Refining Behaviours and Fibre Characteristics of Kraft Pulps of Yield 49 to 67 per cent

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SUMMARY

The utilization of kraft pulps of higher than normal yield in the manufacture of quality products will add to the profitability of the papermaking industry. For this reason the fibre characteristics and compositions, and handsheet properties, were determined for slabwood radiata pine and southern pine kraft pulps over a wide yield range.

Pulps of yield less than about 51% show as an effect of refining extensive delamination of fibre walls and disruption of fibre surface layers. Such effects increase rapidly as pulp yields decrease from 51 to 49%, or as pulp lignin contents decrease from about 9 to about 4.8%. Strength properties are, however, very different for the two furnishes, particularly their tensile strengths and refining potentials. Such effects can be related to very different fibre lengths and wall thicknesses, fibres/gram of pulp, and degrees of pulp fibre population heterogeneity.

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The response to refining of radiata pine kraft pulps and fibres in the 49 to 67% yield range have been characterized and related to those of comparable neutral sulfite-anthraquinone pulps from the same wood supply(1). In the present paper, the papermaking potentials and refining behaviours are determined for an additional series of kraft furnishes which contain high proportions of coarse and extremely long softwood fibres compared with those of the pulp series studied previously.

EXPERIMENTAL

Wood selection, preparation, and pulping conditions

Slabwood *A* consists of wood from the outer 16 to 26 annual growth layers of billets of wood containing 26 growth layers taken from 27 year old radiata pine trees. Chip basic density was 430 kg/m^3. Conditions of sample selection and preparation, pulping and pulp processing have been described in detail elsewhere(2).

Slabwood *A* pulps where prepared using 18% Na_2O based on o.d. wood, liquor sulfidity 24%, liquor to wood ratio 4:1 and cooking schedule 90 minutes to 170 °C. Times at temperature ranged from 0 to 90 minutes depending on the pulp yields required.

Slabwood *B* chips, rich in southern pine fibre, were obtained from Waipa sawmill. Pulping conditions were: alkali charge — 18% active alkali on o.d. wood, sulfidity 30%, liquor to wood ratio 4:1, maximum temperature 170 °C, time to maximum temperature 90 minutes. Period at maximum temperature varied depending on the pulp yield required.

Slabwood *A* chips were air dried and stored for about nine months before rewetting by soaking in water under vacuum for 16 hours. Slabwood *B* chips were never dried.

Pulp processing and evaluation

Pulps of total yield less than 51% were defibred by propeller disintegration at 2% concentration for 10 minutes and then screened through a 0.25 mm slotted screen. Higher Kappa number pulps were defibred at approximately 2% concentration using a water flow rate of 4 litres per minute in a 200 mm Bauer refiner. The plate gap was chosen for each pulp to cause as little damage as possible. The degree of fibre damage was assessed by examination of a water suspension of the pulp on a microscope slide using a low powered binocular microscope.

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, 4000, 8000, and 16 000 rev.

Tear and burst indices, bulk and air resistance were obtained from 60 ± 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 using 15 mm wide strips of gauge length 100 mm and an extension rate of 10 mm/min. Light scattering coefficient was determined from 60 ± 2 g/m^2 handsheets by the SCAN procedure using an Elrepho reflectance meter.

Cross-section dimensions of embedded fibres

Pulp samples were stored at low stock concentration (about 1 to 2%) at 4 °C. Wet fibres were dehydrated through an acetone series before impregnation and embedment in Spurr's resin. Sections were cut and stained, and fibre cross-section dimensions determined using procedures and the image processing system described previously(3).

Fibre lengths and length distributions

Fibre lengths and fibre length distributions were 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% 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 analysis. Arithmetic or numerical average values only are presented.

Origins of wall lamellae on fibre surfaces

The origins of wall lamellae on fibre surfaces were characterized by the orientation of microfibrils visible in the surfaces of processed fibres in handsheet surfaces. Surface replicas of handsheets were prepared and microfibril orientations relative to fibre axes determined(4). The number of fibres examined for each pulp or pulp fraction was normally in excess of 100.

Chemical analyses

Klason lignin analyses were made in general accordance with the procedures of Moore and Johnson(5). All determinations made on o.d. carbohydrates were determined using high performance liquid chromatography in general accordance with the procedure of Petersen *et al*(6).

RESULTS

Pulp quality

For the slabwood *A* and *B* pulps, quality and handsheet property trends for different kraft yields are generally similar with tear/tensile relationships and apparent density and tensile values increasing with decreasing pulp yields (Fig. 1,2, Tables 1,2).

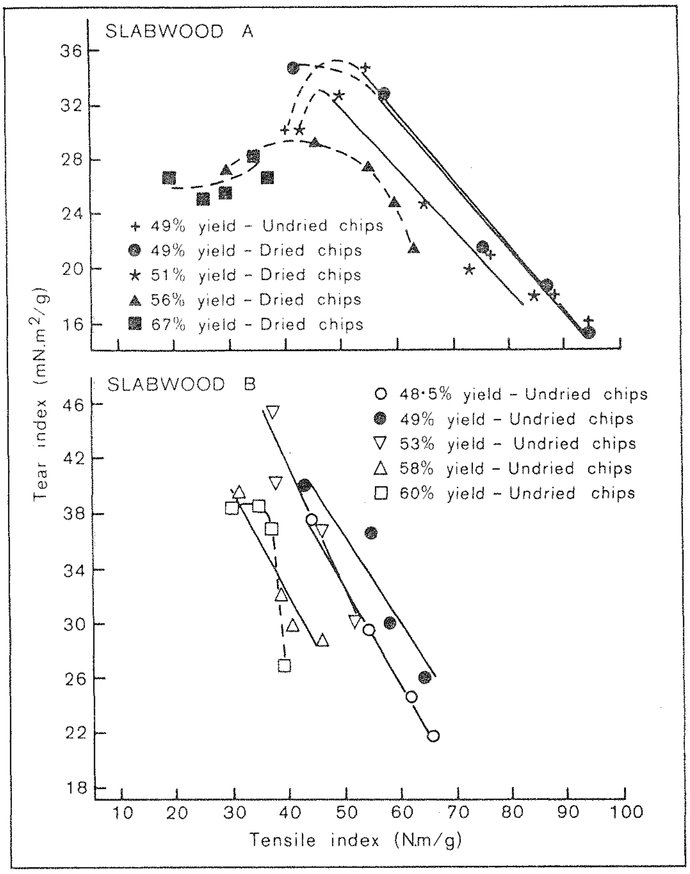

Fig. 1 — Handsheet tear index and tensile index.

