Preferred citation: R.P. Kibblewhlte. Qualities of kraft and thermomechanical radiata pine papermaking fibres. In **Papermaking Raw Materials**, *Trans. of the VIIIth Fund. Res. Symp. Oxford, 1985*, (V. Punton, ed.), pp 93–131, FRC, Manchester, 2018. DOI: 10.15376/frc.1985.1.93.

QUALITIES OF KRAFT AND THERMOMECHANICAL RADIATA PINE PAPERMAKING FIBRES

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ABSTRACT

This review examines the extent to which wood property variation in New Zealand's radiata pine resource determines pulp quality. The qualities of radiata pine papermaking fibres are very dependent on their original position within a tree (growth rings from pith and/or height in tree), as well as the geographic altitude and latitude of sites on which the trees are grown. Two categories of radiata pine pulpwood are recognised in New Zealand: slabwood of high basic density from the outside of sawlogs; and corewood of relatively low basic density from the smaller logs (non-sawlogs) of the upper part of a tree and from whole-trees less than 20 years old.

The kraft pulp fibres from corewood are shorter and have thinner walls than corresponding fibres from slabwood, but the diameters of these two fibre populations are essentially identical. The handsheet properties (apparent density, and burst, tear, and tensile indices) are strongly correlated with, and can be predicted from, the wall thickness:diameter ratio of pulp fibres or the basic density of the wood sample pulped. These trends hold for whole trees of different age, for parts of trees, and for commercial pulpwood and slabwood material obtained from throughout New Zealand.

Mechanical pulps can be correlated with wood properties to a lesser extent than are kraft pulps. In thermomechanical (TMP) pulp production, slabwood consumes more energy to a given freeness and produces pulps of higher strength than corewood. Pulps from corewood, however, have excellent optical properties whereas those from slabwood are of slightly lower quality. These differences are partly

explained by the very different qualities of slabwood and corewood fibres and fines. Slabwood TMP pulps are rich in fibrillar fines, which have a strong consolidating influence on the long and relatively stiff fibres of this furnish. Alternatively, corewood fines are of a more heterogeneous and coarse quality (and have a lesser consolidating effect on fibres which are shorter and more collapsible than corresponding slabwood fibres) and therefore pack more tightly within handsheets. The handsheets of corewood pulps have excellent optical properties since the fibres and fines of this furnish give more air-to-fibre and air-to-fibre element interfaces than do those of corresponding slabwood fibres and fines.

INTRODUCTION

New Zealand's forest-related industries are mainly based on plantation forestry. Radiata pine constitutes more than 90% of the planted forest resource. During the period 1985 to 1990, remaining stands of the first rotation forest crop (a resource which consists of trees of age 50 to 60 years) will be cut-out, and utilisation will commence of the stands of the second rotation crop (the replanted and additional newly established forest resource, which consists of trees of age 25 to 30 years). For the period beyond 1990, New Zealand's forest industry will be based on second generation or new-crop material(1,2).

The qualities of the first (old-crop) and second (new-crop) generation wood resources are very different because of their different ages and growing sites, and the varying degrees of silvicultural treatment given the new-crop forest stands(2). Relative to old-crop, the new-crop forest resource is younger (25 to 30 years compared with more than 50), is smaller (mean breast height diameter 45 to 50 cm compared with more than 65 cm), contains less heartwood (about 15% compared with about 50%), and is of lower wood basic density (400 compared with 425 kg/m^3).

RADIATA PINE WOOD RESIDUE QUALITIES

The term wood residue refers to that part of the utilisable tree stem remaining after solid wood products such as sawn timber and veneer have been cut from it, i.e. logs below the merchantable size for sawlogs, and residual material from processing plants (offcuts and chips, excluding sawdust). Wood residues will constitute a significant proportion of the large increase in the volume of radiata pine wood which will become available in New Zealand in the 1990s and beyond(2,3). It has been estimated that wood residue volumes could ultimately constitute some 60 to 70% of the total radiata pine resource harvested in the period 1990 to 2015(9). The qualities of these residues could well determine future utilisation options in terms of the types of pulp and paper products which can best be manufactured from them. The present paper, therefore, examines radiata pine wood residue types in relation to kraft and thermomechanical pulp (TMP) papermaking fibre qualities.

The stems of radiata pine trees contain a central core of low density wood (corewood) with tracheids which are short and thin-walled compared with those in the outerwood(4). Somewhat variable transition zones with indeterminate boundaries exist between corewood and outerwood. Within radiata pine stems, wood basic density and tracheid length increase with increasing numbers of growth layers from the pith(5). Radiata pine stems are therefore divided into two categories: corewood and outerwood (Figure 1).

Based on such a classification, corewood is of low basic density and contains short tracheids when compared with outerwood which is of significantly higher basic density and contains longer tracheids(4,5).

Radiata pine stems can also be divided into several sawlogs and top logs depending on tree size and age (Figure 2)(6). Based on such a classification, top logs generally consist of corewood, and the sawmill residues (mainly from the outside of sawn sawlogs) are mainly outerwood. It needs to be recognised that the value of the merchantable small end diameter (s.e.d.) can range from 15 to 35 cm depending on the type and processing requirements of a sawmill(3). The value of 25 cm used by Cown and McConchie(6) represents a middle-of-the-road value. Wood residues which result from the solid wood utilisation of radiata pine forests can, therefore, also be divided into two wood quality categories:

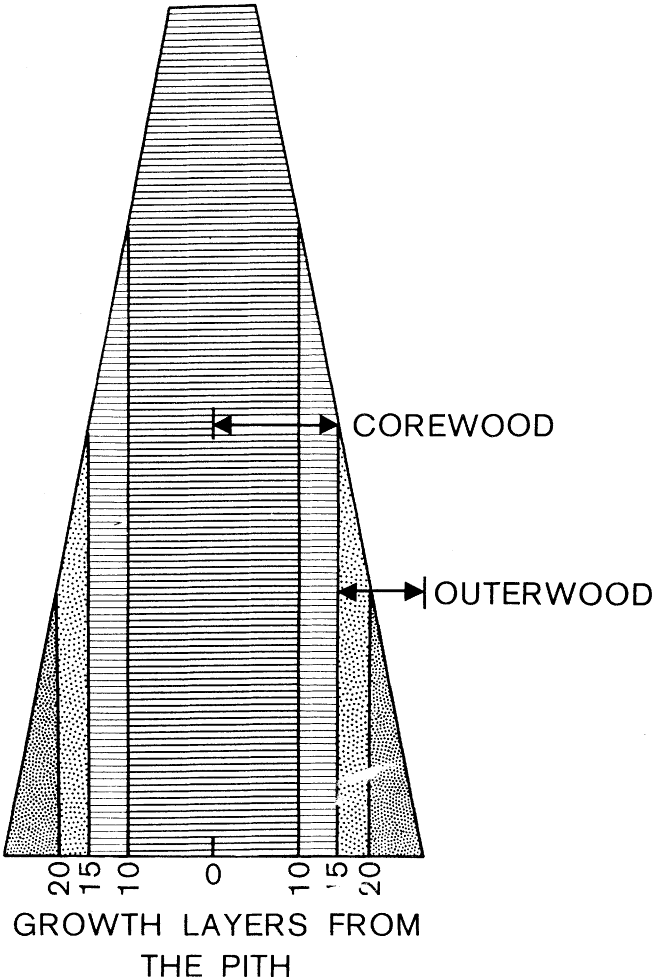

Fig 1—Schematic diagram of the corewood and outerwood zones for a 30- to 35-year old radiata pine stem. Zones of transitional corewood and outerwood quality are indicated for the 10 to 15, and 15 to 20 growth layers respectively (**9**)

