PRODUCTION OF PAPERS WITH HIGH TENSILE AND LOW STRETCH PROPERTIES

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ABSTRACT

A commercial softwood kraft pulp was beaten in a PFI mill for various periods and subsequently processed for 2000 revolutions in a Lampen mill. The ball mill post-treatment caused stretch but not breaking length to be decreased by up to 15 percent. The drop in handsheet stretch was explained by a re-distribution of mass, within fibres and within handsheets, which minimised fibre elongation in paper webs under strain. The decrease in stretch obtained by the Lampen mill post-treatments was examined in terms of paper properties and changes in fibre characteristics brought about by beating, i.e., fibre dimensions, fibre collapse and internal bonding, fibre wall fractures and dislocations, and fibre surface structure, fibrillation, and fines contents. Internal bonding was the fibre characteristic most strongly influenced by the Lampen mill post-treatment.

INTRODUCTION

Handsheet stretch (but not breaking length) was lowered by up to 20 percent with Lampen mill beating of softwood kraft pulps previously processed in industrial Jordon and Sprout Waldron refiners (Kibblewhite, 1973). The effect was irreversible and handsheet stretch was not redeveloped by further beating in the Lampen mill. In the present study, handsheet stretch behaviour is examined in terms of changes in fibre characteristics brought about by beating.

Previous studies showed that Lampen mill beating selectively modifies fibres so as to develop maximum internal fibre bonding in standard handsheets (Kibblewhite, 1974; Kibblewhite and Brookes, 1975). The present study was designed to confirm these earlier results and also to explain why Lampen mill beating lowers handsheet stretch values developed by other beating and refining treatments (Kibblewhite, 1973).

EXPERIMENTAL

The undried and unbleached softwood kraft pulp had a Kappa number of 23.1 and consisted of fibres of radiata pine (*Pinus radiata* D. Don) with up to 5 percent Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and a trace of Corsican pine (*Pinus nigra* Arnold (laricio)). The pulp was obtained from the Tasman Pulp and Paper Company at Kawerau.

Fibre lengths were estimated by tracing projected fibre images and subsequently recording their length with a map-measuring wheel. Trials showed that 300 fibres had

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to be measured to obtain confidence limits of ± 0.1 mm at the 95% level. For each pulp, 50 fibres on each of six microscope slides were measured. Mean diameters of undried fibres and of fibres in handsheet surfaces *in situ* were estimated by methods outlined elsewhere (Kibblewhite and Brookes, 1975).

Beating effects on fibre surface structure and fines production were characterised by the orientations of microfibrils in fibre surfaces (Kibblewhite, 1975). The incidence of removal of "intact" layers from fibre surfaces was estimated by direct fibre counts using polarised-light microscopy. "Intact" wall layers have been defined and described elsewhere (Kibblewhite, 1975).

Estimates of fibre collapse were made on 16 sample replicates prepared from handsheets of basis weight 60 g/m^2. A minimum of 45 fibres was examined for each replicate. Sample preparation and evaluation procedures were similar to those reported elsewhere (Kibblewhite and Brookes, 1975).

Quantitative estimates of the numbers of fractures and zones of dislocation in the walls of undried pulp fibres were made by direct counts using polarised-light microscopy (Kibblewhite, 1976). A total of 210 fibres, being 35 fibres on each of six microscope slides, was examined for each pulp.

The fibre length, fibre diameter, fibre surface structure, and fibre wall fracture and dislocation analyses were made on coded samples which were examined in random order to eliminate observer bias.

Handsheets were prepared and evaluated by standard APPITA procedures except that, for each beating point, 16 rather than 8 paper strips were tested in the Instron. Analyses of variance of differences between regression slopes and intercepts were made using mean test data and conventional F tests. Pulps were beaten for 2 000, 4 000, 8 000, 12 000, and 16 000 revolutions in the PFI mill at 10% stock concentration with an applied load of 1.8 kg/cm. Two standard PFI mill beatings were made in each case so that half of the prepared pulps could be beaten in the Lampen mill for an additional 2 000 revolutions.