Very different strength levels are shown for pulps from the two slabwood samples. The marked shifts between the two sets of pulps in sheet density for given tensiles, or in actual tensile values for given refining treatments, are noteworthy. For given sheet densities, tensile values and refinabilities increase with decreasing yield and are substantially greater for slabwood *A* than for slabwood *B*. For data presented in Figure 1 it is noteworthy that values for unrefined pulp are presented for slabwood *A* material only (Table 1).

There is very little difference in the qualities of pulps made from undried, and dried and rewetted slabwood *A* chips (Table 1 and unpublished data).

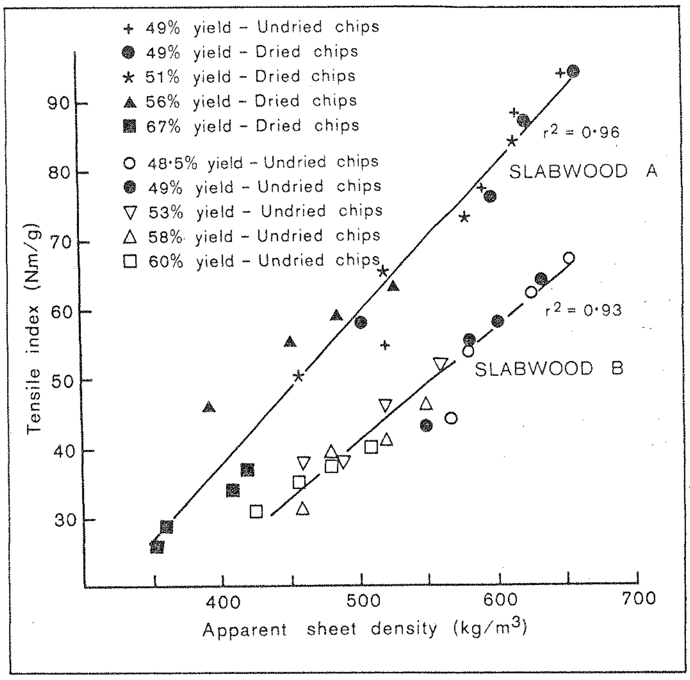

Fig. 2 — Handsheet tensile index and apparent density.

Table 1
Physical evaluation data for slabwood *A*

Pulp yield %	PFI mill refining rev	Chip condition	Freeness CSF	Tear index $mN.m^2/g$	Burst index $KPa.m^2/g$	Apparent density Kg/m^3	Air resistance s/100 mL	Tensile index N.m/g	Stretch %	Tensile energy abs J/m^2	Young's modulus MN/m^2	Light scattering coefficient o.d. m^2/kg
49*	0	Undried	710	33.5	4.0	544	<1	54	2.0	45	-	23.2
	4000		685	21.8	8.0	616	3.4	84	3.4	112	-	17.3
	12000		495	18.4	9.0	654	26.5	98	3.9	143	-	14.6
	16000		385	17.1	8.0	673	57.1	96	3.9	150	-	13.7
49	0	Undried	700	30.1	2.6	409	<1	41	1.75	27	2100	27.6
	1000		700	34.8	4.5	520	<1	55	2.51	54	3100	22.0
	4000		690	21.0	7.2	591	<1	77	3.15	91	4400	17.3
	8000		630	17.8	8.2	617	2.1	88	3.44	115	4900	15.5
	16000		430	15.9	8.7	650	20.0	94	3.71	132	5700	13.7
49	0	Dried	710	34.9	2.8	397	<1	42	1.82	28	2000	26.7
	1000		710	32.8	4.5	503	<1	58	2.60	56	3100	21.5
	4000		690	21.4	6.7	595	<1	76	3.05	89	4300	17.5
	8000		620	18.6	7.7	621	3.3	87	3.55	116	4700	15.4
	16000		420	15.3	8.6	658	18.5	94	3.61	126	5700	14.0
50	0	Dried	720	32.0	2.7	407	<1	43	1.66	26	2100	26.1
	1000		720	32.3	4.4	514	<1	55	2.33	50	3100	22.3
	4000		710	22.4	6.5	581	<1	75	2.98	85	3400	18.1
	8000		660	18.9	7.3	612	1.1	84	3.45	107	3900	16.1
	16000		450	17.3	8.5	644	10.0	89	3.70	122	4900	14.3
51	0	Dried	700	30.2	2.5	358	<1	43	1.54	25	2000	25.9
	1000		700	32.7	3.9	457	<1	50	2.28	45	2600	22.1
	4000		700	24.5	5.4	520	<1	65	2.79	69	3200	19.5
	8000		710	19.8	6.6	579	<1	73	2.98	85	4200	17.5
	16000		600	17.9	8.0	613	4.2	84	3.52	127	4500	16.3
56	0	Dried	750	27.2	1.8	278	<1	30	2.04	24	1800	21.7
	1000		720	29.2	3.4	392	<1	46	2.14	38	2000	23.5
	4000		720	27.3	4.4	452	<1	55	2.48	52	2400	21.4
	8000		720	24.7	4.7	486	<1	59	2.64	59	3100	19.6
	16000		700	21.3	6.0	526	<1	63	3.23	77	3300	14.2
67	0	Dried	710	26.5	1.7	268	<1	19	1.30	9	1400	23.3
	1000		720	25.8	1.4	350	<1	26	1.52	15	1200	21.3
	4000		720	25.5	1.7	358	<1	29	1.58	18	1400	21.9
	8000		720	28.2	2.3	409	<1	34	1.90	25	1600	20.0
	16000		720	26.8	2.5	418	<1	37	1.95	29	1900	19.8

* Previously published data for kraft pulp made from fresh chips (2).

Fibre quality

For pulps prepared from slabwood *A* and slabwood *B*, fibre lengths and widths are essentially unchanged as pulp yields (or Kappa numbers) increase (Table 3). Fibre thicknesses, wall areas, and wall thicknesses, on the other hand, are lowest for pulps of yield 49% but are similar for pulps of yields 51 to 67%. Furthermore, fibre length, width, and wall area remain unchanged, whereas fibre thickness decrease and wall thickness increases with pulp refining.

