Chemimechanical and thermomechanical pulps of radiata pine corewood and slabwood. Part 3. — Factors determining paper quality

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SUMMARY

This paper examines factors which determine the qualities of papers made from radiata pine corewood and slabwood chemimechanical pulps (CMP) of yield about 90%, and thermomechanical pulps (TMP) of yield about 98%. Study of the morphological, surface and chemical properties of fibres and fines showed that factors other than the collapse or flexibility behaviours of fibres in the +14, +30, and +50 pulp fractions can strongly influence pulp quality. Major factors which determined CMP and TMP paper qualities were (a) fibre surface compositions; (b) the morphology and/or surface chemistry of the −200 fines and of the coarse fines-type material in the −50/+200 pulp fraction; and (c) probably fibre collapse behaviours.

The first paper in this series(2) described processing conditions and qualities of a wide range of chemimechanical pulps (CMP) and thermomechanical pulps (TMP) made from samples of radiata pine corewood and slabwood. The second paper(3) examined papermaking qualities of fibre and fines fractions through a study of the web properties of (a) fibre fractions mixed with standard fines, and (b) fines mixed with standard kraft pulp. The present paper identifies further differences in fibre and fines characteristics and relates these to CMP and TMP pulp properties.

It has been shown previously that, when compared at the same freeness, radiata pine CMP pulps have more long fibre and higher strength than TMP pulps made from the same wood samples *ie,* either corewood or slabwood(1,2). However, for both the corewood and slabwood pulps, the CMP furnishes consume more energy to reach a given freeness than do corresponding TMP pulps. Other features of note are the greater apparent densities and air resistance values of the CMP furnishes, and their lower opacities and light scattering coefficients. These features have been related in part to the higher proportions of long fibre, and the apparent higher bonding and web consolidating characteristics of the fibres and/or fines components in the CMP pulps(2,3).

A comparison of handsheet apparent densities reveals interesting trends. For handsheets made from slabwood pulp fractions +14, +30, +50, and +200, Corson and Kibblewhite(3) found the apparent densities of CMP pulps were substantially greater than the values for TMP pulps. Similar differences were observed between the apparent densities of sheets made from CMP and TMP furnishes to which were added slabwood TMP fines up to a fines content of 50%(3) (Fig. 1, 2). Furthermore, sheet apparent densities increased with increasing fineness of the pulp fractions (or decreasing mesh sizes), both without added fines and with these present. Considering the data presented in Figure 1, these questions arise:

- For both CMP and TMP pulps, why do the longer and thicker walled slabwood fibres form handsheets which are of similar density or denser than those made from the shorter and thinner walled corewood fibres?

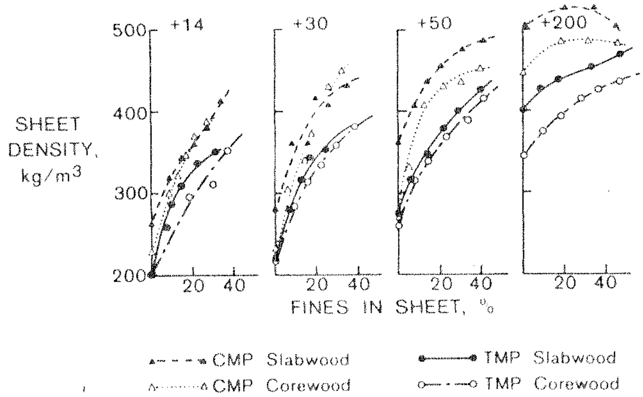

Fig. 1 — Apparent density and per cent fines in handsheets.

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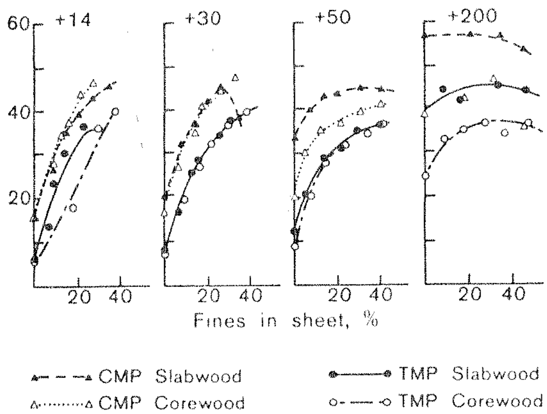


Fig. 2 — Tensile index and per cent fines in handsheets.

- In what ways do CMP fibres and fines differ from those in TMP pulps made from the same wood material, and why do CMP pulps form handsheets of substantially higher apparent density than corresponding TMP furnishes?

A probable answer to the first question has been presented previously(4) and relates the similar corewood and slabwood handsheet apparent densities to first, the different qualities of the fines (−200 material), and of the coarse fines in the finer fibre fractions within the two furnish types; and second, their influence on web consolidation. Identification and explanation of factors which influence the behaviour and properties of CMP and TMP pulps are the major emphases of the present paper.

RESULTS AND DISCUSSION

Some pulping and pulp physical evaluation data for the four representative pulps selected for study — slabwood CMP and TMP, and corewood CMP and TMP — are listed in Table 1 [see reference(2) for details]. To determine possible differences between the fibres in the +14, +30, and +50 fractions, measurements were made of their length and cross-sectional dimensions, and of a range of fibre wall and surface characteristics (Tables 2 to 5). Based on these data, it can be concluded that few configurational and morphological differences (if any) exist between CMP and TMP fibres of the +14, +30, and +50 pulp fractions.

Although the CMP pulps contained high proportions of long fibre relative to the TMP pulps, actual weighted average fibre lengths within the individual Bauer McNett fractions were generally similar (Table 2). This is particularly true for the longer fibred pulp fractions which suggests that fibre configurations and hydrodynamic specific volumes are similar for specific CMP and TMP pulp fractions. Fibre cross-sectional dimensions of diameter, lumen diameter, and wall thickness were also generally similar for the CMP and

Table 1
Pulp physical evaluation data

	Corewood		Slabwood	
	TMP	CMP	TMP	CMP
Energy input, kW.h/o.d.t	3190	4125	2845	3945
Adjusted pulp yield %o.d.	98.3	90.0	—	—
Sulphonate content, %	0.05	1.78	—	—
Pulp freeness, CSF	55	110	110	105
Bauer McNett classification				
+14	—	0.1	1.6	2.4
+30	26.8	41.7	46.8	51.7
+50	19.8	18.2	15.6	13.6
+100	10.1	7.6	6.2	4.7
+200	8.4	5.4	5.4	4.6
−200	34.9	27.0	24.4	23.0
Apparent density, kg/m³	390	421	334	438
Tensile Index, N.m/g	42.2	56.3	38.9	65.4
Stretch, %	2.7	2.8	3.1	3.1
Tensile energy index, J/kg	744	993	812	1346
Tear index, mN.m²/g	7.3	7.7	12.8	8.8
Burst index, kPa.m²/g	3.5	4.6	2.9	5.9
Air resistances, s/100 mL	96	66	30	103
Opacity, %	97.7	91.5	98.1	88.9
Scattering coefficient, m²/kg₉₀	55.4	34.5	47.3	32.3
Brightness, %	53.9	58.1	48.7	60.2
Absorption coefficient, m²/kg	4.6	2.7	6.4	2.0

Table 2
Weighted average pulp fibre lengths*

Pulp sample	Pulp fraction			
	+14	+30	+50	+200
	mm	mm	mm	mm
TMP, slabwood	3.49	2.87	1.71	1.04
CMP, slabwood	3.40	2.73	2.07	1.21
TMP, corewood	3.26	2.48	1.59	1.02
CMP, corewood	3.24	2.50	1.59	0.88

*Mean values different at the 95% level if fibre lengths differ by more than 0.15 mm.