RESULTS

Fibre Morphology

The morphological appearance of the undried fibres before and after the Lampen mill beatings was similar when examined using both light microscopy and scanning electron microscopy. Fibres appeared twisted and kinked to similar extents and it was impossible to classify unlabelled microscope slides and photomicrographs into specific groups.

Fibre lengths and fibre diameters were statistically unchanged when PFI mill beatings were followed by treatment of pulp in a Lampen ball mill for 2 000 revolutions (Table 1). It is noteworthy, however, that fibre diameters were consistently decreased by the Lampen mill after-treatments (Table 1). Separate PFI mill and Lampen mill beating modified fibre diameters to similar extents (Kibblewhite and Brookes, 1975).

The diameters of fibres in the surfaces of handsheets with similar densities were smaller after the Lampen mill post-treatment (Table 2). This difference was statistically significant only in handsheets prepared from the more heavily beaten pulps. Also, handsheet density was not increased further when pulps beaten for 12 000 revolutions in the PFI mill were processed for an additional 2 000 revolutions in the Lampen mill.

TABLE 1—Mean lengths and mean diameters of undried fibres

Beating revolutions PFI mill	Lampen mill	PFI mill	Handsheet density (kg/m³)	Fibre length Mean (mm)	S.E.	Fibre diameter Mean (μm)	S.E.
0	0	0	510	2.52	0.10	40.9	0.84
8 000	0	0	663	2.54	0.09	39.4	0.96
8 000	2 000	0	661	2.47	0.10	37.5	0.95
8 000	2 000	2 000	674	2.36*	0.11	38.3	0.85
16 000	0	0	691	2.41	0.10	40.4	0.87
16 000	2 000	0	681	2.37*	0.10	38.0	0.87

* Differ from unbeaten pulp at the 95% level

Standard errors calculated from $\sigma / \sqrt{n}$

TABLE 2—Mean diameters of fibres visible in handsheet surfaces, and incidence of removal of intact layers from the surfaces of pulp fibres (as percent of fibres examined)

Beating revolutions PFI mill	Lampen mill	Handsheet density (kg/m³)	Fibre diameter Mean (μm)	S.E.	Fines index	Outer layers intact	Outer layers partly removed	Number of fibres examined
2 000	2 000	638	27.6	0.52	163	96.3	3.7	621
4 000	0	640	28.3	0.56	147	98.3	1.7	509
12 000	2 000	669	25.3*	0.52	223	85.6	14.4**	600
12 000	0	670	28.1*	0.50	221	91.2	8.8**	519

* Differ from one another at the 99% level

** Differ from one another at the 90% level

Standard error calculated from $\sigma / \sqrt{n}$

Fibre Surface Structure

The 2 000-revolution Lampen mill post-treatments disrupted fibre surfaces to negligible extents when compared with the PFI mill treatments (Table 3). It is apparent that the Lampen mill treatments selectively removed material which had been loosened and/or partly stripped from surfaces by PFI mill beating. This conclusion is supported by a high incidence of partly removed "intact" surface layers (Table 2), and the general lack of penetration into fibre walls by the short Lampen mill post-treatments (Table 3).

TABLE 3—Effects of beating: A — on fibre surfaces* B — On handsheet physical evaluation data

Beating revolutions PFI mill	+ Lampen mill	+ PFI mill	$P\text{-}S_1$	S_1	S_{1-70}	S_{70-30}	S_2	Fines index**	Freeness (Csf)	Tear index	Apparent density (kg/m³)	Scattering coefficient (cm²/g)	Burst index	Air resistance (sec/100 cm³)	Breaking length (km)	Stretch (%)	Rupture energy (J/kg)
0	0	0	3	63	32	1	1	134	724	24.2	510	270	2.9	1	4.1	2.9	780
2 000	0	0	6	67	23	3	1	126	683	19.3	610	208	6.0	4	6.7	3.1	1320
2 000	2 000	0		54	31	13	2	163	681	14.7	638	179	6.3	5	7.9	2.8	1360
4 000	0	0		63	29	6	2	147	630	16.4	640	175	6.9	9	7.8	3.3	1610
4 000	2 000	0	2	53	36	6	3	155	642	14.1	648	167	6.7	8	8.3	2.8	1480
8 000	0	0		46	36	10	8	180	463	14.6	663	161	7.9	41	8.7	3.5	1920
8 000	2 000	0		45	37	9	9	182	512	13.1	661	158	7.5	30	9.1	3.1	1770
8 000	2 000	2 000		36	34	15	15	209	485	13.3	674	154	8.1	86	8.8	3.2	1780
12 000	0	0		35	27	20	18	221	313	13.6	670	153	8.5	123	8.8	3.6	1910
12 000	2 000	0		34	32	11	23	223	381	13.0	669	156	7.8	73	9.1	3.3	1850
16 000	0	0		21	26	24	29	261	206	14.6	691	146	8.5	466	9.3	3.7	2150
16 000	2 000	0		32	27	13	27	233	234	13.2	684	152	8.2	323	9.0	3.3	1880