Fibre qualities of the slabwood *A* and *B* pulps differ considerably with the fibres of slabwood *A* furnishes being significantly shorter, narrower and thinner walled than those in the series *B* pulps (Table 3). The relatively high wall area values of the slabwood *B* pulps shown them to be substantially coarser on a mass per unit length basis, than the series *A* furnishes. Fibre population distributions for the two pulp types can be very different (Fig. 3, 4, 5).

Fibre surface structure

Fines index (Table 4), or the rate of removal of wall material from fibre pulp refining, increases with decreasing pulp yields (Fig.6). It is noteworthy that all pulps retain their primary wall on unrefined fibre surface except for the 49% yield furnish made from undried slabwood *B* chips. The ease with which the primary wall is removed from fibre surfaces with pulp refining decreases as pulp yields increase from 49 to about 51%; thereafter high extents of refining are required to disrupt the primary wall layer. Thus, the primary wall is removed most readily from the low yield (49%) pulps. In fact, for the 49% yield pulp made from undried slabwood *B* chips, more than 60% of the unrefined fibre surfaces examined are void of the primary wall. Such a result is confirmed by earlier studies of pulps made from undried slabwood *A* chips(7). Retention of the primary wall on 99% of the 49% yield unrefined *A* fibres (Table 4) is therefore explained by chip drying before pulping. Proportions of fibres with S_1 layers removed and S_2 layers exposed are low even for heavily refined fibres at pulp yields above 53%.

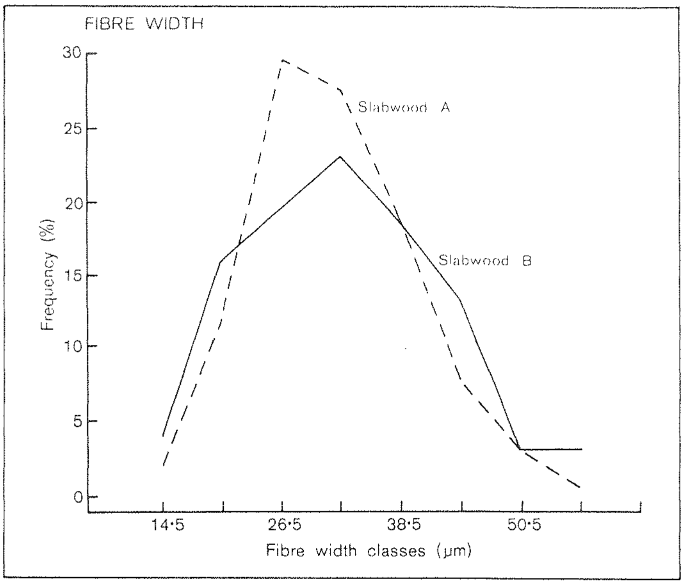

Fig. 3 — Pulp fibre width distributions.

The relatively low fines index value for the 49% yield pulp and the relatively high fines index value for the 56% yield pulp (both refined for 16 000 rev) from slabwood *A* are unexplained (Fig.6). It is however noteworthy that the ease of identifying fibre wall surfaces in refined fibres decreases with increasing extents of pulp refining.

Chemical composition

Lignin proportions increase and carbohydrate proportions decrease with increasing pulp yields (Table 5). Lignin contents, Kappa numbers, and pulp yields are generally proportional to one another. Xylan, glucan, and mannan contents are roughly unchanged over the yield range 49 to 67%.

Table 2
Physical evaluation data for slabwood *B*

Pulp yield %	PFI mill refining rev	Chip condition	Freeness CSF	Tear index mN.m²/g	Burst index KPa.m²/g	Apparent density Kg/m³	Air resistance s/100 mL	Tensile index N.m/g	Stretch %	Tensile energy abs J/m²	Young's modulus MN/m²	Light scattering coefficient o.d. m²/kg
48.5	2000	Undried	736	37.6	4.7	566	<1	44.1	2.40	64	1700	17.6
	4000		712	29.5	6.1	577	<1	53.8	2.83	68	2300	16.3
	8000		651	24.6	7.4	625	2	62.3	3.20	101	2400	14.4
	16000		342	21.6	8.7	654	15	66.4	3.79	144	3300	13.8
49	2000	Undried	744	39.8	4.4	548	<1	43.2	2.03	55	–	18.1
	4000		729	36.6	5.8	579	<1	54.9	2.68	80	2200	16.4
	8000		661	30.5	6.8	601	<1	58.4	2.83	97	3100	15.0
	16000		394	26.4	8.1	621	9	63.6	3.64	131	3300	13.9
53	2000	Undried	745	40.9	3.8	450	<1	37.7	2.09	18	1400	19.1
	4000		760	45.6	3.8	485	<1	37.6	2.24	52	1800	17.2
	8000		751	37.2	5.0	520	<1	46.4	2.57	72	2000	16.1
	16000		715	30.2	6.1	560	<1	52.0	3.09	96	2200	14.9
58	2000	Undried	744	39.6	3.1	459	<1	31.5	1.91	36	1400	17.8
	4000		746	32.0	3.9	479	<1	39.1	2.16	53	1400	17.0
	8000		751	29.6	4.5	519	<1	41.3	2.37	58	1600	15.7
	16000		703	28.6	4.8	548	<1	46.4	3.06	86	2100	14.4
60	2000	Undried	740	38.3	2.9	424	<1	30.9	1.85	34	1300	17.2
	4000		755	38.4	3.2	456	<1	35.4	2.04	44	1400	16.2
	8000		741	37.2	3.7	480	<1	37.3	2.38	53	1500	15.7
	16000		740	26.7	4.6	509	<1	40.2	2.64	60	1300	15.0