Table 3
Mean fibre cross-section dimensions

Pulp sample	Pulp fraction	Fibre diameter* (μm)	Fibre wall thickness† (μm)	Fibre lumen diameter‡ (μm)
TMP, slabwood	+30	35.1	5.0	25.1
CMP, slabwood	+30	35.6	5.1	25.5
TMP, slabwood	+50	34.2	4.6	25.0
CMP, slabwood	+50	36.6	4.6	27.4
TMP, corewood	+30	37.5	4.4	28.6
CMP, corewood	+30	36.0	4.5	27.1
TMP, corewood	+50	33.9	4.3	25.2
CMP, corewood	+50	34.2	3.8	26.5

* Different at the 95% level of confidence if mean diameters differ by more than 2.1 μm.
† Different at the 95% level of confidence if mean wall thicknesses differ by more than 0.57 μm
‡ Different at the 95% level of confidence if mean lumen diameters differ by more than 2.20 μm

Table 4
Per cent of various fibre properties in total pulp fraction populations

Pulp sample	Pulp fraction	Fibre cross-section intact* (%)	Middle lamella present or partly present* (%)	Latewood fibres† (%)
TMP, slabwood	+30	77.7	31.0	27.0
CMP, slabwood	+30	78.3	33.0	37.3
TMP, slabwood	+50	71.3	40.0	25.3
CMP, slabwood	+50	70.3	38.7	31.3
TMP, corewood	+30	75.0	33.3	25.7
CMP, corewood	+30	80.3	32.0	27.7
TMP, corewood	+50	72.7	30.3	22.3
CMP, corewood	+50	76.0	37.7	27.3

* Differences not significant.
† Different at the 95% level of significance.

Table 5
Origins of wall lamellae on fibre surfaces

Pulp sample	Pulp fraction	Per cent of fibres examined					Fines index*
		P	$P-S_{ou}$	S_{ou}	S_{trans}	S_2	
TMP, slabwood	+30	—	—	18	11	71	253
CMP, slabwood	+30	—	—	8	8	84	276
TMP, slabwood	+50	—	—	15	14	71	256
CMP, slabwood	+50	—	—	5	20	75	270
TMP, corewood	+30	—	—	9	10	81	272
CMP, corewood	+30	—	—	—	9	91	291
TMP, corewood	+50	—	—	5	9	86	281
CMP, corewood	+50	—	—	11	8	81	270

* Fines index = $[S_{ou} + 2\ S_{trans} + 3\ S_2]$.

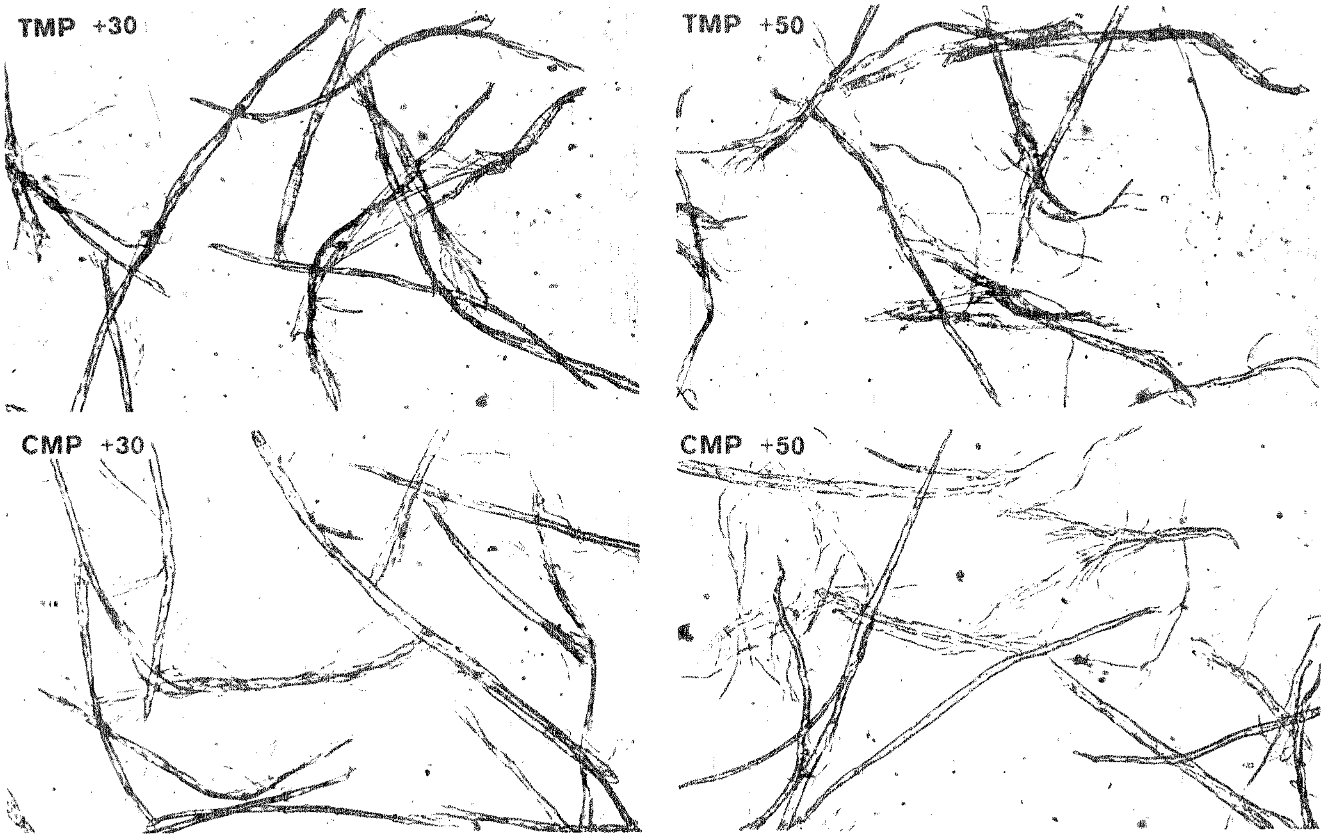


Fig. 3 — CMP and TMP long fibred fractions — fibre qualities.