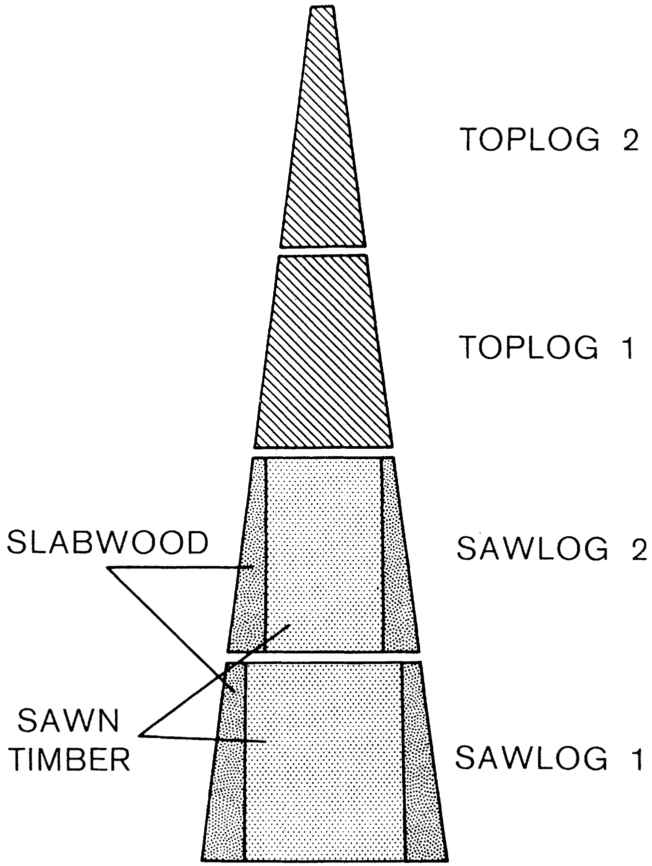

Fig 2—Schematic diagram of tree components (after Cown (**6**))

(1) top logs, which are predominantly of a corewood quality, and

(2) sawmill residues, which are predominantly from slabwood and of an outerwood quality.

The top log category necessarily also includes whole-tree thinnings and trees less than 20 years old. Wood chips from this type of material are predominantly of a corewood quality with basic densities of 340 to 435 kg/m^3 depending on tree age, site, and silvicultural history(5).

Geographic locations of tree growing sites within New Zealand also influence wood basic density and tracheid length. As latitudes increase from north to south and as altitudes increase, wood basic density and tracheid length generally decrease (Figure 3)(5,7).

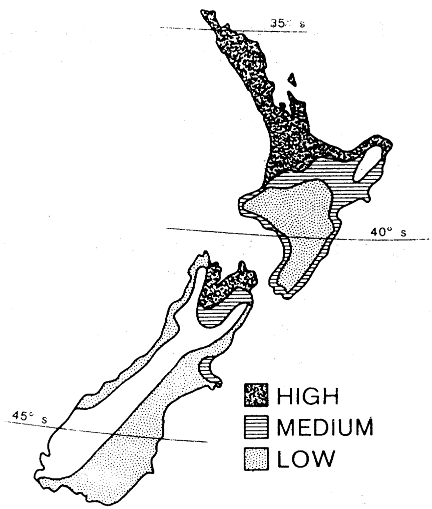

Fig 3—Geographic distribution of radiata pine wood basic densities in New Zealand (after Cown (**5**))

Wood basic density and tracheid length values which can be expected from the top log and slabwood residue categories are listed in Table 1. The values presented vary with tree

	Top logs (<25 cm s.e.d.)	Sawmill slabwood residues
Selected trees from Kaingaroa Forest(6)		
Basic density (kg/m^3)	325-410	420-475
Tracheid length (mm)	2.5-3.2	3.6-4.0
Commercial wood chips from throughout New Zealand(8)		
Basic density (kg/m^3)	320-407	399-500
Kraft pulp weighted average fibre length (mm)*	2.0-2.7	2.6-3.6

* Refers to both the intact and shortened tracheids of wood chips(8). Tracheid length normally refers to intact wood tracheids only(5).

Table 1 - Wood properties of residue types

or crop age, the geographic location of tree growing sites, and sawmill processing constraints (i.e. sawlog s.e.d.). Because of this, the variation within each of the wood residue types can be expected to be high. Irrespective of such quality ranges, the two wood residue categories are very different and are easily segregated during log harvesting and/or wood processing operations.

General wood quality descriptions (or expectations) for the new-crop radiata pine top log and slabwood residues are as follows. Respective mean wood basic density and tracheid length values for slabwood and top log residues are generally greater than and less than 400 kg/m^3, and greater than and less than 3.0 mm. For pulp and paper products, it has been shown that qualities are very much affected by wood and tracheid characteristics(9,10,11,12). The remainder of this review is, therefore, concerned with the relationships between top log and slabwood residue qualities and kraft and TMP pulp and paper properties.

WOOD QUALITY AND KRAFT PULP INTERRELATIONSHIPS

Bases of comparison

Selection of a suitable basis for comparing the wood, kraft pulp, and handsheet properties of radiata pine wood residues is a major concern. Dinwoodie(13), in a comprehensive review of the literature concerning the relationships between fibre morphology and paper properties, clearly illustrates how the basis of comparison used can determine the validity or otherwise of any relationships obtained. Since the rate and effectiveness of pulp refining can vary greatly with fibre quality (fibre density and fibre dimensions)(14), a meaningful method of comparison must necessarily be based on unrefined pulps. To achieve this, kraft pulps were evaluated at four levels of refining and their interpolated (or extrapolated) handsheet property values determined for very low extents of PFI mill refining; 1000 revolutions with an applied load of 1.8 N/mm (Appendix 1). Extrapolation(15) or interpolation(16,17) to low refining is necessary since it has been found that handsheet physical evaluation data for unrefined pulps are substantially more variable than those obtained with refined furnishes (unpublished data). Correlation of wood and fibre characteristics with the handsheet properties of essentially unrefined pulps is considered the most meaningful basis of comparison since all pulps are processed to similar extents before sheetmaking.

When the basis of comparison is a given burst or tensile index, or apparent sheet density, extents of pulp refining are very different for pulps made from radiata pine wood of different basic density(15). In fact, for a wood basic density range of 380 to 540 kg/m^3, the burst indices common to all the pulps examined fell between 8 and 9 kPa.m^2/g. Such high burst indices are of limited value in evaluating kraft pulp qualities, particularly since such values are determined for very different extents of pulp refining. For the present studies, therefore, wood, pulp, and handsheet interrelationships are determined for very lightly refined (essentially unrefined) pulps in accordance with procedures detailed in Appendix 1.

Wood, pulp, and handsheet relationships

Very definite wood, pulp, and handsheet property interrelationships were found for kraft pulps prepared from radiata pine top logs (roundwood billets which contain 15 growth layers) and slabwood residues from old-crop (52 year old)(15) and new-crop (24 year old)(17) trees, and from new-crop, whole-stem thinnings (12 year old)(16). Surface and section views of corewood and slabwood kraft handsheets are shown in Figure 4. Selection procedures and experimental methods for the various wood and pulp samples are detailed in Appendix 1. Mean kraft pulp fibre length and fibre wall thickness values (Table 2) and their population distributions (Figures 5,6) are very different for the various wood samples. Fibre lengths and wall thicknesses of corewood fibres are always significantly less than those of slabwood fibres, and also increase with tree age in accordance with

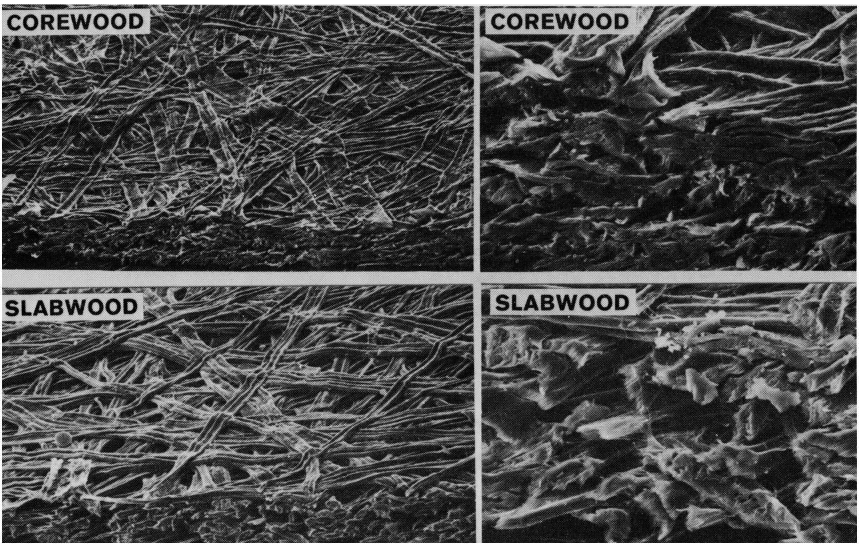

Fig 4—Section and surface views of radiata pine corewood and slabwood Kraft handsheets. Note the collapsed and ribbon-like configuration of the corewood fibres and the consolidated appearance of the corewood web.