Table 3
Mean fibre cross-section and length dimensions

Pulp type	Pulp yield %	Kappa no.	Fibre dimensions: Length (mm)		Thickness (μm)		Width		Wall area		Wall thickness (μm)	
			Unrefined	Refined	Unrefined	Refined	Unrefined	Refined	Unrefined	Refined	Unrefined	Refined
A	49	38	2.9	2.8	19.9	–	30.2	–	293	–	4.0	–
	51	64	2.8	2.8	21.9	–	29.9	–	312	–	4.2	–
	56	94	2.9	2.8	20.4	–	30.6	–	316	–	4.3	–
	67	147	2.8	2.6	20.6	–	31.1	–	313	–	4.1	–
B	49	38	3.9	3.6	19.0	18.2	32.3	30.3	339	344	4.5	4.8
	53	84	3.8	3.6	20.9	19.1	32.1	33.4	369	379	4.5	5.0
	58	105	3.7	3.6	21.9	18.8	32.5	32.2	399	386	4.7	5.1
	60	117	3.7	3.6	21.4	19.5	32.3	33.2	398	386	4.8	4.9
Least significant difference at 95% level			*A* 0.3, *B* 0.1		1.2		1.8		30		0.2	

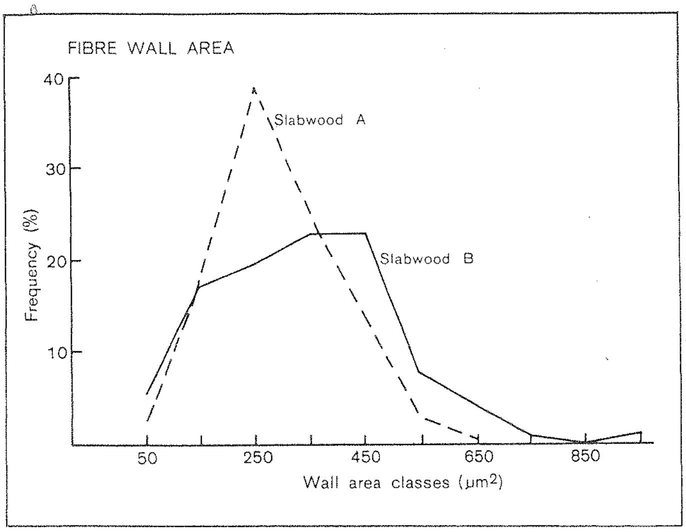

Fig. 4 — Pulp fibre wall area distributions.

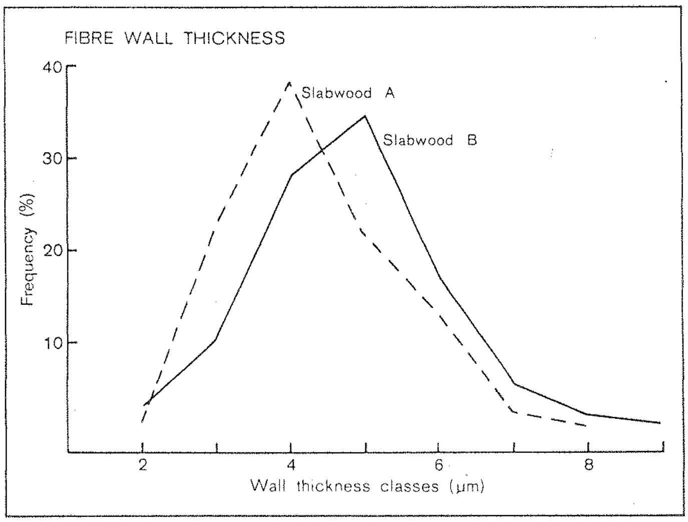

Fig. 5 — Pulp fibre wall thickness distributions.

Refining effects on fibre structural organizations

Unrefined fibre cross-sections for slabwood *A* (Fig.7) and slabwood *B* (Fig.8) are generally angular rather than circular in shape. Also, fibre walls and surfaces are generally intact and not disrupted. Fibres are shown using interference contrast (Fig.7) and bright field illumination (Fig.8). For high yield (67%) pulp fibres which contain high proportions of lignin (Table 5) toluidine blue stain is used to show different lignin concentrations across fibre walls (Fig.9). The darkly stained outermost layers of the fibres and shives show the high lignin contents of the compound middle lamella (middle lamella and/or primary wall) of fibre aggregates (shives) and individual fibres.

Pulp refining causes fibre walls to become disrupted and delaminated, fibre cross-section shapes to become more circular, and fibre diameters to decrease (Fig. 9, 10 and Table 3). Such effects of refining are greatest for the low 49% yield pulps. Over the pulp yield range 49 to about 51% the response to refining of fibre walls, surfaces, and cross-section shapes progressively decreases (Fig. 10, Tables 3, 4). Proportions of fibres with disrupted walls and circular cross-sections are low in pulps of yield greater than about 52%.

DISCUSSION

Kraft yield considerations

The low 49% yield unbleached kraft furnishes clearly form handsheets with the highest tear and tensile strengths (Fig. 1,2). As yields increase, the potential, and the reponse to refining, of kraft pulps to develop tearing resistance and tensile strength progressively decreases. The fibre dimensions of length and width are similar over the pulp yield range examined (Table 3). Fibre thickness, wall areas, and wall thickness, on the other hand, are consistently lower for the 49% than for the pulps of higher yield (Table 3). Fibre surface structural organizations (Fig. 6, Table 4), fibre wall delamination potentials (Fig. 4, 5, 6), and pulp lignin contents (Table 5) change substantially with increasing pulp yield. In all three cases changes are greatest over the yield range 49 to 51%, and rapidly diminish as pulp yields increase from about 53 to about 58%. Beyond yields of about 58%, wall delamination and fibre surface disruption potentials are very low, and lignin contents increase only slowly with increasing pulp yield.