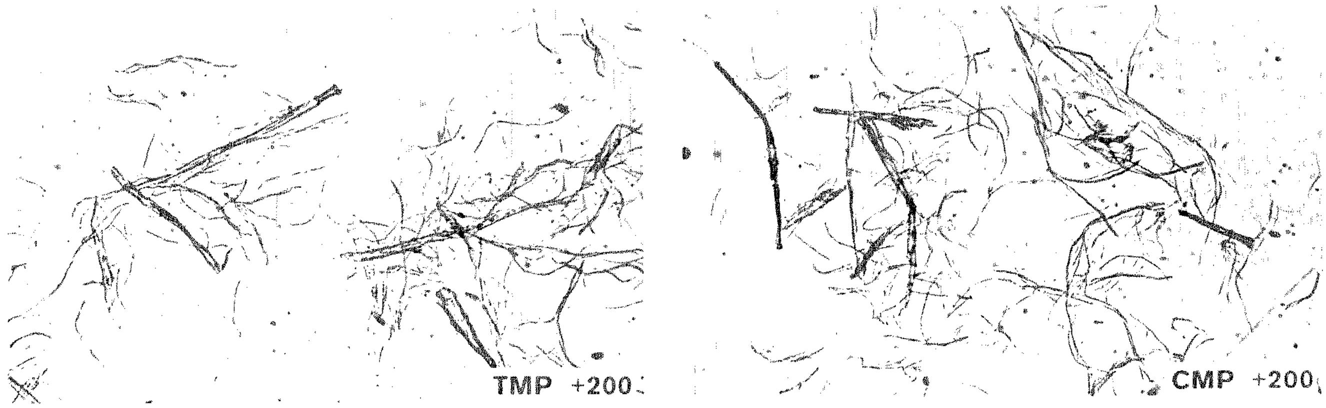


Fig. 4 — CMP and TMP +200 fraction fibre and fines qualities.

TMP pulps (Table 3). An examination of the extent of fibre wall damage also lent support to the hypothesis that configurations and surface morphologies are similar for fibres in corresponding CMP and TMP pulp fractions (Table 4). A difference may exist, however, in the proportion of latewood to earlywood fibres in the respective furnishes (Table 4). Origins of exposed wall lamellae on fibre surfaces are shown in Table 5. These data indicate that more CMP fibres have their S2 layer exposed than do TMP fibres. This trend may be explained by a difference between the pulps in the most favoured site of fibre separation. An alternative explanation could be that secondary refining (refining after chip defibration) removes fibre surface lamella more readily from the CMP fibres than from corresponding TMP material. Qualitative light microscopy of individual pulp fractions also supported the view that few identifiable morphological and configurational differences exist between CMP and TMP fibres (Fig. 3,4).

For the CMP and TMP +30 and +50 fractions, wet fibre diameters and wall thicknesses were similar but numbers of latewood fibres in the furnishes were greatest for the CMP (Table 4). Also fibres in CMP handsheets, made from both +30 fraction pulp and whole pulp, have thicker walls than those in handsheets made from TMP (Tables 6,7). Z-direction fibre diameters in the CMP and TMP were similar as were the numbers of uncollapsed fibres in the whole pulp webs except for the TMP corewood value (Table 6). Numbers of fibres per unit length of sectioned handsheet were, however, greater for TMP than CMP (Table 6). For the whole pulps many interactive factors can be involved in determining handsheet qualities and extents of web consolidation, and many of these cannot be measured or isolated *in situ*. The different wall thickness values for the CMP and TMP fibres (Tables 6,7) do, however, indicate that thinner walled CMP fibres may be selectively disrupted during pulping and/or collapsed to greater extents during handsheet preparation than are TMP fibres. For the first possibility a decrease of about 10% in pulp yield could be expected to cause a corresponding decrease in wall thickness; this was not observed (Table 3). The alternative and/or additional possibility is that highly bonded and collapsed thin walled fibres in the consolidated CMP handsheets (Fig. 5, 6, 7) may not always be identified as fibres during the *in situ* measurement of fibre cross-section dimensions. Thus the possibility that CMP fibres may be more collapsed and flexible than TMP fibres cannot be totally discounted from the data presented in Tables 2 to 7. Finally, the high latewood fibre contents of the +30 and +50 fraction CMP pulps noted in Table 4 are inconsistent with the wet fibre dimensions (Table 3) — a feature not yet explained or reconciled.

Table 6
Fibre cross-section dimensions measured '*in situ*' in whole pulp handsheets

Pulp sample	Number of fibres*	Uncollapsed fibres† (%)	Z-direction fibre diameter‡ (μm)	Fibre wall thickness§ (μm)
TMP, slabwood	36	75.3	14.6	4.68
CMP, slabwood	24	66.4	14.11	5.18
TMP, corewood	35	67.2	12.5	4.12
CMP, corewood	27	70.6	14.3	4.79

* Measured on a per unit length of sectioned handsheet basis. Different at the 95% level of significance.
† Measured on a per unit length of sectioned handsheet basis. Differences between CMP and TMP not significant.
‡ Different at the 95% level of significance if mean fibre diameters differ by more than 1.1 μm.
§ Different at the 95% level of significance if mean fibre wall thicknesses differ by more than 0.38 μm.

Table 7
Influence of fines on extents of fibre collapse in +30 fraction handsheets

Pulp samples	Fines in furnish (%)	Z-direction fibre diameter* (μm)	Fibre wall thickness† (μm)
TMP, slabwood	0	16.3	4.77
	20	16.6	5.34
	40	15.1	5.66
CMP, slabwood	0	15.7	5.50
	20	15.7	5.61
	40	15.0	5.66

* Different at the 95% level of significance if mean fibre diameters different by more than 1.09 μm.
† Different at the 95% level of significance if mean fibre wall thicknesses different by more than 0.38 μm.