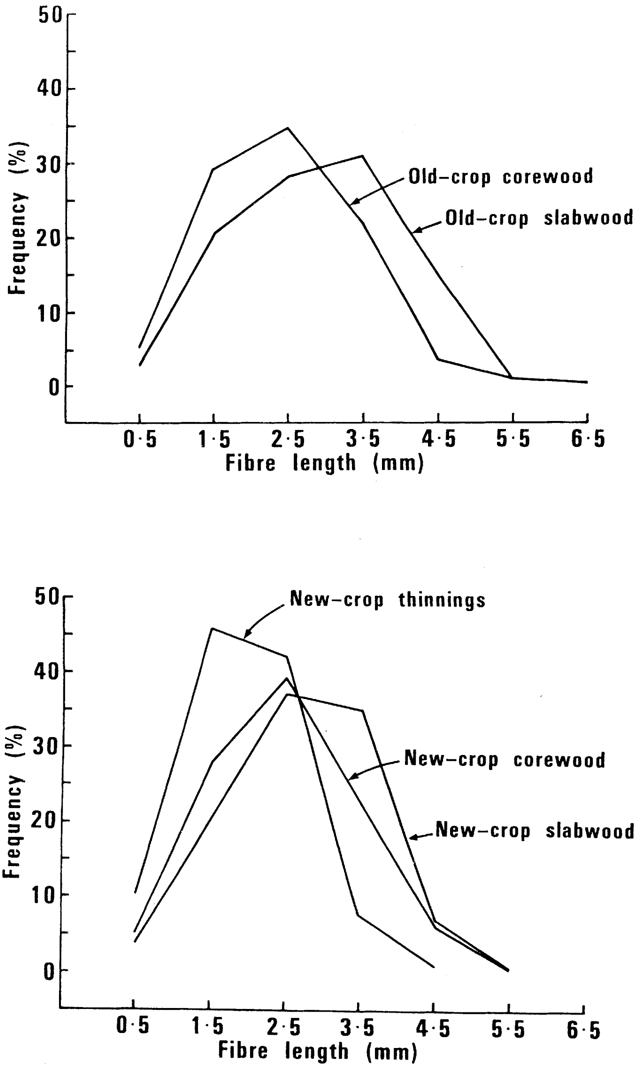

Fig 5—Fibre length distributions for Kraft pulps prepared from corewood and slabwood of old-crop and new crop radiata pine.

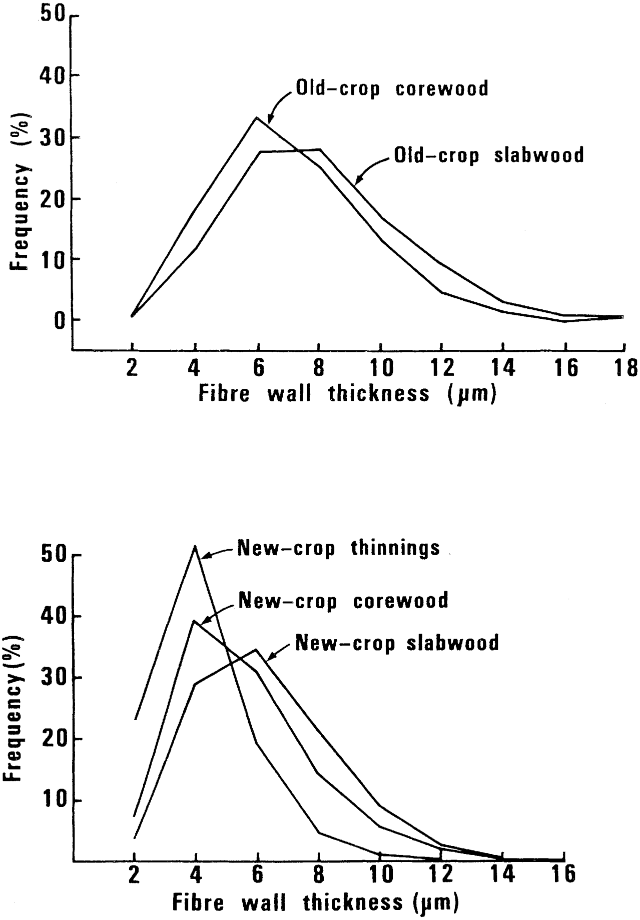

Fig 6—Fibre wall thickness distributions for Kraft pulps prepared from corewood and slabwood of old-crop and new-crop radiata pine.

the trends shown for radiata pine wood by Cown(4,5). In contrast, corresponding fibre diameter values are generally similar for the range of wood residue types examined (Table 2, Figure 7).

	Age of trees in sample (years)	Chip basic density (kg/m^3)	Kraft pulp properties		
			Weighted average fibre length (mm)	Fibre wall thickness (um)	Fibre diameter (um)
Old-crop					
Slabwood	52	468	3.3	8.0	40.0
Pulpwood*	52	402	2.8	7.2	40.7
New-crop					
Slabwood	24	423	3.1	6.2	38.4
Pulpwood*	24	383	2.9	5.5	38.7
New-crop					
Thinnings**	12	331	2.2	4.2	36.7

* From billets of wood containing 15 growth layers only.
** Whole-tree logs to 10 cm small end diameter

Table 2 - Sample chip basic densities and kraft pulp mean fibre dimensions

Irrespective of these fibre dimension differences, the handsheet properties of tear, burst and tensile index, and apparent density can be predicted from a knowledge of wood

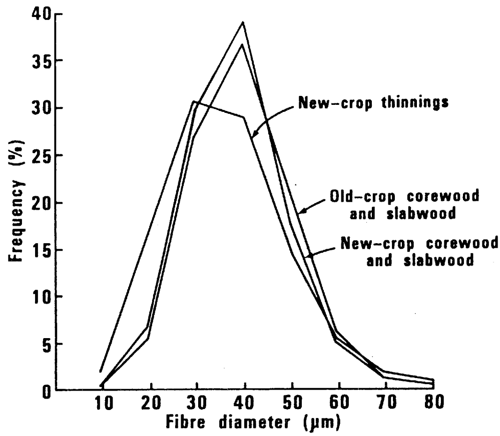

Fig 7—Fibre diameter distributions for Kraft pulps prepared from corewood and slabwood of old-crop and new-crop radiata pine.

basic density alone (Table 3, Figure 8)(8). Correlations between chip basic density and the handsheet properties of stretch and light scattering coefficient are generally low (unpublished data). Handsheet stretch has, however, been found to be correlated with fibre wall thickness rather than chip basic density(16,17). Furthermore, wood basic density is also strongly correlated with the fibre wall thickness: fibre diameter ratio, which is in turn correlated with handsheet tear and burst index, and apparent density (Figures 9,10, Table 3). The handsheet property/wall thickness: diameter ratio correlations are significantly higher when the old-crop corewood data are omitted (Figure 10) (Table 3). This apparent deviation from "normal" of the old-crop corewood data is unexplained. The correlation between fibre wall thickness and chip basic density is significantly less than that obtained with the wall thickness:diameter ratio (Table 3). Handsheet tensile index/chip basic density correlations have been found to be consistently lower than those obtained for tear and burst index, and apparent sheet density; an effect which is not yet fully explained (Tables 3,4)(8).