Table 4
Influence of pulp yield and refining on fibre surface structure

Slabwood *A*

Pulp yield %	PFI mill refining rev	Freeness CSF	Percent of fibres examined* P*	S_{90}	S_{Trans}	S_2	Fines index§
49	0	710	99	1			1
	1000	710	90	9	1		11
	4000	690	53	29	7	1	46
	8000	620	17	68	11	4	102
	16000	420	4	66	20	10	136
50	0	720	94	6			6
	1000	720	89	11			11
	4000	710	69	25	6		37
	8000	660	38	34	20	8	98
	16000	450	9	51	27	13	144
51	0	700	100				0
	1000	700	85	12	3		18
	4000	700	77	19	4		27
	8000	710	56	34	10		54
	16000	600	16	58	16	10	120
56	0	750	100				0
	1000	720	100				0
	4000	720	89	8	2	1	15
	8000	720	84	10	5	1	23
	16000	700	18	41	24	17	140
67	0	710	91	6	2	1	13
	1000	720	95	2	2	1	11
	4000	720	94	4		2	10
	8000	720	90	5	5		15
	16000	720	82	7		11	40

Slabwood *B*

Pulp yield %	PFI mill refining rev	Freeness CSF	Percent of fibres examined* P	S_{90}	S_{Trans}	S_2	Fines index§
49	0		38	54	8		70
	2000	744	49	34	12	5	73
	4000	729	44	49	7		63
	8000	661	5	49	26	20	161
	16000	394		54	14	32	178
53	0		98	2			2
	2000	745	85	15			15
	8000	751	58	35	4	3	52
	16000	715	9	61	10	20	141
58	0		95	5			5
	2000	744	94	6			6
	4000	746	89	7	2	2	17
	8000	751	80	15	5		25
	16000	703	25	55	8	12	107
60	0		84	10	6		22
	2000	740	85	13	2		17
	4000	755	65	32	3		358
	8000	741	92	8			8
	16000	740	53	42	4	1	54

*P Primary wall intact or partly removed to reveal the S_1 layer with microfibrils perpendicular to fibre axes.
S_{90} Primary wall absent and S_1 layer with microfibrils perpendicular to fibre axes visible.
S_{Trans} S_1 layer partly removed to reveal microfibrils at angles of 60 to 30 degrees to fibre axes.
S_2 S_1 layer removed to the S_2 layer.
§ Calculated from: [S90 + (STrans x 2) + (S2 x 3)].

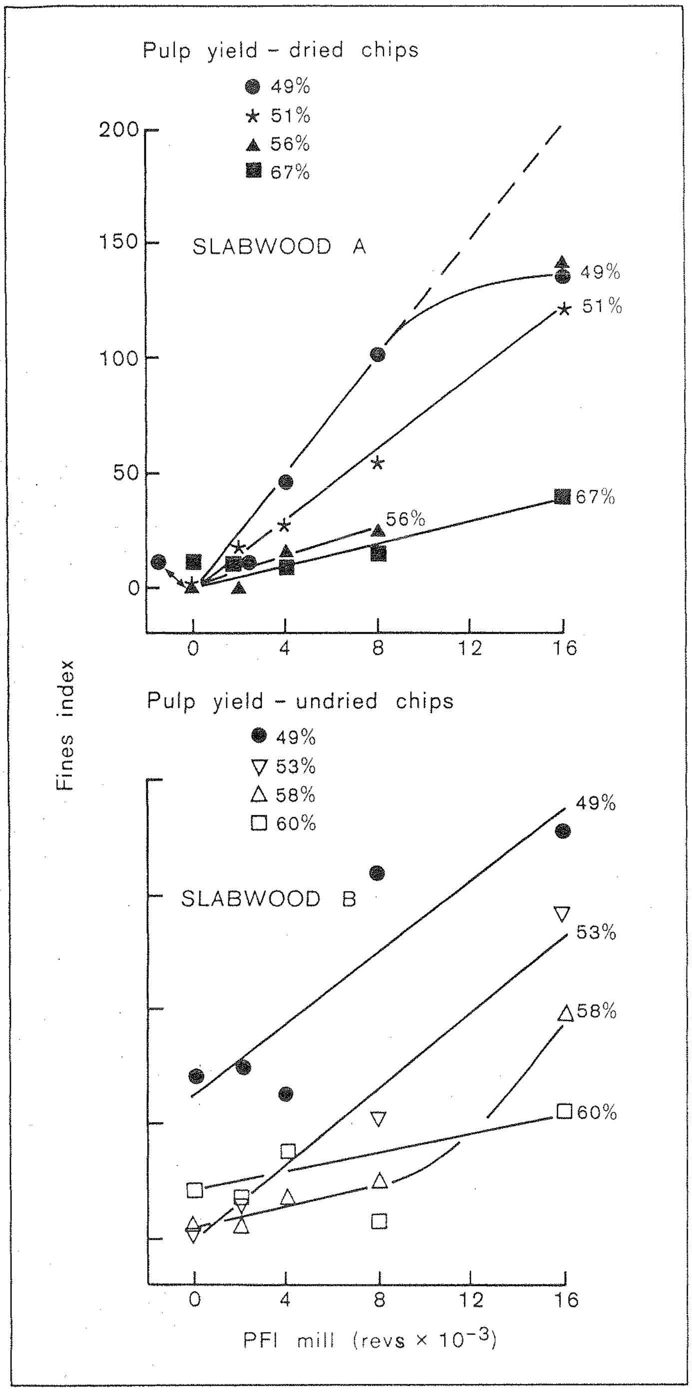

Fig. 6 — Fines indices and PFI mill refining.

The papermaking potential of unbleached softwood kraft pulps of yield about 49% (Kappa number about 38) for the manufacture of products which require strength is clearly obvious from the relationships of Figures 1 and 2. Maximum tearing resistance and tensile strength are, therefore, developed with fibres which have lost their primary wall (and/or compound middle lamella) and have surfaces and walls which are respectively readily disrupted and delaminated by pulp refining (Fig. 6 to 9).

Table 5
Pulp chemical compositions

Pulp type	Pulp yield %	Kappa number	Klason lignin %	Per cent of total carbohydrate %		
				Glucan	Xylan	Mannan
A	49	38	5.5	86.5	8.0	5.5
	51	64	9.5	87.2	8.4	4.4
	56	94	13.5	86.4	7.7	5.9
	67	147	23.1	85.5	8.0	6.5
B	48	30	4.6	86.5	7.8	5.7
	49	38	5.3	86.8	7.3	5.9
	53	84	12.4	83.4	9.3	7.3
	58	105	15.8	87.2	7.6	5.2
	60	117	18.0	85.8	8.2	6.0

Trends obtained for the kraft pulps described herein concur with the somewhat related studies of Mohlin(8, 9) which consider the specific bond strengths, conformabilities and handsheet breaking lengths of unbleached and unrefined spruce kraft fibres over the pulp yield range 47 to 55%. When compared against pulp yield, specific bond strengths for the spruce fibres reached an abrupt maximum at 51.8%. At yields greater and less than 51.8% specific bond strengths were found to decrease rapidly — a behaviour which was related to lignin contents on fibre surfaces increasing as pulp yields increase, and to hemicelluloses decreasing as pulp yields decrease, albeit only slightly(8). Conformabilities of the unrefined spruce fibres, on the other hand, increased only slightly and linearly as pulp yields decreased. Using the same pulps as for the specific bond strength and conformability studies, Mohlin(9) showed that when calculated on a 'same

