14	93	3.69	2183	13.6
	16000	370	14.7	8.6	702	80	95	4.02	2451	12.4
11	2000	690	13.4	7.8	675	9	87	3.22	1806	16.6
	4000	640	12.4	8.1	695	13	97	3.33	2095	14.4
	8000	510	11.1	9.1	710	45	98	3.66	2298	12.9
	16000	300	11.5	9.0	732	232	106	3.88	2650	11.5
12	2000	710	14.6	6.4	654	4	77	3.03	1546	17.3
	4000	—	13.7	7.5	679	6	86	3.44	1922	15.5
	8000	560	13.0	7.9	693	19	91	3.69	2191	13.7
	16000	290	12.1	8.4	716	176	99	3.82	2470	12.6
13	2000	700	14.7	7.4	670	5	77	3.24	1657	17.3
	4000	680	13.7	7.8	685	9	84	3.52	1968	15.2
	8000	560	13.1	8.0	705	16	92	3.76	2272	13.5
	16000	360	12.7	8.6	720	77	95	4.02	2495	12.0
14	2000	650	12.3	8.0	707	18	88	3.84	2228	18.1
	4000	610	11.7	8.5	723	30	93	4.07	2471	16.4
	8000	480	11.6	9.0	740	72	100	4.37	2815	14.1
	16000	300	11.6	9.4	757	360	104	4.48	2991	12.7
15	2000	690	15.2	7.2	681	12	79	3.52	1848	17.6
	4000	640	14.1	7.7	696	19	85	3.68	2057	15.7
	8000	540	13.1	8.1	719	60	90	3.90	2781	13.8
	16000	300	11.3	8.2	733	—	99	3.89	2498	12.3
16	2000	650	13.7	7.4	716	27	82	3.81	2094	18.3
	4000	590	13.0	8.0	736	57	88	4.02	2350	15.6
	8000	500	12.0	8.2	753	110	89	4.20	2502	13.9
	16000	300	11.7	8.6	764	>500	96	4.51	2832	12.5
17	2000	580	11.6	7.5	762	143	81	4.58	2633	16.0
	4000	540	10.9	7.6	775	259	83	4.81	2806	13.8
	8000	440	10.2	8.2	789	425	92	5.22	3328	12.0
	16000	290	10.0	8.3	803	>500	99	4.87	3273	10.5
18	2000	630	11.7	7.6	737	70	85	3.69	2085	17.2
	4000	570	10.7	7.9	752	140	90	3.82	2266	14.8
	8000	470	10.7	8.0	768	325	97	3.90	2511	13.1
	16000	300	9.7	8.6	777	>500	99	3.92	2573	11.6

REFERENCES

(1) Kibblewhite, R. P. — *N.Z. J. For. Sc.* **10**(3): 533 (1980).

(2) Kibblewhite, R. P. and Lloyd, J. A. — Interrelations between the wood, fibre and kraft pulp properties of new-crop radiata pine corewood and slabwood. New Zealand Forest Service, Forest Research Institute, FRI Bulletin No. 45 (1983).

(3) Kibblewhite, R. P. and Lloyd, J. A. — Interrelations between the wood, fibre and kraft pulp properties of new-crop radiata pine 12 year old thinnings. New Zealand Forest Service, Forest Research Institute, FRI Bulletin No. 44 (1983).

(4) Kibblewhite, R. P. — *Appita* **35**(4): 289-298 (1982).

(5) Cown, D. J. and Kibblewhite, R. P. — *N.Z. J. For. Sc.* **10**(3): 521 (1980).

(6) Cown, D. J. — *N.Z. J. For. Sc.* **10**(3): 502 (1980).

(7) Kibblewhite, R. P. — *N.Z. J. For. Sc.* **3**: 220 (1973).

(8) Cown, D. J. and McConchie, D. L. — Radiata pine wood properties survey (1977-1982). New Zealand Forest Service, Forest Research Institute, FRI Bulletin No. 50 (1984).

(9) Cown, D. J. — *N.Z. J. For. Sc.* **10**(3): 504 (1980).

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