Regression equation*		Number of samples	Coefficient of determination (R^2 x 100)
Tear index	= 0.120(CD) - 26.4	55	73.6
Tear index	= 176.8(WT/D) - 7.8	55	51.0
Tear index	= 223.8(WT/D) - 13.4	46**	80.6
Burst index	= 0.019(CD) + 13.5	55	75.7
Burst index	= -25.8(WT/D) + 10.2	55	44.7
Burst index	= -31.9(WT/D) + 10.9	46**	70.6
Tensile index	= -118(CD) + 119.2	55	34.8
Tensile index	= -128.2(WT/D) + 93.5	55	12.9
Apparent density	= -0.973(CD) + 1011.5	55	82.8
Apparent density	= -1606(WT/D) + 888	55	72.0
Chip basic density	= 1487(WT/D) + 151	55	74.9
Chip basic density	= 31.8(WT) + 205	55	42.2

* CD: Chip basic density (unextracted)
WT: Fibre wall thickness
WT/D: Fibre wall thickness:fibre diameter ratio

** Old-crop corewood data ommitted

Table 3 - Regression equations relating selected wood, pulp fibre, and handsheet properties for central North Island pulps

The data of Figures 8-10 and Tables 2 and 3 are based on a radiata pine wood resource located in the centre of the North Island of New Zealand (Kaingaroa State Forest). To take into account variations in wood quality which occur with different tree growing sites (Figure 3), and to verify the trends obtained previously for individual trees and parts of trees, kraft pulps were prepared from commercial top logs and sawmill residues collected from throughout New Zealand(8). For the 18 pulps studied, chip basic density is strongly correlated with handsheet tear, burst and tensile index, and

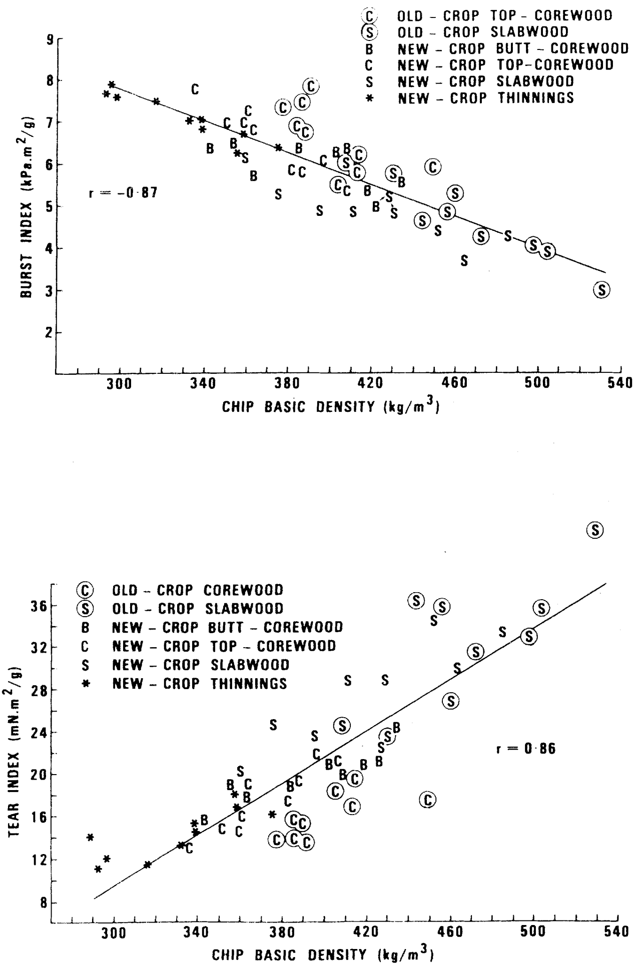

Fig 8—Handsheet burst and tear indices, and chip basic density relationships - influence of wood quality and tree age (**8**).

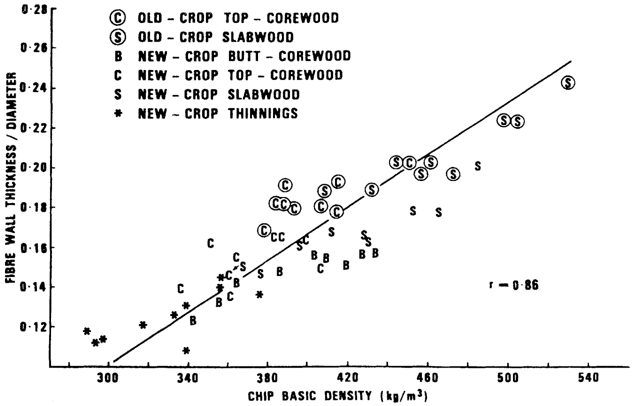

Fig 9—Fibre wall thickness : diameter ratio and chip basic density relationship - influence of wood quality and tree age.

Regression equation*	Coefficient of determination (R^2 x 100)
Tear index = 0.125(CD) - 31.54	81.0
Tear index = 0.071(CD) + 6.29(FL) - 27.4	83.7
Burst index = -0.018(CD) + 13.69	79.0
Burst index = -0.017(CD) - 0.14(FL) + 13.6	79.1
Tensile index = -0.129(CD) + 123.9	62.1
Tensile index = 0.171(CD) + 4.90(FL) + 127.0	63.4
Apparent density = -1.015(CD) + 1055.5	92.4
Apparent density = -0.683(CD) - 38.64(FL) + 1030.6	94.3

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

Table 4 - Regression equations relating chip basic density and pulp fibre length to the handsheet strength properties for commercial chip samples

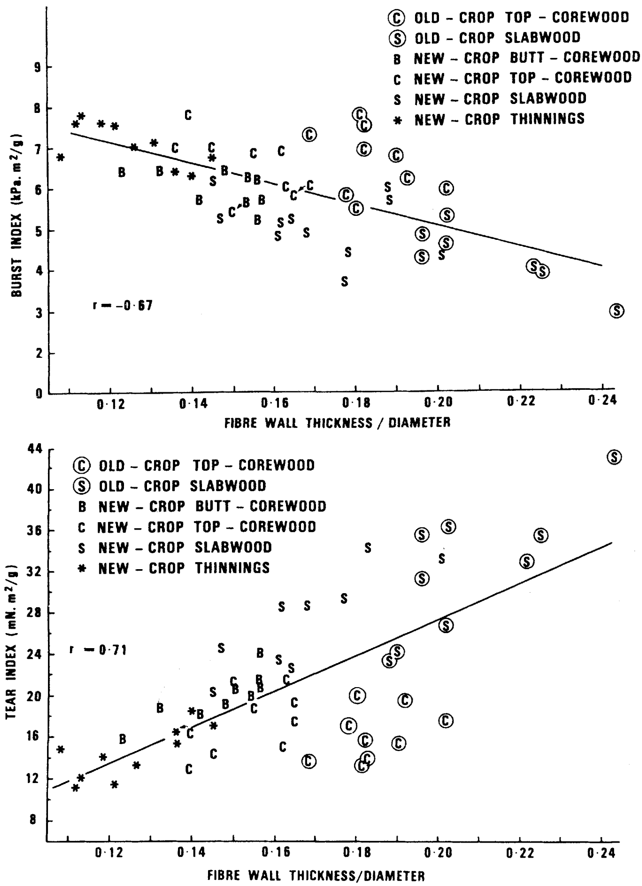

Fig 10—Handsheet burst and tear indices and pulp fibre wall thickness : diameter ratio relationships - influence of wood quality and tree age.

apparent density (Figure 11), and the regression equations obtained are remarkably similar to those of the central North Island pulps (Tables 3,4).