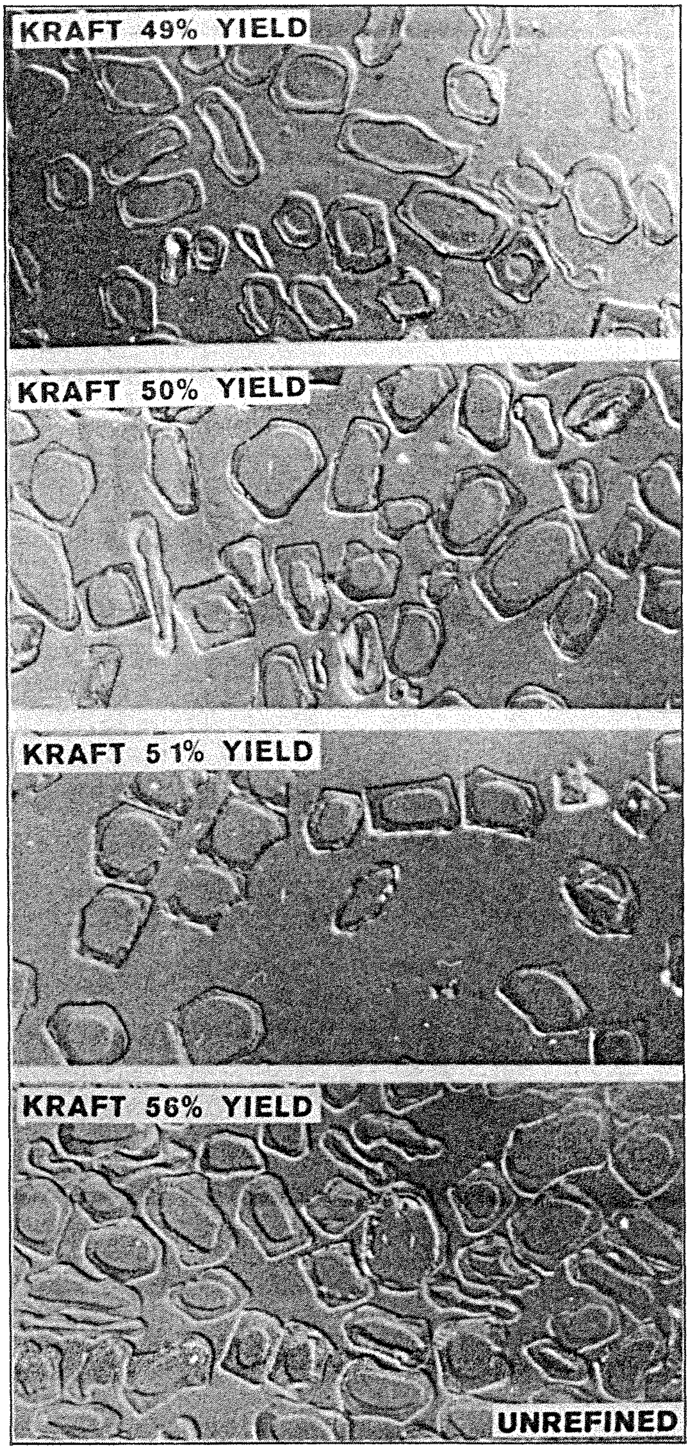

Fig. 7 — Unrefined radiata pine fibre cross-sections for kraft pulp yields 49 to 56%.

number of fibres basis' handsheet breaking length maxima occur at pulp yields of about 49%. Mohlin reasoned that the breaking length/pulp yield relationship follows closely that of specific bond strength and pulp yield. The fact that the breaking length maximum occurs at about 49 rather than 51.8% yield is explained as experimental difficulties inherent in the measurement of the bond strength of individual fibres, or to other fibre and web properties which determine handsheet breaking length.