* Results as percent of fibres examined

** Calculated from $\{S_1 + (S_{1-70} \times 2) + (S_{70-30} \times 3) + (S_2 \times 4)\}$

$P\text{-}S_1$ Primary wall partly removed to reveal the S_1 layer with microfibrils perpendicular to fibre axes

S_1 Primary wall largely removed to reveal the S_1 layer with microfibrils perpendicular to fibre axes

S_{1-70} S_1 layer partly removed to reveal microfibrils at angles of 90 to 70 degrees to fibre axes

S_{70-30} S_1 layer partly removed to reveal microfibrils at angles of 70 to 30 degrees to fibre axes

S_2 S_1 layer removed to reveal the S_2 layer

Fibre Internal Structure

Fibres were collapsed to similar extents in handsheets of the same density prepared from pulps beaten in the PFI mill, and in both the PFI and Lampen mills (Table 4). The number of wall fractures and zones of dislocation per unit length of fibre was statistically unchanged by the Lampen mill after-treatment.

Handsheet density and degrees of fibre collapse in handsheets increase with increasing extents of pulp beating (Hartler and Nyren, 1970; Kibblewhite, 1974; Page *et al.,* 1966). Thus, the fibre collapse values of Table 4 could be misleading because the method of analysis is apparently insensitive for handsheets with high densities and/or with high degrees of fibre collapse before beating. Degrees of fibre collapse in the laboratory kraft pulps examined in an earlier study were less variable, lower, and sensitive to changes in beating conditions (Kibblewhite and Brookes, 1975).

TABLE 4—Fibre collapse in handsheets

Data set*	Beating revolutions PFI mill	+ Lampen mill	Handsheet density (kg/m³)	Fibres uncollapsed Percent	S.E.	Fibres collapsed Percent	S.E.
I	2 000	2 000	638	9.3	1.13	41.0	2.35
	4 000	0	640	8.9	1.03	41.9	2.94
	12 000	2 000	669	5.1	0.68	44.7	2.62
	12 000	0	670	5.6	1.00	43.1	3.68
II	12 000	2 000	669	4.9	0.68	50.7	1.67
	12 000	0	670	5.3	0.96	50.8	2.21