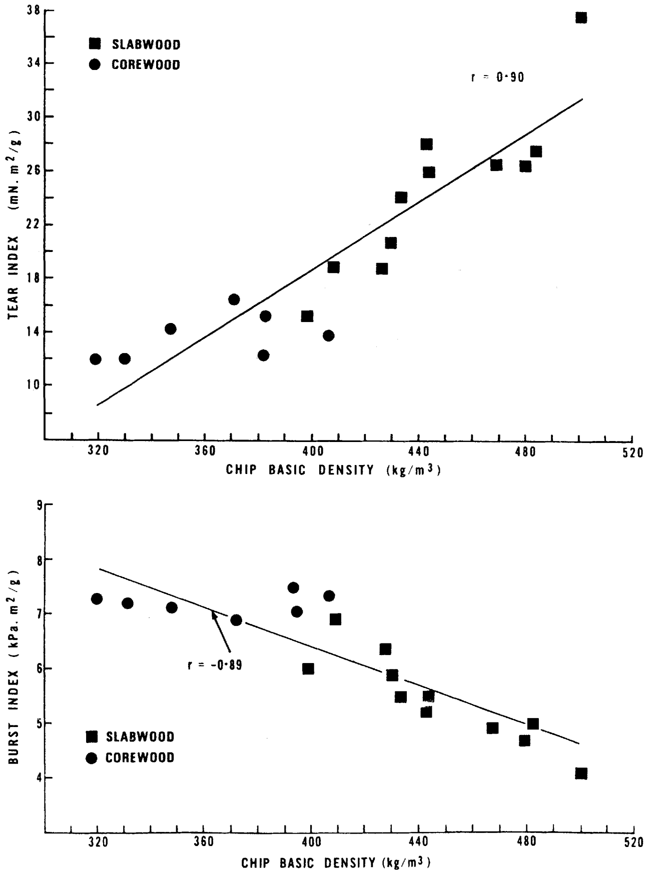

Fig 11—Handsheet burst and tear indices and chip basic density relationships - influence of wood residue quality.

Multiple regression analyses show that effects are negligible of including pulp fibre length in the handsheet property/chip basic density predicting equations of Tables 3 and 4(8). Pulp fibre length and chip basic density can, however, be strongly correlated to one another, particularly when the range of chip densities included in the overall sample is high (Table 5). When such correlations exist, the influence of these pulp (fibre length) and wood (density) property parameters on selected handsheet characteristics are generally similar to one another. Chip basic density is, however, always more highly correlated with kraft pulp quality and is entirely independent of wood processing and pulping operations (8).

HANDSHEET PROPERTY INTERRELATIONSHIPS

Handsheet properties for the old- and new-crop slabwood and corewood pulps are generally as expected: with the slabwood pulps having relatively high handsheet tear characteristics; and the corewood material relatively low tear but high bonding (burst and tensile) and high apparent density properties(15,17). Measured differences between the new-crop, butt-corewood, and top-corewood handsheets require comment, however, since for given burst indices (or sheet densities) the butt-corewood pulps give somewhat higher tear indices than the top-corewood material. In contrast, generally similar tensile relationships are obtained for all the new-crop corewood pulps(17). The higher proportion of long and thick-walled fibres in the top-corewood pulps (Figures 5,6, Table 3) can be expected to enhance their handsheet tear strengths relative to the butt-corewood webs. Since this enhancement does not occur, alternative explanations are required. In consequence, the different tensile and burst characteristics of the butt-corewood and top-corewood pulps (Figure 12) appear related to differences in handsheet stretch (Figure 13) and ultimately to different fibre extensibilities(13,14,17). Apparently, the butt-corewood pulps contain more extensible fibres than the top-corewood material; as a result, butt-corewood pulps have higher handsheet extensibilities and burst indices, and lower tensile strengths. This conclusion is supported by further data of Cown and McConchie (unpublished data 1981); their findings show that longitudinal wood shrinkage is relatively high for butt-corewood (0.1 to 0.3%) and minimal for

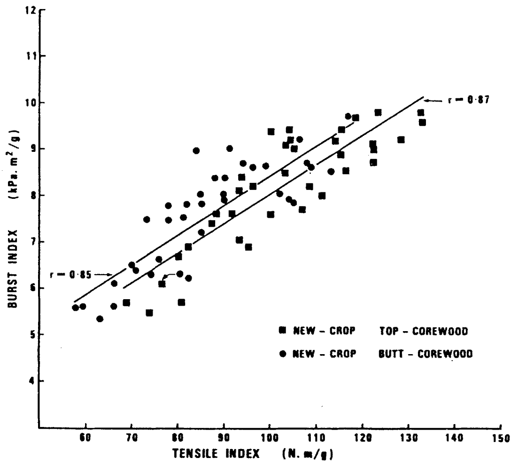

Fig 12—Handsheet burst and tensile index relationships for top- and butt-corewood Kraft pulps. The two regressions are different at the 1% level of significance.

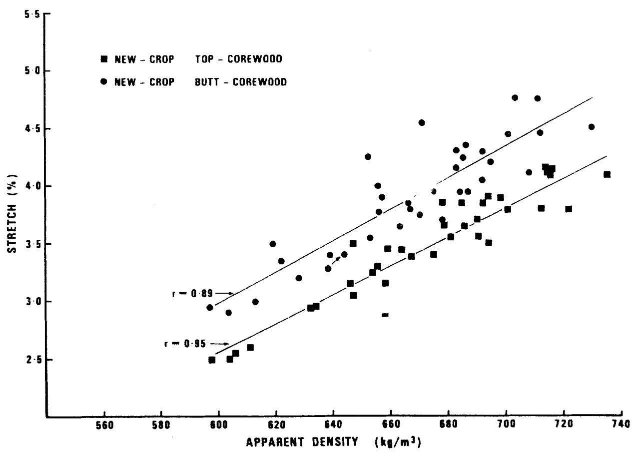

Fig 13—Handsheet strength and apparent density relationships for top- and butt-corewood Kraft pulps. The two regressions are different at the 1% level of significance.

	Number of samples	Coefficient of determination (R^2x100)	Mean basic density (kg/m^3)	Mean fibre length* (mm)	Literature reference
1. Old-crop slabwood and corewood	18	40	378-531	2.7-3.7	(15)
2. New-crop slabwood and corewood	27	22	336-486	2.5-3.3	(17)
3. New-crop whole-tree thinnings	10	<1	289-376	2.1-2.8	(16)
4. Combined data (1+2+3)	55	55	289-531	2.1-3.7	(8)
5. Commercial pulpwood and sawmill residues	18	85	320-500	2.0-3.6	(8)

* Weighted average pulp fibre length

Table 5: Chip basic density/pulp fibre length correlations

top-corewood material (0.05 to 0.13%). The high longitudinal shrinkage characteristics of the butt-corewood material suggest large tracheid fibril angles and hence high pulp fibre extensibilities(13).

Compared with pulps prepared from 52-year-old old-crop trees(15), the intensively managed 24-year-old new-crop trees(17) give slabwood pulps with somewhat lower tear indices. For a tensile strength of 80 N.m/g, the new-crop slabwood tear index is 23 mN.m^2/g compared with 26 mN.m^2/g for the old-crop slabwood pulps (Figure 14).

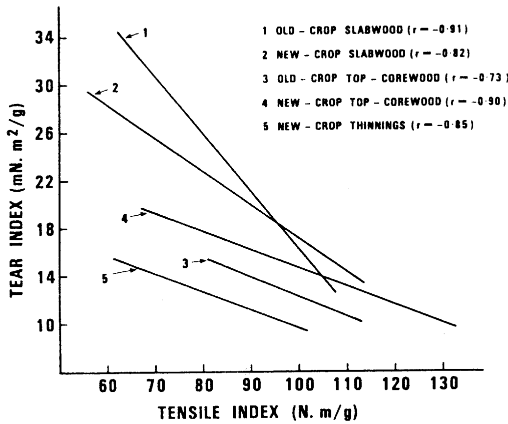

Fig 14—Handsheet tear and tensile index relationships for Kraft pulps prepared from radiata pine trees of different age and wood quality.