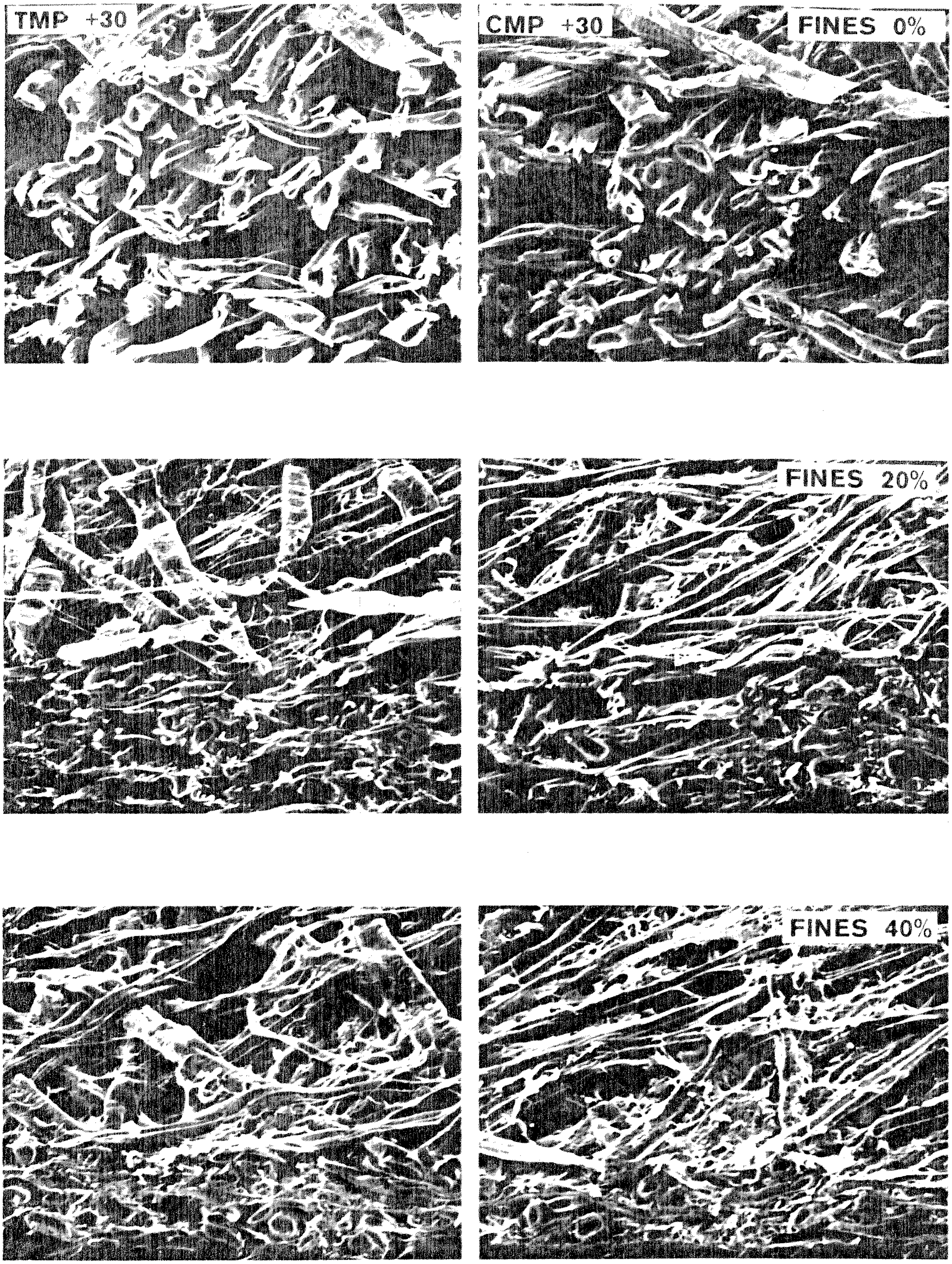
The generally consistent values of Z-directional diameter in Table 7 support the evidence of Table 6 that Z-direction fibre diameters in handsheets for CMP and TMP pulps are similar. The apparently anomalous Z-direction diameter of 14.3 μm (Table 6) for the corewood CMP pulps is high compared with previous results(4) and can be interpreted as being associated with experimental error and variation.

Qualitative microscopic study of CMP and TMP fibres in handsheets supports the conclusions reached from quantitative data of Tables 2 to 7. Although the CMP webs were consolidated to greater extents than corresponding TMP webs, fibre Z-direction diameters or extents of fibre collapse were statistically similar for handsheets made from the +30 fraction pulps (Table 7, Fig. 5, 6). Fibre wall thicknesses, on the other hand, were significantly greater for CMP (Table 7). Addition of 'standard' fines(3) to the two furnishes caused TMP Z-direction diameters to decrease slightly and wall thicknesses to increase to values comparable with those of fibres in the corresponding CMP handsheets. Thus the addition of 'standard' fines to the CMP +30 furnish influences both web consolidation and the collapse behaviour of the fibres. An examination of Figures 1, 2, 5, 6 shows the relative consolidating influence of the 'standard' fines on the CMP and TMP +30 fraction handsheets. The CMP webs were very much more consolidated by the 'standard' fines than were the TMP webs — an effect which was apparently independent of the influence of fines on fibre collapse (Table 7). Thus, factors additional to fibre collapse or fibre flexibility must account for the high extents of web consolidation attained with the CMP furnishes. Different fibre surface properties and bonding potentials are, therefore, proposed as an explanation for the high extents of consolidation obtained in handsheets made from the longer fibred (+14, +30 and +50) CMP pulp fractions (Fig. 1, 2, 5, 6).

For the +200 pulp fractions, the addition of 'standard' fines to the CMP and TMP furnishes had a greater consolidating effect on the CMP webs (Fig. 7). 'Pores or voids' in the CMP web are finer and more evenly distributed than in the coarser TMP web. Z-direction fibre diameters were not measured in these +200 fraction handsheets, although it is evident that few uncollapsed fibres were present in the CMP web which contained 40% fines (Fig. 6). The general absence of uncollapsed fibres in the +200 CMP fraction webs suggests that the CMP fibres may be more readily collapsed than those in corresponding TMP fractions. If fibres are in fact more collapsed in the CMP than in the TMP +200 fraction handsheets, this is probably related to the influence of the very high concentration of CMP-quality fines-type material present in this pulp fraction (Fig. 4)(4).

CMP and TMP fines qualities and behaviours

The qualities of fines or −200 material in the CMP and TMP pulps, in contrast to those of the fibres, are very different. Although CMP and TMP fines may appear morphologically similar (Fig. 8), their bonding behaviours and potentials are very different. CMP fines are highly bondable and individual fines elements cannot be redispersed in water (or rewetted) from a dried matt. Dried matts of CMP fines remain intact after being torn into small pieces and soaked in agitated or stirred water heated slowly to boiling temperature, and subjected to ultrasound treatments. Under such treatment conditions matts of TMP fines are readily disintegrated. Chemical composition data for the CMP and TMP fines show that carbohydrate compositions and Klason and acid soluble lignin, and sulphur and extractive contents can be very different (Table 8).