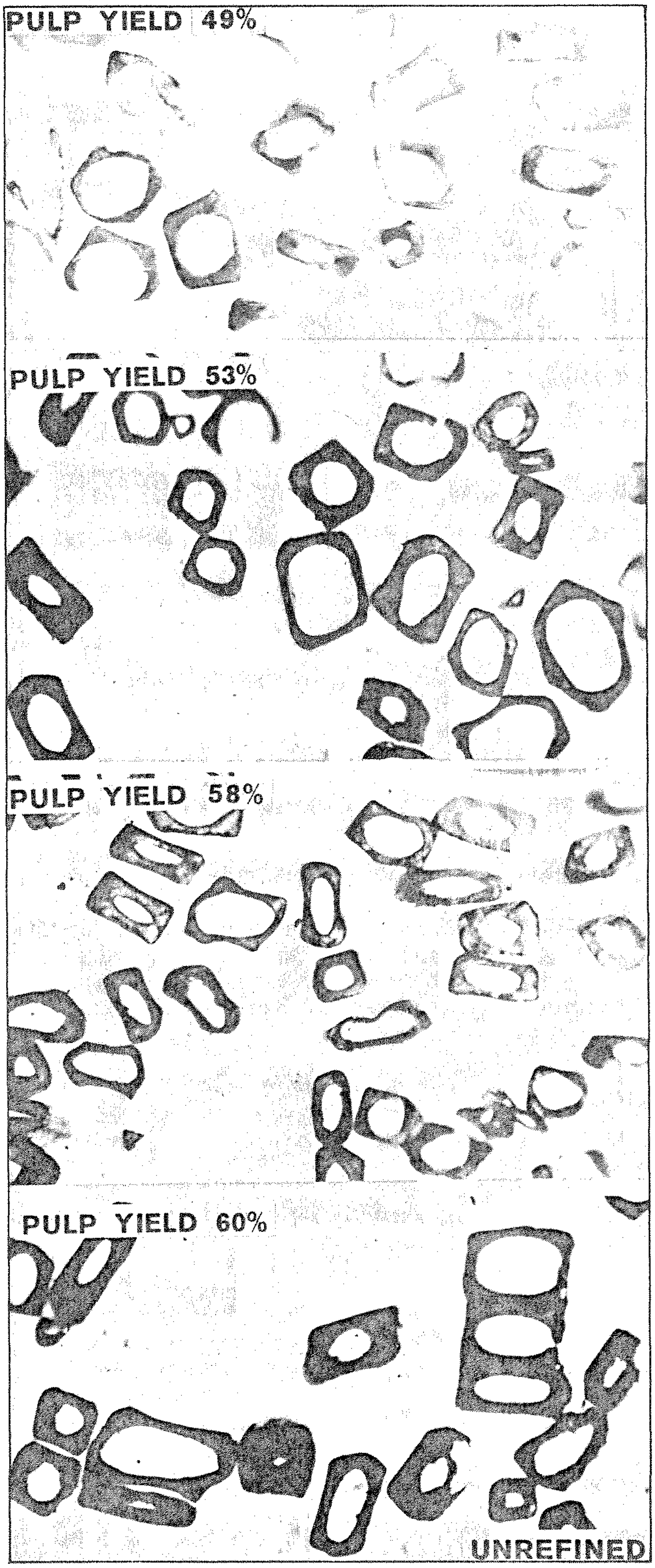

Fig. 8 — Unrefined southern pine fibre cross-sections for kraft pulp yields 49 to 60%.

For the unrefined spruce fibres the breaking length maximum at about 49% yield(9) corresponds to the yield at which radiata pine fibres are very responsive to pulp refining since the potentials are high for wall delamination (Fig. 7, 8, 10) and for the structural modification of fibre surfaces (Fig. 6). Unfortunately insufficient data are available(8) to assess effects of refining on relationships among specific bond strength, fibre conformability, and pulp yield.

Slabwood *A* and *B* pulp qualities

Slabwood *B* fibres are substantially longer and thicker walled than slabwood *A* fibres (Table 3). Typical radiata pine tear/tensile and tensile/sheet density relationships are obtained for the low yield *A* furnishes(10) (Fig. 1,2). The high tearing resistances at low tensile strengths obtained for slabwood *B* furnishes, on the other hand, are atypical of radiata pine but in accordance with slabwood *B* being rich in southern pine-type fibre. Effects of changing pulp yield are essentially the same for both pulp series.

Some of the tensile potential of the slabwood *A* fibres can be related to their thin walls, short lengths, and equivalent diameter relative to those of the slabwood *B* pulps(10). Based on the data of Table 3 mean lengths and wall areas for the slabwood *A* and *B* 49% yield pulps are respectively 2.9 mm and 293 μm^2, and 3.9 mm and 339 μm^2. Numbers of fibres per gram of slabwood *A* and *B* pulps are, therefore, estimated respectively as 7.65×10^5 and 4.91×10^5 fibres per gram. Slabwood *A* pulp can therefore be expected to contain about 1.56 times as many fibres per gram or per standard handsheet than does the slabwood *B* pulp. The different refining and tensile strength potentials of the slabwood *A* and *B* pulps can to a large extent be accounted for by the very long and thick walled fibres (Table 3), smaller numbers of fibres, and generally broader fibre property distributions (Fig. 3, 4, 5) of the slabwood *B* furnish.

Although the very different numbers of fibres and fibre dimensions for the two pulp series explain in part the high tensile strength and response to refining potentials of the

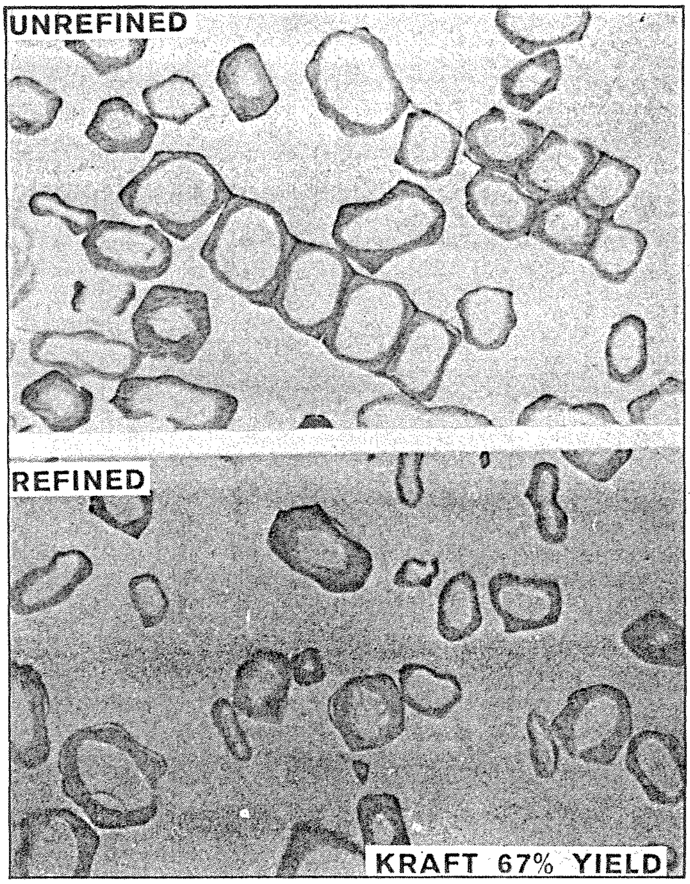

Fig. 9 — Unrefined and refined fibre cross-sections for a kraft pulp of 67% yield.

slabwood *A* furnishes, previous studies (11, 12) have shown that they are probably not the complete answer. The high tensile strength and ease of refining of the slabwood *A* pulps is also evident from an analysis of burst/tensile relationships (Fig. 11). The effect is greatest for heavily refined pulps, and for the pulps of low yield. Thus, slabwood *A* pulps have a high potential for developing handsheet tensile properties which is not paralleled by the development of burst strength. The relationships of Figure 11 strongly suggest that factors which influence handsheet stretch may account for the differences between slabwood *A* and *B*(10,12). Although stretch/apparent density relationships could be different for the slabwood *A* and *B* pulps, trends are somewhat inconsistent, and not altogether in accordance with the burst/tensile relationships (Fig. 11). There appears to be no reason why the 53% yield data for the slabwood *B* pulp should follow that of the slabwood *A* data, whereas the 49% yield data do not. Also handsheet stretch values tend to coincide for the two pulp series at high levels of refining which is the converse of trends shown in Figure 11 for burst/tensile relationships.