Alternatively, for a burst index of 6 kPa.m^2/g, tear indices of 23.7 and 28.4 mN.m^2/g are obtained for the new-crop and old-crop pulps, respectively (Figure 15). The lower tear indices of the new-crop pulps are related primarily to lower wood basic densities when compared with those of the old-crop pulps. The range of densities for nine new-crop slabwood samples was 376 to 486 kg/m^3 compared with 401 to 543 kg/m^3 for the corresponding old-crop material(15,17). Similar but reversed comments can be made concerning the higher burst and tensile strengths of the new-crop pulps since high strengths correlate with low wood

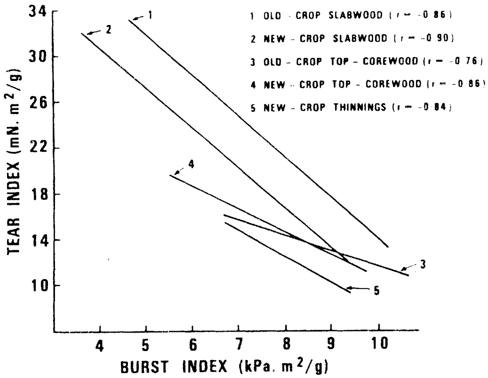

Fig 15—Handsheet rear and burst index relationships for Kraft pulps prepared from radiata pine trees of different age and wood quality.

basic densities. Burst/tensile relations for the old-crop and new-crop pulps also require comment since the old-crop pulps have substantially higher burst indices, for given tensile strengths, than the new-crop pulps (Figure 16). These differences are related to different fibrillar angles and ultimately to pulp fibre extensibilities through the measurement of longitudinal wood shrinkage. Longitudinal shrinkage values of between 0.2 and 0.3 percent for the old-crop, and of about zero (0.05 to 0.13 percent) for the new-crop are obtained for both the slabwood and top-corewood wood samples(18).

Comparison of the whole-tree thinnings pulps(16) with old- and new-crop top-corewood(15,17) shows that the thinnings have slightly lower tear indices for given burst values (Figure 15) but somewhat higher tear strengths for given handsheet apparent densities (Figure 17). The top-corewood pulps were prepared from billets of wood containing 15 growth layers only, whereas the thinnings pulps were made from whole logs that contained the range of 4 to 12 growth layers of wood material. Hence, the thinnings logs contain substantially higher proportions of low-density and

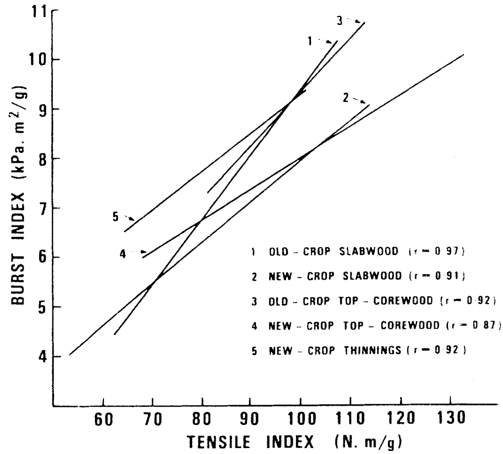

Fig 16—Handsheet burst and tensile index relationships for Kraft pulps prepared from radiata pine trees of different age and wood quality.

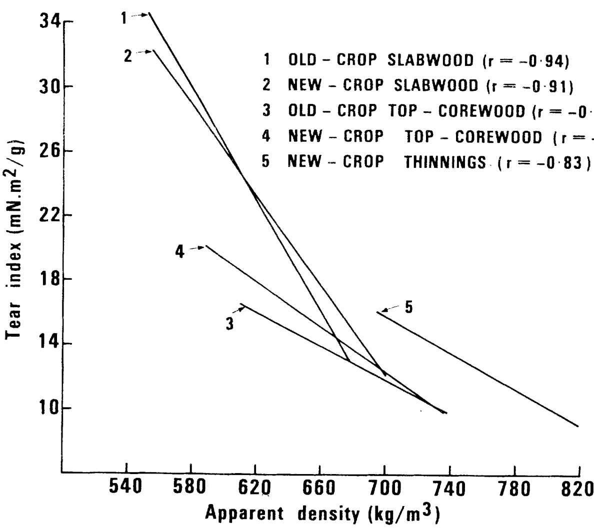

Fig 17—Handsheet tear index and apparent density for Kraft pulps prepared from radiata pine trees of different age and wood quality.

short fibred innerwood(4) and account for the very high handsheet densities of the thinnings pulps when compared with those prepared from top-corewood.

The high handsheet apparent densities obtained with the 10 thinnings pulps requires comment. The presence of high proportions of low-density and short fibres(4) in these pulps increase the packing densities and collapsibilities of fibres in handsheets and overall apparent densities are increased(14). In this earlier study, it was shown that for radiata pine kraft pulps handsheet strength and optical properties are increased or decreased with refining (depending on the property involved) until handsheet densities of about 700 kg/m^3 are obtained. Most handsheet strength and optical properties are observed to level off beyond apparent densities of about 700 kg/m^3. Data for the thinnings pulps deviate from this trend since handsheet densities range from 690 to 810 kg/m^3(16). Again, the explanation must relate to the type of wood used. In studies in which pulps are prepared from roundwood billets that contain constant numbers of growth layers, handsheet strength maxima (or minima) develop at sheet densities of about 700 kg/m^3(14). In contrast, when "whole-tree" samples are used and the pulps contain high proportions of fibres from innerwood, the data presented in Figure 17 indicate that maximum increases (or minimum decreases) in handsheet properties brought about by refining can be expected to occur at handsheet densities substantially greater than 700 kg/m^3.

WOOD QUALITY AND TMP (AND RMP) PULP INTERRELATIONSHIPS

The wood, pulp, and handsheet properties of TMP and refiner mechanical (RMP) pulp made from radiata pine slabwood and corewood (top logs) have been described in a comprehensive treatise by Corson(10). It was shown in this study that slabwood consumes more energy to a given freeness and produces pulps of higher strength than corewood. Both power consumption and sheet strength increase marginally with an increase in wood density. Conversely pulps from corewood have excellent optical properties whereas those from slabwood are of a slightly lower quality.

Corson's paper(10) gives broad indications of the effects of radiata pine corewood and slabwood. In a study of the fibre and fines qualities of some of the pulps resulting from the study of Corson, the selection of a suitable basis for comparing pulps requires comment(12). What are the most meaningful bases for comparison: energy consumption to a given freeness, or handsheet properties at a given freeness or energy consumption? Handsheet density could be considered as the ultimate basis for comparison, although according to unpublished data (Corson 1983), this parameter is poorly correlated with energy consumption. Handsheet density is, however, correlated with pulp freeness(10), although what such a relationship measures at the pulp component level is uncertain since pulps of very different quality can have the same freeness (or the same handsheet density for that matter). For the study in question(12), the fibre and fines characteristics were examined for pairs of TMP and RMP pulps selected on the basis that they had similar freeness, energy and handsheet property interrelationships (Table 6).

Very definite fibre quality differences exist for TMP (or RMP) pulps made from slabwood and corewood and explain, in part, their different pulp and handsheet properties(12). For example, slabwood pulps consist of high proportions of fibres which are longer, stiffer (less collapsible), and less damaged than those of pulps made from corewood (Tables 7,8). Furthermore, the fines material (of the -100/+200 pulp fraction) of slabwood pulps consist predominantly of fine fibrillar elements whereas the fines in corresponding corewood pulps are heterogeneous in nature, being made up of substantial quantities of both fibrillar material, and short and relatively long fibre fragments with identifiable lumens (Figures 18,19).