TMP +30
CMP +30
FINES 0%
FINES 20%
FINES 40%

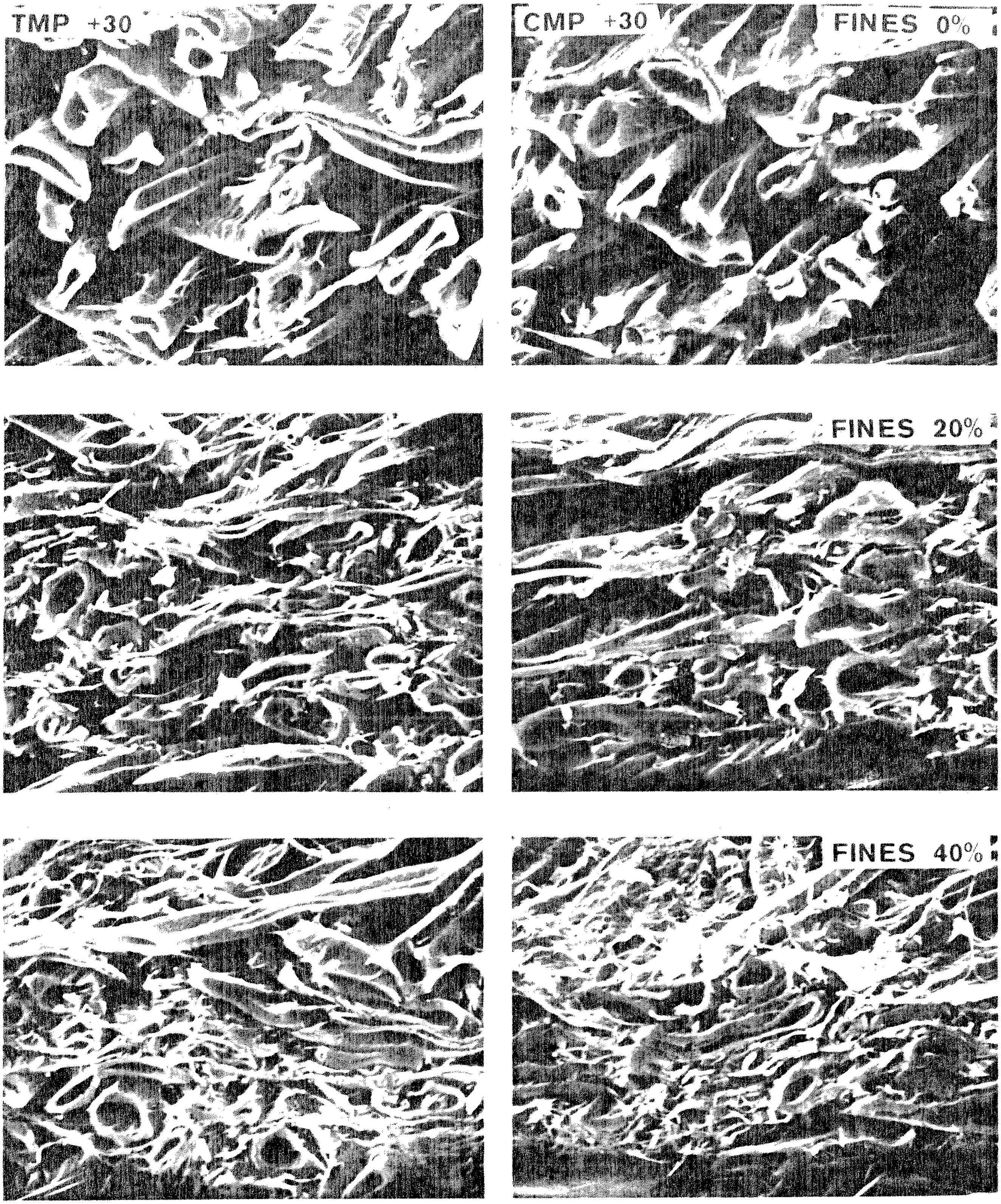


Fig. 5 and 6 — Section and surface views of handsheets made from CMP, and TMP +30 pulp fractions. The addition of up to 40% of standard TMP fines increases extents of web consolidation but not overall extents of fibre collapse.

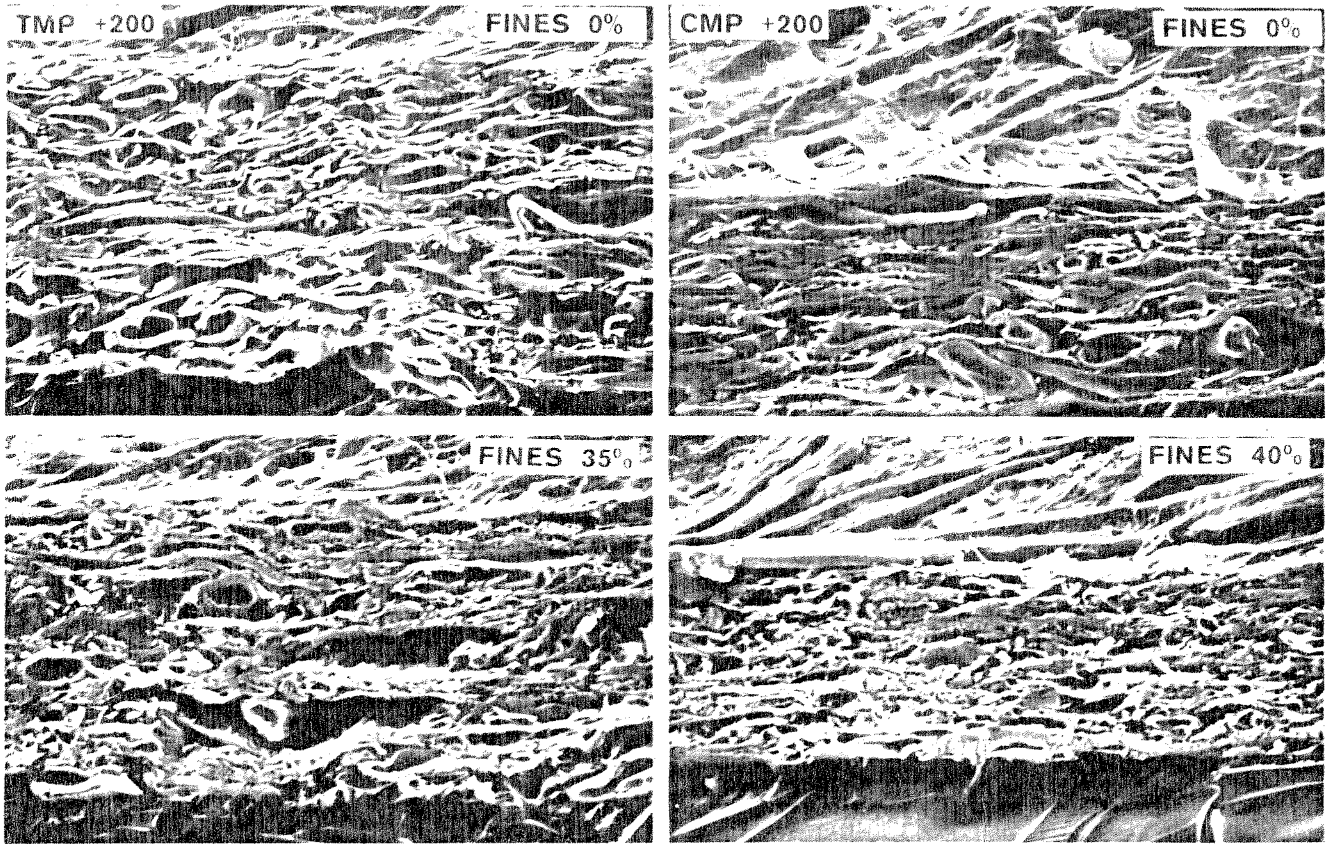


Fig. 7— Section and surface views of handsheets made from CMP and TMP +200 pulp fractions. The addition of up to 40% fines increases extents of web consolidation and fibre collapse, particularly for the CMP furnishes.