* Data in Set I should not be compared with those in Set II

Standard error calculated from $\sigma / \sqrt{n}$

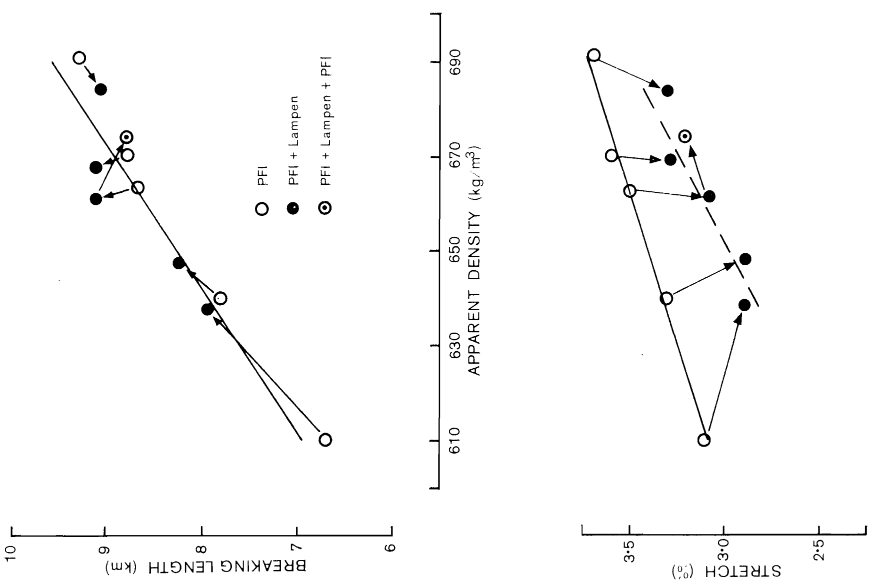
Handsheet Characteristics

Pulp freeness remained unchanged or increased when PFI-mill-beaten pulps were treated for an additional 2 000 revolutions in the Lampen ball mill (Table 3, Fig. 1).

Handsheet breaking length increased linearly with increasing sheet density and with decreasing sheet light-scattering coefficient as expected (Fig. 2, Table 3). PFI mill, and mixed PFI and Lampen mill beating produced similar handsheet breaking lengths for given density and scattering coefficient values. Handsheet stretch values, on the other hand, were decreased by up to 15 percent (Table 3, Fig. 2).

Handsheet burst index was consistently lower after the additional 2 000 revolutions of Lampen mill beating than after PFI mill processing alone (Figs. 3, 4). This behaviour contrasted with the effects of separate Lampen mill beating when handsheet burst properties were similar to those developed by PFI mill beating (Fig. 5). Tear index and air resistance were also lowered by the Lampen mill post-treatments (Table 3).

Regression analyses of data presented in Figs. 1 to 5 have been included in an unpublished report. The separate regressions drawn in Figs. 1 to 4 were different at the 95 percent level of confidence.



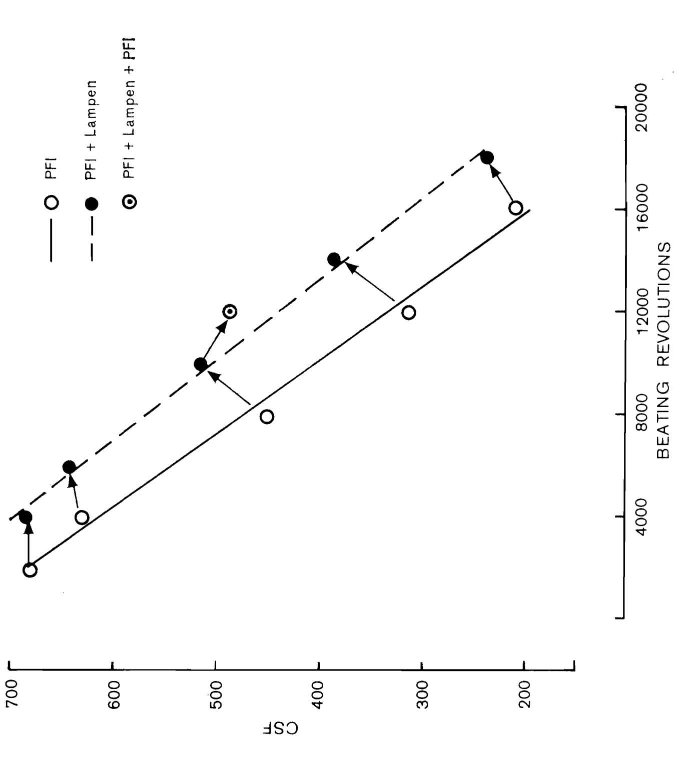


FIG. 1—(above) Pulp freeness (C.s.f.) and beating revolutions.

FIG. 2—(right) Breaking length, stretch and apparent density. In each figure paired treatments of PFI mill, and of PFI mill plus Lampen mill beatings are joined by arrows.