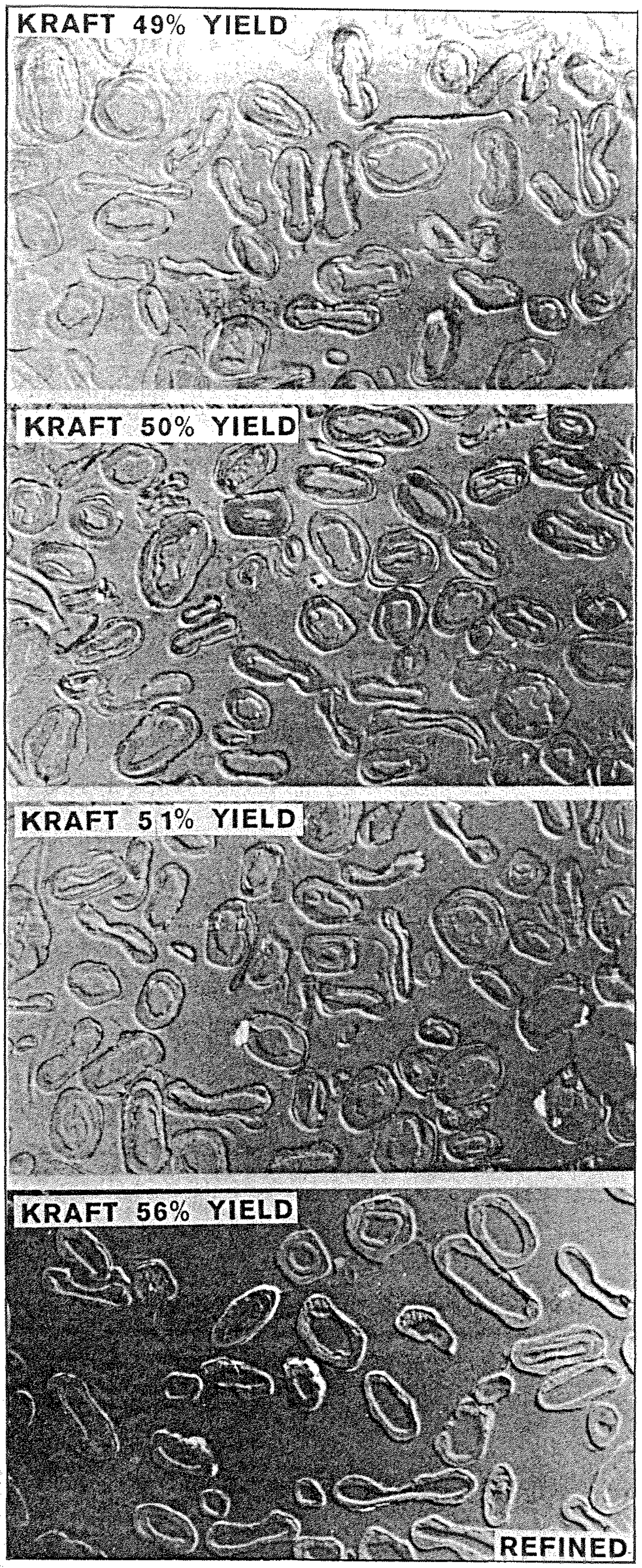

Fig. 10 — Refined radiata pine fibre cross-sections for kraft pulps of yield 49 to 56%.

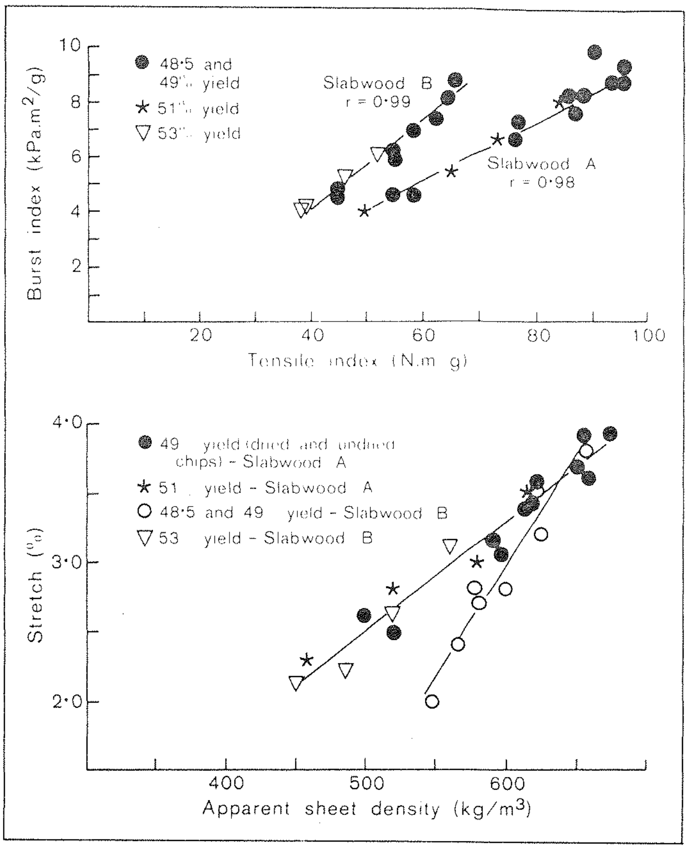

Fig. 11 — Handsheet burst index, stretch, and apparent density.

CONCLUSIONS

The strength qualities of kraft pulps increase gradually as yields decrease progressively from 67 to about 52%. As pulp yields decrease from about 51 to 49%, pulp lignin contents decrease abruptly and the response of fibres to pulp refining increases equally abruptly. Response to pulp refining is measured in terms of the development of fibre wall delamination, the disruption of fibre surface layers, and handsheet tear/tensile relationships. At lignin contents of about 5% and yields of about 49% the radiata pine unbleached kraft pulps probably attained their maximum potential quality as far as handsheet strength relationships are concered.

Potential tensile strength qualities of low yield (49%) unbleached kraft pulps can vary greatly depending on fibre properties which determine the numbers of fibres per gram of pulp — length, diameter and wall thickness.

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