Table 8
Chemical composition of CMP and TMP pulps

Pulp	Wood type	Pulp fraction	Lignin%		Total carbohydrate %	Total carbohydrate %					Methylene chloride extractives %	Unaccounted %
			Klason	Acid-soluble		Glucan	Xylan	Galactan	Arabinan	Mannan		
TMP	Slabwood	whole pulp	26.56	N.D.*	71.35	71.59	7.12	2.35	1.35	17.59	—	—
CMP	Slabwood	whole pulp	22.37	2.38	72.39	71.16	6.78	2.06	1.46	18.54	—	
TMP	Slabwood	+ 30	24.79	N.D.	72.13	74.23	7.08	0.43	0.65	17.60	0.41	2.67
CMP	Slabwood	+ 30	20.71	2.80	72.63	72.96	6.97	2.00	0.62	17.46	0.30	3.56
TMP	Slabwood	+ 200	25.72	N.D.	72.61	71.41	6.67	2.60	1.22	18.10	0.60	1.07
CMP	Slabwood	+ 200	23.85	2.09	71.98	72.84	6.22	1.35	0.61	18.98	0.48	1.60
TMP	Slabwood	− 200	34.83	N.D.	55.82	66.73	7.52	5.79	4.23	15.73	0.59	8.76
CMP	Slabwood	− 200	30.33	0.52	57.67	66.18	7.20	5.39	3.22	18.01	0.48	11.00
TMP	Corewood	whole pulp	27.57	N.D.	68.91	67.91	9.43	3.42	1.93	17.31	—	—
CMP	Corewood	whole pulp	23.99	1.88	70.05	68.65	9.68	3.13	1.67	16.87	—	—
TMP	Corewood	+ 30	25.06	N.D.	70.96	70.20	9.51	1.17	1.49	17.63	0.26	3.72
CMP	Corewood	+ 30	22.10	2.15	70.88	70.09	9.78	2.53	0.82	16.79	0.14	4.73
TMP	Corewood	+ 200	26.24	N.D.	69.12	69.00	9.45	2.81	1.78	16.96	0.19	4.45
CMP	Corewood	+ 200	24.60	1.75	69.48	68.34	9.69	3.61	1.67	16.69	0.19	3.98
TMP	Corewood	− 200	32.74	N.D.	58.86	64.31	9.65	6.08	4.21	15.75	0.25	8.15
CMP	Corewood	− 200	29.90	0.40	57.03	64.13	9.73	6.77	3.26	16.11	0.17	12.50

* Not detected.

The bonding potentials of CMP fines are also very much greater than those of corresponding TMP fines when their respective abilities to promote web consolidation are considered(3). For handsheets prepared from bleached kraft fibres and various proportions of CMP or TMP fines (−200 material), apparent densities and bonding strengths (tensile index) are substantially greater for those which contain the CMP fines (Fig. 9, 10). Thus, the morphological and/or chemical properties of the fines can strongly influence the apparent density (Fig. 9), strength (Fig. 10)(3), and optical properties(3) of pulp furnishes.

Chemical compositions of CMP and TMP pulps and pulp fractions

Carbohydrate compositions of the CMP and TMP whole pulp and pulp fractions (other than the −200 fraction) were similar as were total lignin contents; Klason lignin for TMP pulps, and Klason plus acid soluble lignin for the CMP fractions (Table 8). Methylene chloride extractive contents were extremely low and, for TMP at least, atypical. Thus the fact that CMP extractive contents were substantially lower than those for TMP should be interpreted with caution. For each pulp fraction, other than −200 fines fraction, relative pro-

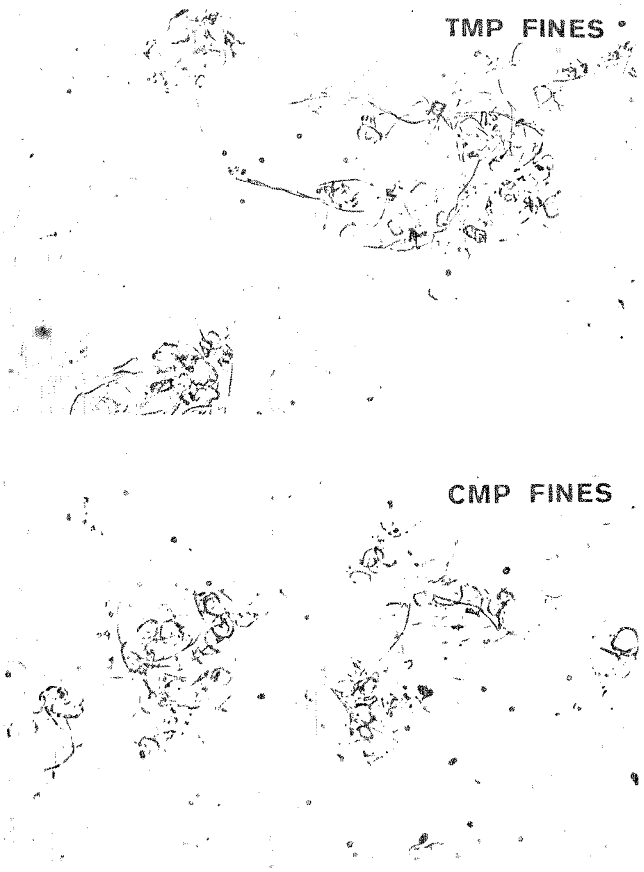


Fig. 8 — Photomicrographs of CMP and TMP −200 fines partly redispersed in water from dried handsheets. The CMP fines may be morphologically different from the TMP fines. A definitive statement cannot be made since it was not possible to redisperse the dried CMP fines in water.

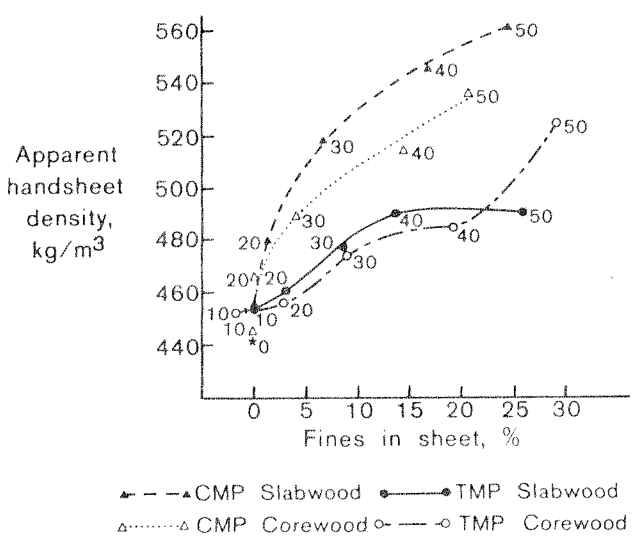


Fig. 9 — Handsheet apparent density and proportions of CMP and TMP −200 fines in a web containing bleached kraft pulps. Subscripts 0, 10, 20, 30, 40, and 50 refer to fines per cent added to pulp furnishes(3).