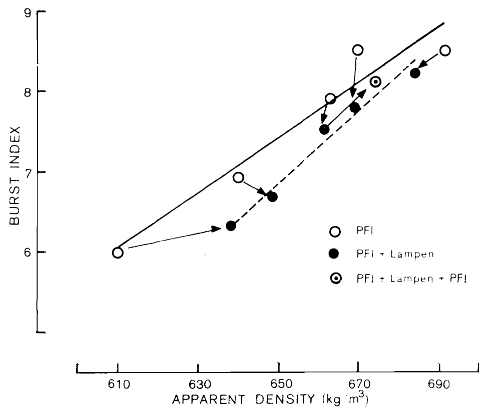


FIG. 3—Burst and apparent density.

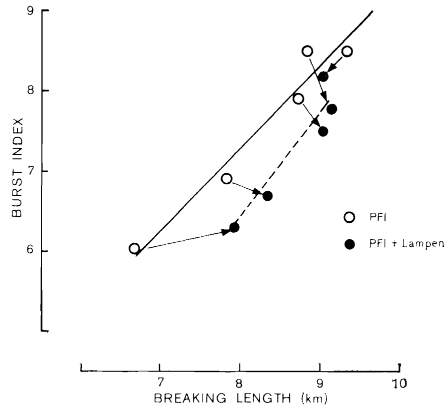


FIG. 4—Tasman radiata pine kraft — burst and breaking length.

Paired treatments of PFI mill and of PFI mill plus Lampen mill beatings are joined by arrows.

DISCUSSION

The main purpose of the study was to explain the lowering of handsheet stretch by Lampen mill treatment of pulps previously processed in other beaters and refiners. In addition to lowering handsheet stretch, the Lampen mill post-treatment:

(1) Reduced handsheet density after high levels of PFI mill beating;
(2) Decreased the diameters of fibres in handsheets after high levels of PFI mill beating;
(3) Decreased handsheet burst index;
(4) Increased pulp freeness.

Stretch and Tensile Properties

Earlier studies showed that Lampen mill beating produces handsheets with low stretch characteristics and that this is related to the selective development of internal fibre bonding by this beating treatment (Kibblewhite, 1974; Kibblewhite and Brookes, 1975). In handsheets of the same apparent density, fibres beaten in the Lampen ball mill were more collapsed and their diameters (in handsheets *in situ)* were less than those beaten in the PFI mill. High extents of collapse in handsheets prepared from the Lampen-processed pulps were balanced by narrower fibres in the XY plane, and thicker fibres in the vertical plane of handsheets (Kibblewhite and Brookes, 1975). Lampen mill beating apparently makes fibres more swollen, and fibre cross-sectional shapes more circular than corresponding PFI mill treatments. Thus, during handsheet preparation, extensive intrafibre wall folding and compaction probably takes place, which increases fibre thickness and decreases fibre diameter in dried webs.

Fibre diameters within handsheet surfaces were decreased by the short Lampen mill after-treatments (Table 2). This effect was greatest in the more heavily beaten pulps. These quantitative data were indirectly supported by the fact that the additional Lampen mill treatments caused handsheet density to decrease with increasing periods of PFI mill beating (Figs. 2, 3; Table 3). After 18 000 beating revolutions (PFI 16 000,