Handsheet densities of the slabwood and corewood pulps are generally similar(10) (Table 6). This contrasts markedly with their widely different wood basic densities and with the fact that slabwood fibres measured "in-situ" in handsheets are less collapsed than corresponding corewood fibres. The high handsheet densities obtained with the relatively long and stiff fibres of slabwood furnishes are explained in part by the consolidating influence of the fibrillar fines present in this pulp-type. In contrast, the heterogeneous nature of the fines in corewood pulps can be used to explain their low handsheet densities (relative to the slabwood pulps) and their excellent handsheet optical properties.

Sample Nomenclature	RMP corewood	RMP slabwood	TMP corewood	TMP slabwood
Density, kg/m^3	359	453	359	453
O.D. fibre, %	37.5	43.4	37.5	43.4
Energy, kWh/t_{100}	2150	1985	2020	1885
Freeness, Csf	90	135	145	175
Tensile index, Nm/g	25.5	31.3	32.4	30.1
Tear index, $mN.m^2/g$	7.6	10.0	8.1	11.3
Burst index, $kPa.m^2/g$	2.0	2.3	1.9	2.0
Bulk, cc/g	2.8	2.9	3.0	3.2
Sheet density, kg/m^3	357	340	339	315
Air resistance, s/100 ml	22	26	28	12
Brightness, %	63.3	60.8	58.7	58.0
Scatt. coeff. A.D., m^2/kg_{90}	67.3	55.1	50.1	60.1
Opacity, %	96.8	95.3	96.9	95.2
Fibre classification				
Bauer McNett +14	0.3	3.8	0.7	6.7
+30	19.5	33.0	29.1	35.2
+50	22.5	18.9	21.8	17.0
+100	3.5	4.9	2.3	5.1
+200	21.2	11.5	10.8	8.5
-200	33.0	27.9	35.3	27.5

Table 6 - Pulp processing, and pulp and handsheet evaluation data(12)

The excellent optical properties obtained with corewood pulps(10) (Table 6) appear related to the effects on web consolidation of large numbers of short and thin-walled fibres and fibre elements (Table 7), and to the coarse quality of the fines (Figures 18,19). Thus, handsheets prepared from the corewood pulps contain high numbers of air-to-fibre (or air-to-fibre element) interfaces relative to those made with corresponding slabwood pulp (Figure 20). For slabwood pulps, high proportions of long and thick-walled fibres (and therefore fewer fibres), and fine fibrillar fines, together give proportionately fewer air-to-fibre

Pulp type	Chip basic density (kg/m^3)	Weighted average fibre length (mm)	Fibre cross-section dimensions: Diameter (um)	Wall thickness (um)	Wall thickness / Diameter
RMP slabwood	453	2.39	37.2	4.82	.139
RMP corewood	359	1.82	38.3	3.97	.116
TMP slabwood	453	2.54	38.4	5.05	.142
TMP corewood	359	2.09	39.3	4.58	.128

Statistical significance

Weighted average pulp fibre lengths different at the 5% level if differ by more than 0.17 mm.

Mean fibre diameters different at the 5% level if differ by more than 2.9 um.

Mean fibre wall thickness different at the 5% level if differ by more than 0.45 um.

Wall thickness: diameter ratios different at the 5% level if differ by more than 0.015 units.

Table 7 - Fibre length and cross-section dimensions of +30 pulp fraction(12)

Pulp type	Chip basic density (kg/m^3) (%)	Fibre cross-section intact (%)	Middle lamella present or partly present (%)	Fibre wall delaminated within S2 layer (%)	Number of latewood fibres (%)
RMP slabwood	453	74	27	11	26
RMP corewood	359	63	29	15	14
TMP slabwood	453	75	31	12	30
TMP corewood	359	67	35	15	19
Statistical significance					
Overall difference between pulps		Highly significant	Significant (5%)	Significant (10%)	Highly significant

Table 8 - Extents of fibre damage in total +30 fraction pulp populations(12)

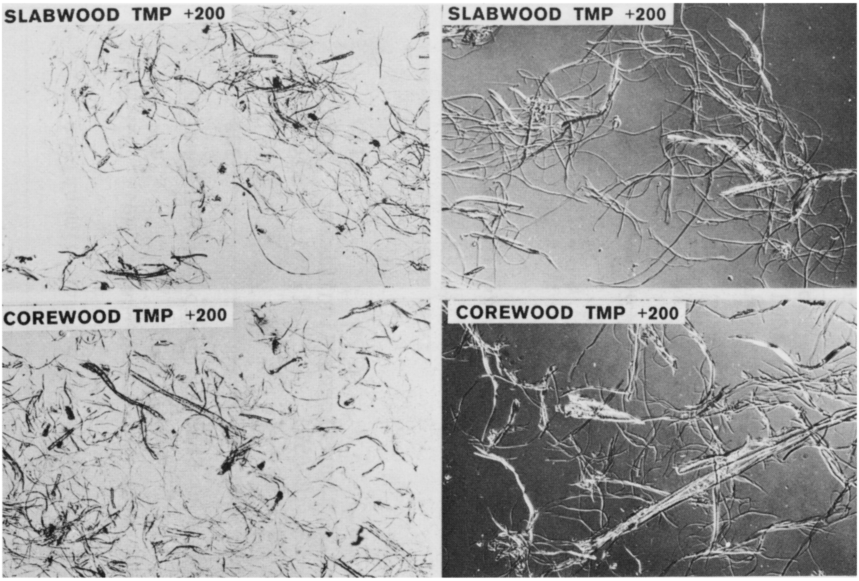

Fig 18—Coarse fines of slabwood and corewood (– 50/ + 200) TMP pulp fractions (**12**).

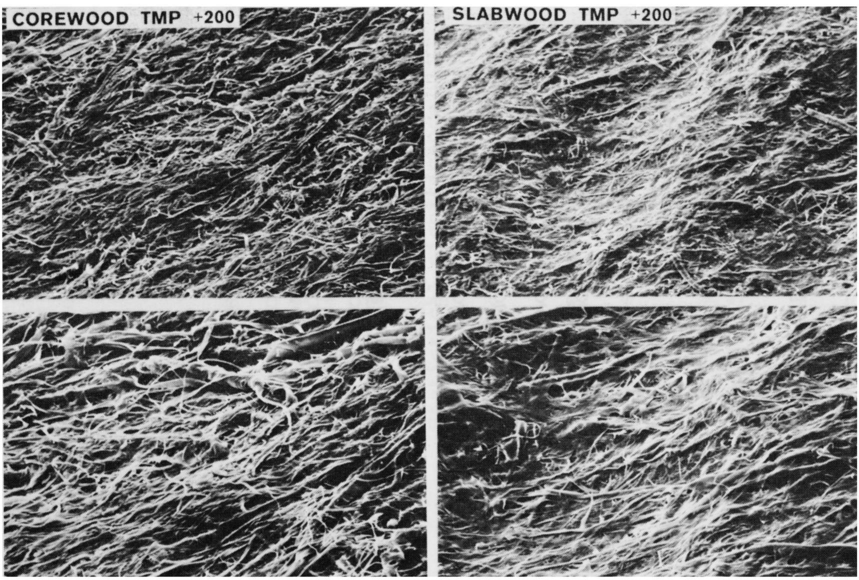

Fig 19—Surface views of slabwood and corewood handsheets made from coarse fines (– 50/ + 200) TIMP pulp fractions (**12**).