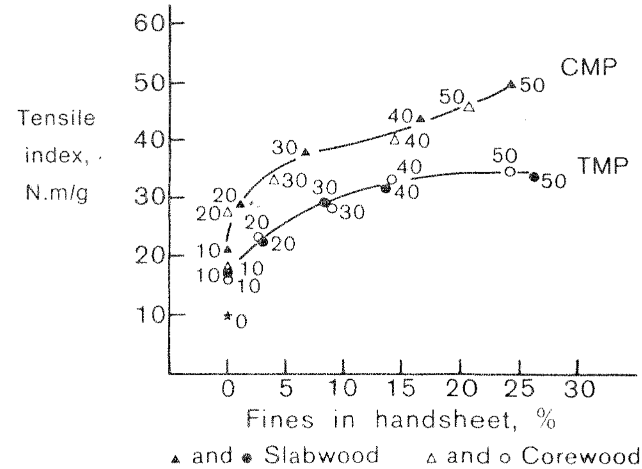


Fig. 10 — Handsheet tensile index and proportions of CMP and TMP −200 fines in a web containing bleached kraft pulps. Subscripts 0, 10, 20, 30 40 and 50 refer to fines per cent added to pulp furnishes(3).

portions of unaccounted material were similar for the CMP and TMP pulps. For fines fractions, on the other hand, percentages of material not accounted for by the analysis were greater for CMP. Furthermore, percentages of unaccounted material in the −200 fractions are also higher than those of all other fractions by factors of at least two, and often three or four. Much of the unaccounted material could be explained by dirt particles, *etc* being concentrated in the −200 fraction. Differences between the quantities of unaccounted material in the CMP and TMP fines fractions can be related in part to the high sulphur content of the CMP fines which is approximately 15 to 20 times greater than that of the TMP fines. This is, however, not the major reason for the difference since for all the other pulp fractions analysed sulphur contents are also much higher in CMP than in TMP pulp, *ie*, of the order of 10 to 15 times.

Pulp sulphur content values were estimated qualitatively using x-ray fluorescence spectrophotometry as noted in the experimental section. Sulphonate values listed in Table 1 were quantitative and were determined by a different method. All data listed in Table 1 were determined by methods described in a previous paper(2).

For the −200 fines fractions lignin contents were higher, carbohydrate contents were lower, and extractive contents were roughly similar to those of the other pulp fractions analysed. Glucan contents were lower and xylan and galactan contents higher for the −200 material than for the whole pulp or +30 and +200 pulp fractions. These data, along with the high proportion of unaccountables in the −200 fractions, show the fines to be chemically very different from the +200 and the longer fibred fractions.

The high sulphur (probably lignin sulphonate) contents of the CMP pulps and pulp components (for −200 fines 15 to 20 times, and for whole pulps and other pulp fractions 10 to 15 times, greater than corresponding TMP material) most probably determine, at least in part, their bonding potentials during papermaking. Thus, the sulphonated lignin present in the CMP fibre and fines surfaces must strongly influence their ability to bond one to another and, hence, to greatly enhance the consolidation and bonding properties of paper webs.

Corewood and slabwood effects on TMP and CMP properties

Trends for the properties of slabwood and corewood TMP and CMP pulps, fibres, and handsheets were generally in agreement with those described elsewhere for TMP and RMP pulps(4,5). Corewood pulps generally have lower strengths and better optical properties than corresponding slabwood pulps(2,3,6). Information additional to that presented previously is listed in Table 5. These data show that more corewood than slabwood fibres have the S2 layer as the outermost surface layer for both the CMP and TMP pulp types. Also, extents of damage to fibre surfaces and to fibre cross-sections (Table 4) are generally similar (or differences are not significant) which contrasts to some degree with previous observations(4). The emphasis of this paper is on differences between CMP and TMP furnishes since data and findings for the corewood and slabwood pulps are in general agreement with previous studies.

The trends toward high xylan and arabinan contents for the corewood TMP and CMP furnishes relative to those of the slabwood pulps (Table 8) are in accordance with the results of previous studies of radiata pine wood(6). The relatively high slabwood extractive contents compared with those of the corewood material are unexplained, although all the values listed are generally low(7). The extractive data, however, need to be interpreted with caution since their apparent low values may be related to long pulp storage periods.

Whole pulp CMP and TMP handsheets

For comparative purposes, sectional and surface views of CMP and TMP whole pulps are shown in Figure 11. The similar extents of fibre collapse or Z-direction fibre diameters are clearly visible, as are the different degrees of web consolidation and different fibre packing arrangements within the webs. Overall, packing densities appear to be higher and more uniform for the CMP than the TMP webs.

CONCLUSIONS

Differences between CMP and TMP pulp qualities can be related to fines chemistry and morphology, fibre surface qualities, and probably the collapse behaviours or flexibilities of the longer fibred pulp components. For CMP and TMP pulp furnishes, handsheet properties are largely determined by the morphological and/or chemical qualities of the fines (−200 material) and of the coarse type fines in the −50/+200 fraction, as well as by the surface quality and chemistry of both the long and short fibres in the respective furnishes. Chemi-mechanical fines and fibre surfaces have very much higher bonding and web consolidating potentials than do corresponding TMP pulp components. Although