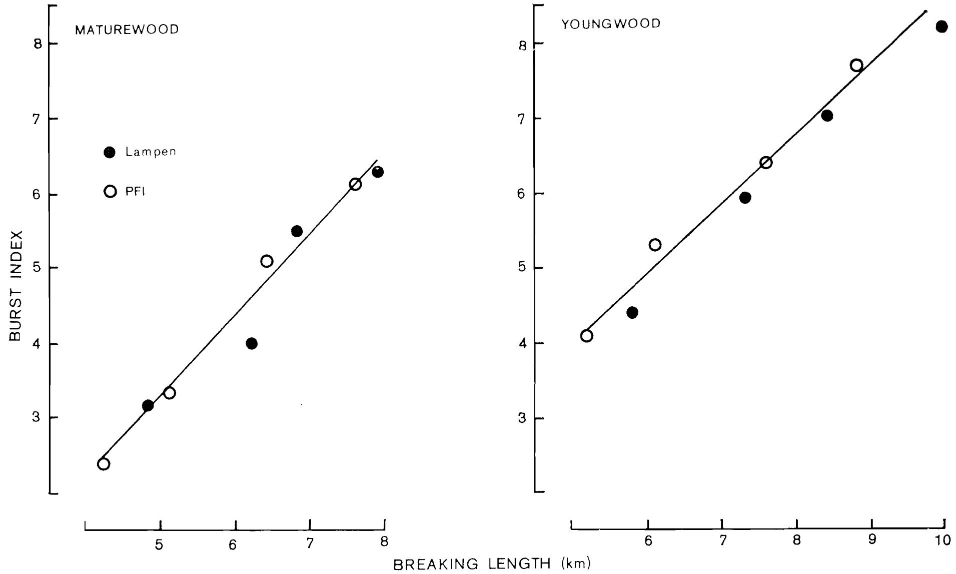


FIG. 5—Laboratory radiata pine kraft (Kibblewhite, 1973) — burst and breaking length.

Lampen 2 000), handsheet density was less than that obtained by 16 000 revolutions of PFI mill beating. Breaking length was generally increased by the additional Lampen treatments, while handsheet density or the extent of web consolidation was decreased (Fig. 2, Table 3). Handsheet tensile properties and density are normally increased by pulp beating (Kibblewhite, 1974). Thus, a re-distribution of fibre mass within fibres and within handsheets must have occurred as a result of the after-treatments. This re-distribution of fibre mass was also shown by the lowering of handsheet stretch with the Lampen mill treatments (Fig. 2, Table 3). The very significant changes in the diameters of fibres in handsheet surfaces brought about by the additional Lampen mill beatings showed that this treatment must modify internal fibre organisation, and consequently internal fibre bonding and handsheet stretch characteristics (Kibblewhite and Brookes, 1975). Handsheet stretch characteristics are strongly influenced by changes in internal fibre structure, particularly by factors which affect the extent of fibre elongation in strained webs (Kibblewhite, 1974; Kibblewhite and Brookes, 1975).

Handsheet Burst Strength

Handsheet burst strength (but not breaking length) was decreased by the Lampen mill after-treatments. This increase in breaking length and the corresponding decrease in burst strength has been explained in terms of a direct relationship between burst and stretch (Dinwoodie, 1965; Parsons, 1972; Sapp and Gillespie, 1947). The general behaviour of handsheet bursting strength only deviates from that of breaking length or tensile strength when stretch values are abnormal (Dinwoodie, 1965).

It is of interest that burst and breaking length deviated from one another only when pulps were beaten in the Lampen mill after treatment in the PFI mill (Fig. 4). Separate Lampen mill or PFI mill beatings of laboratory kraft pulps gave similar handsheet burst/breaking length regressions (Fig. 5).

Pulp Freeness

The increase in pulp freeness which occurred with the Lampen mill post-treatments (Fig. 1) was of interest, and was probably related to the following changes in fibre morphology and pulp fines contents.

1. The Lampen mill after-treatments did not penetrate into fibre surfaces (Table 3), but removed and disintegrated material which had been loosened and partly stripped from fibre surfaces by the preceding PFI mill treatments (Table 2). Thus, smaller fines, and smaller sheet-like lamellae fragments were available to fill interfibre voids in the pad of pulp formed in a freeness test (Kibblewhite, 1975).
2. The consistent drop in the diameters of undried fibres brought about by the Lampen mill treatments (Table 1), although not statistically significant, probably also increased interfibre voids and allowed freeness values to be increased.

CONCLUSIONS

Lampen mill beating of kraft pulps previously processed in a PFI mill, and in industrial Jordon and Sprout Waldron refiners, caused handsheet stretch but not breaking length to be decreased by 15 to 20 percent. This behaviour was explained by a re-distribution of mass, both within fibres and within handsheets, which increased the extents of internal fibre bonding and minimised fibre elongation in paper webs under strain.

The study showed that beating tackle typified by the Lampen ball and housing could possibly be designed to produce papers with low stretch and high tensile properties. Pulps processed in this manner would also have higher than normal freenesses — a pulp property which would be useful in the formation and rapid drainage of wet webs.

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