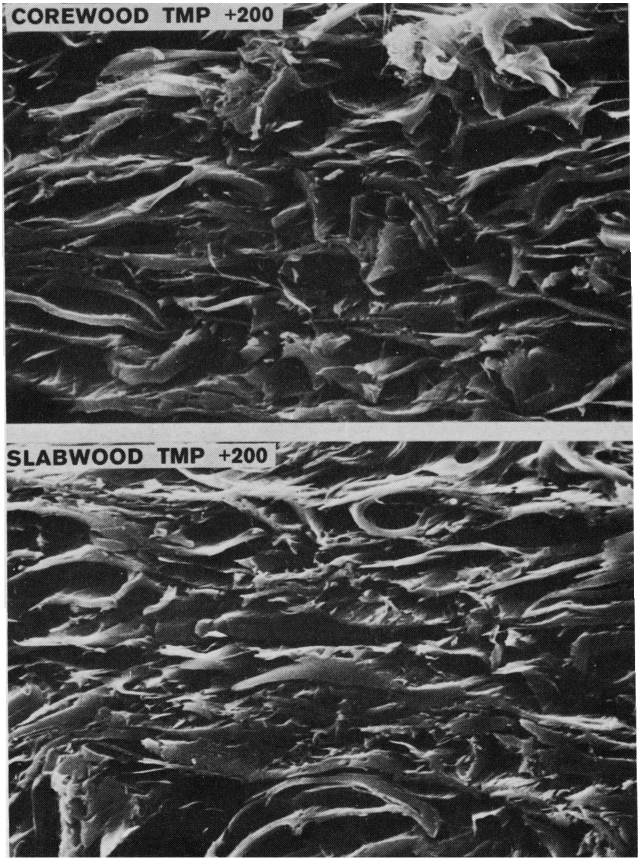

Fig 20—Sectional views of slabwood and corewood handsheets made from coarse fines (– 50/ + 200) TMP pulp fractions (**12**).

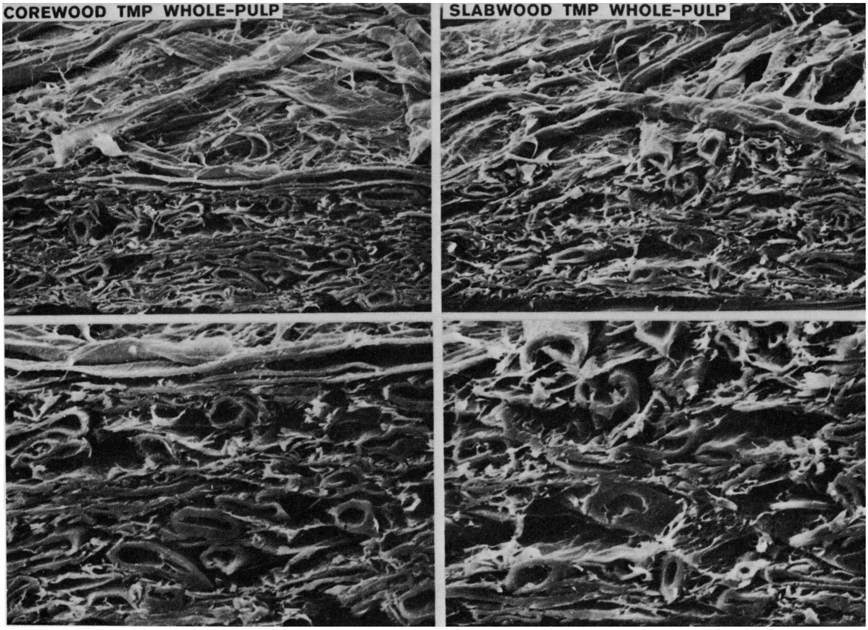

Fig 21—Fibre configurations and packing arrangements in handsheets prepared from slabwood and corewood TMP "whole pulp" (**12**).

	Chip basic density (kg/m^3)	Weighted average fibre length	Dimensions of fibres "in-situ" in handsheets		
			Fibre diameter (um)	Lumen diameter (um)	Wall thickness (um)
RMP slabwood	453	2.39	16.54	7.55	2.52
RMP corewood	359	1.82	14.76	7.35	1.94
TMP slabwood	453	2.54	17.44	8.42	2.57
TMP corewood	359	2.09	13.93	6.60	1.96

Statistical significance

1. Different at the 5% level if fibre diameters differ by more than 1.39 um.
2. Different at the 5% level if lumen diameters differ by more than 1.11 um.
3. Different at the 5% level if fibre wall thicknesses differ by more than 0.18 um.
4. Different at the 5% level if fibre lengths differ by more than 0.17 mm.

Table 9 - Fibre dimensions of "whole-pulp"(12)

interfaces within handsheets. Such an explanation accounts for the relatively low scattering coefficients and opacities of slabwood pulps(10).

Examination of sectioned corewood and slabwood handsheets clearly shows a greater number of air-to-fibre (and fines) interfaces for the corewood furnish (Figure 21). Furthermore, the corewood web also appears to be more consolidated and homogeneous than the corresponding slabwood web. Extents of fibre collapse are also greatest in the corewood web (Figure 21, Table 9).

CONCLUSIONS

Two radiata pine wood residue qualities are recognised: top logs and whole trees, which are less than 20 years old and are predominantly of a corewood quality; and sawmill residues, which are predominantly from slabwood and are of an outerwood quality. The basic densities of these two residue types are generally less than 400 kg/m^3 and greater than 400 kg/m^3, respectively.

The different basic densities and tracheid dimensions (length, wall thickness, and wall diameter) of the two wood residue types strongly influence the qualities of chemical and thermomechanical pulps, and of the papers made from them.

Different pulp-types and pulp qualities are required for the manufacture of different paper products. Thus, the universal availability of the two (easily segregated) radiata pine residue types is a plus for the New Zealand pulp and paper industry.

APPENDIX I - SAMPLE SELECTION PROCEDURES AND EXPERIMENTAL METHODS FOR KRAFT PULPS(8)

Wood Selection and Preparation

Central North Island wood samples: Three sets of radiata pine wood samples were examined.

(a) 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.

(b) 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.

(c) 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(16). Whole-tree logs to 10 cm s.e.d. were included in the overall sample for each tree.

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.

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. Chips which passed through the 32-mm screen and retained on the 19- or 16-mm screen were used.

Pulping

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

Pulp processing and evaluation

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

Handsheet property values used in the multiple regression analyses were determined by extrapolation to 1000 rev. using the relationship:

$$\text{Handsheet property} = a\,[\ln(\text{rev})] + c$$

Tear index, burst, bulk, and air resistance were obtained on 60 $\pm$ 2 g/cm^2 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 on 15-mm wide strips of gauge length 100 mm and an extension rate of 10 mm/min. Scattering coefficient was determined on 60 $\pm$ 2 g/m^2 handsheets by the SCAN procedure using an Elrepho reflectance meter.

Wood and Fibre Properties

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. Basic densities of unextracted chips only were recorded.

Pulp 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 $\pm$ 0.1 mm at the 95% level. For each pulp, 50 fibres on each of 6 microscope slides were measured. Samples were coded and examined in a randomised order to eliminate observe 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:

$$\frac{\sum l^2{}_i n_i}{\sum l_i n_i}$$

where l_i was the length of any one fibre in the sample and n_i the number of fibres of length l_i.

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Transcription of Discussion

Qualities of Kraft and thermomechanical Radiata Pine Papermaking Fibres
by R.P. Kibblewhite

Dr. R.C. Howard UMIST, Manchester, England

In your paper, you indicated a direct relationship between tear strength and wood density. In Dr.Claudio-da-Silva's paper on Eucalyptus pulp, an inverse relationship was shown between the same parameters. Could you comment on this and would Dr. Claudio-da-Silva like to comment also?

Dr. R.P. Kibblewhite Hardwoods and softwoods are totally different in this respect. With radiata softwood, once chip density is below about 320 kg/m^3, tear will stay at about 10 $mN. m^2/g$. The hardwood has got to get up to this level first. This is also true for mechanical fibres.

Dr. E. Claudio-da-Silva Aracruz Celulose S.A., Brazil

I agree with what you said. For a Eucalyptus pulp, it is a completely different picture, where it was found that tear goes down with basic density of wood, for unbeaten and medium beaten fibres. These differences between hardwood and softwood fibres have been described earlier.