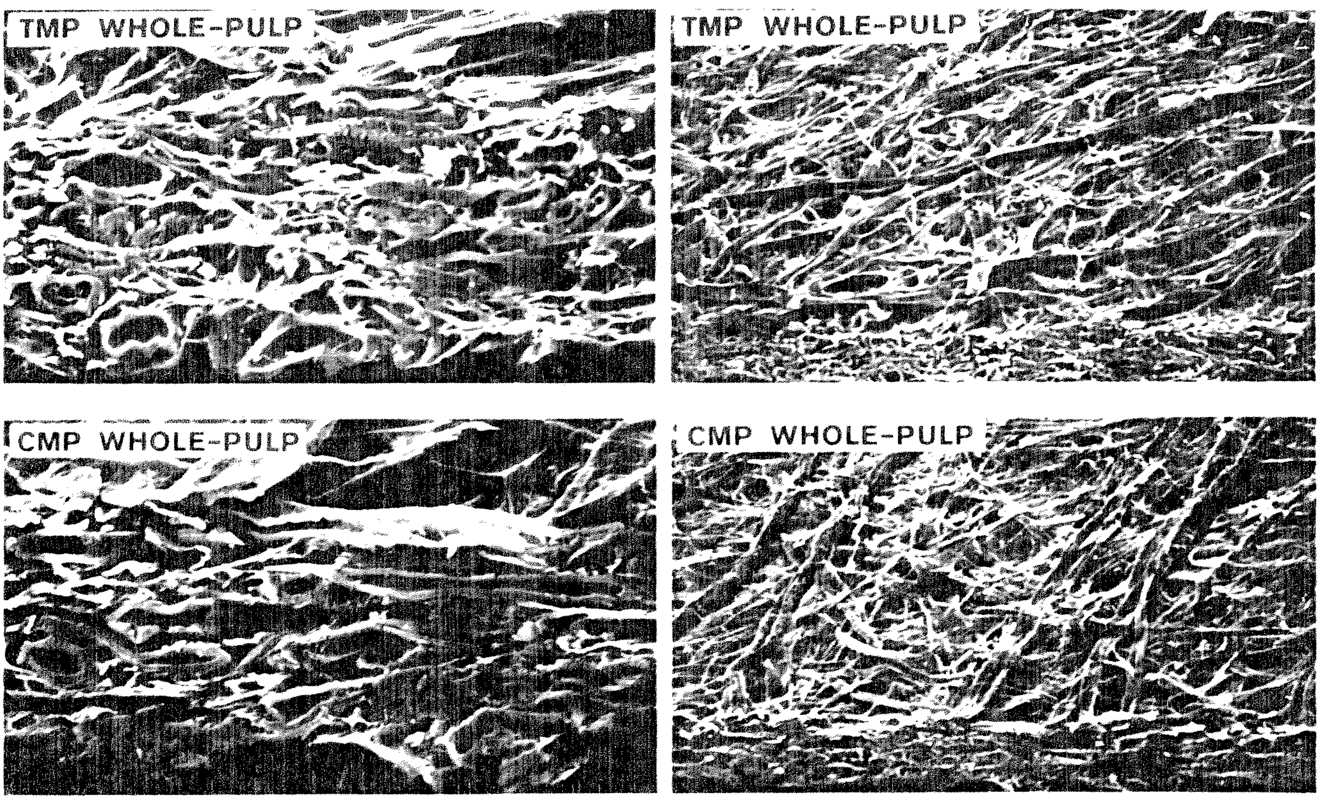


Fig. 11 — Section and surface views of CMP and TMP handsheets made from whole pulp.

fibres in the CMP and TMP fractions are generally similar in length, the high proportion of long fibre in the CMP furnishes must contribute in part to the greater strength of CMP sheets.

For the CMP and TMP pulps fibre morphological features of interest were the fibre collapse behaviours, and the similar fibre configurations, wet-fibre dimensions, and intrawall and surface damage found in the longer-fibred fractions (+14, +30, +50). For handsheets made from the −50/+200 CMP fraction, the fibres with intact cross-sections in the furnish appeared to be more collapsed than those in corresponding TMP webs. Again this effect was related to the high concentration of fines-type material in the −50/+200 fraction and to the apparent ability of this material to cause webs to be consolidated as water is removed during the papermaking process. For the whole pulps the different proportions of the various pulp fractions also clearly influence overall pulp qualities.

It is the collapse behaviours and surface chemistry of fibres in the longer-fibred +14, +30, and +50 fractions, and the morphological and surface chemical properties of the coarse +200 fines-type material and the −200 fines which largely determine pulp properties, and ultimately the extents of web consolidation. The high sulphur (or lignin sulphonate) contents of the CMP pulps and pulp components clearly must influence their bonding potentials during papermaking processes. Sulphonated lignin on fibre and fines surfaces most probably influence their ability to bond one to another and, hence, greatly enhance the consolidation and bonding properties of paper webs.

EXPERIMENTAL

Details of the preparation, sampling and classification of the pulp samples are given elsewhere(2,3).

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, samples of 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.

The weighted average fibre length was defined as:

$$\Sigma l_i^2 n_i / \Sigma l_i n_i$$

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

Fibres in handsheets

Sectioned surfaces of handsheets cut at angles of 45° to the plane of the web were cut and prepared for scanning electron microscopy by procedures outlined elsewhere(8). Cross-sectional dimensions of fibres and fibre fragments visible in the sectional faces were measured from photomicrographs. Fibre wall thickness and fibre and lumen diameters were measured in the vertical plane of the sheet. Minimum wall thickness values were noted, whereas maximum lumen and fibre diameter values were recorded. Double wall thickness values were measured for each fibre. If only one wall was clearly visible, then this value was doubled. Final wall thickness values were halved to account for this initial measurement of double wall values.

Fibre dimensions were measured by a single observer from up to 16 photomicrographs per sample. These were examined in cyclic order to minimize observer bias. Measurements were made over a period of three to four weeks. A total of 300 fibres were measured for each sample.

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 with Spurrs resin. The fibres were then aligned approximately parallel, and rolled in coloured cellophane to retain their alignment when placed in BEEM capsules (size 00, with semi-hyperboloid tip). Six replicate capsules were prepared for each sample, each containing about 80 to 100 fibres.

Sections of 2 to 3 μm thickness were cut using glass knives and an LKB Ultramicrotome III. The sections were stained using a solution of 0.5% toluidine blue and 0.2% borax, and mounted in Depex.

Measurements of the fibre cross-section dimensions of fibre diameter, lumen diameter and wall thickness were made in accordance with procedures detailed elsewhere(4). Fifty fibres in sections made from each of the six replicate capsules were measured. Thus, mean estimates of each fibre dimension were based on the measurement of 300 fibres. Sections of all samples were measured in a cyclic order to minimize observer bias.

Fibre wall damage

Sections of embedded fibres were stained with toluidine blue to improve contrast and to distinguish between the secondary wall and the compound middle lamella. Quantitative analyses were used to determine the proportions of the fibres in each pulp with intact cross-sections; the presence of the compound middle lamella; and the numbers of latewood and earlywood fibres. For each pulp, stained sections were prepared from six blocks of embedded fibres. Fifty fibres from each of the six blocks were examined so that final estimates of wall damage were based on the observation of 300 fibres. Sections were coded and examined in a randomized order to minimize observer bias.

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. Surface replicas of handsheets were prepared and microfibril orientations relative to fibre axes determined(8). The number of fibres examined for each pulp or pulp fractions was normally in excess of 100.

Chemical analyses

Qualitative sulphur determinations were made using x-ray fluorescence spectrophotometry. Klason and acid-soluble lignin analyses were made in general accordance with the respective procedures of Moore and Johnson(9) and Swan(10). Klason lignin values were not corrected for ash. Carbohydrates were determined using high performance liquid chromatography in general accordance with procedure of Pettersen *et al*(11). Methylene chloride soxhlet extractions were of four hours duration after which extracts were evaporated to dryness and dried to constant mass in an oven at 105°C. Pulp samples were stored as standard handsheets for about two years before chemical analyses. All determinations were made on o.d. bases.

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