FIBRE, BEATING, AND PAPERMAKING PROPERTIES OF KRAFT PULPS FROM NEW ZEALAND BEECH (*NOTHOFAGUS*) SPECIES

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ABSTRACT

The fibre, beating, and papermaking properties of kraft pulps prepared from red beech (**Nothofagus fusca** (Hook. f.) Oerst.), hard beech (**Nothofagus truncata** (Col.) Ckn.), and two silver beech (**Nothofagus menziesii** (Hook. f.) Oerst.) wood samples were examined. The anatomical properties and chemical compositions of the wood samples and of fibre and vessel elements in wet pulps and **in situ** in handsheets were examined and related to beating effects and papermaking properties. The effects of pulp beating in a Lampen mill, and in a PFI mill at 10 and 25% stock concentrations were evaluated.

Wood chips from the red beech and silver beech samples had similar densities and similar anatomical characteristics. The hard beech chips, on the other hand, were denser by more than 100 kg/m^3 and contained proportionately fewer rays and vessels and more fibres than the silver beech and red beech chips. Methanol extractives, ash, lignin, and carbohydrate contents were similar for the silver beech and red beech samples. The high-density hard beech chips contained more methanol extractives and less lignin than the other species.

Pulp yields, fibre and vessel lengths, fibre and vessel diameters, and chemical compositions were in general similar for the red beech and the two silver beech pulps. The hard beech pulp, on the other hand, had the highest yield, the thickest fibre walls, and the longest and widest fibres and vessels.

Effects of beating on beech fibres were in general similar to those on softwood fibres. Ease of pulp beating was dependent on fibre dimensions, particularly fibre wall thickness, and on the conditions and types of beating. Depending on the species and the degree and conditions of pulp beating, wall material was progressively removed from fibre surfaces, fibrillated, and converted into fines. At the same time, fibre walls were progressively disorganised through the development of wall dislocations and delamination, fibres were made flexible and more able to collapse during papermaking, and fibre configurations (kinking) were modified.

Pulp beating at high stock concentrations selectively caused vessels to become fibre-like and ropy. Thus, pulps processed in this way should not be susceptible to vessel picking from paper surfaces during printing. This conclusion was supported by microscopic examination of vessel configurations in paper webs.

Trends for the strength and optical properties of paper prepared from the beech pulps were found to be generally predictable from a knowledge of their characteristics and the types of beating treatments given the pulps. General trends for the different species and the different beating conditions were similar to those obtained with softwood fibres. The exception was paper tearing-strength which increased rather than decreased with pulp beating. The typically low tearing-strengths of hardwood kraft pulps must be related to the shortness and narrow diameters of their fibres when compared with those of softwood fibres.

INTRODUCTION

The pulping and papermaking properties of the New Zealand *Nothofagus* (beech) species have been studied in some detail over the last 12 years (Corson, 1974; Kerr and Harwood, 1976; Uprichard, 1968; 1972; 1976a; b). The pulping properties of the four major species—silver beech (*Nothofagus menziesii* (Hook f.) Oerst), red beech (*Nothofagus fusca* (Hook. f.) Oerst.), hard beech (*Nothofagus truncata* (Col.) Ckn.), and mountain beech (*Nothofagus solandri* var. *Cliffortioides* (Hook. f.) Poole) — have been examined both separately and in composite samples. Of the various pulping processes examined (kraft, prehydrolysis kraft, neutral sulphite semichemical, soda, bisulphite, cold soda, and refiner) the manufacture of bleached kraft pulps holds the most promise (Uprichard, 1976b). The general conclusion of the pulping studies was that "*Nothofagus* pulps are similar to those of eucalypt pulps, and would be suitable for the manufacture of fine writing papers and, in admixture with long-fibred pulps, other grades of paper" (Uprichard, 1968).

The present study was designed to characterise kraft fibres from beech wood and determine how they may be modified to give papers with improved and/or selected properties. Particular emphasis was placed on the study of:

(1) Effects of different beating treatments on the morphology and on the surface and internal wall characteristics of beech kraft fibres;

(2) Interrelations between final paper properties and fibre modifications brought about by pulp beating;

(3) Behaviour of vessels in papermaking systems and their effects on paper properties and end uses.

EXPERIMENTAL

Wood Sample Selection and Characterisation

Wood samples were obtained from silver beech. red beech, and hard beech trees which were selected from the West Coast region on the basis of their densities. The trees were selected as part of a general survey of the wood properties of the beeches and other selected hardwoods in the West Coast Beech Scheme (Harris, 1975). Each composite chip sample consisted of wood from three to four trees of variable ages and dimensions, but roughly similar wood densities. Composite chip samples were prepared from hard beech (average density 584 kg/m^3) and red beech (485 kg/m^3), and two samples from silver beech (439 and 477 kg/m^3).

Methanol extractives (Uprichard, 1976b), ash (Tappi method T211 m-58), lignin (Kerr, 1976), and carbohydrates (Kibblewhite and Harwood, 1973) were determined by conventional procedures.

Volume percentages of rays, vessels, and fibres were obtained by weighing these "anatomical elements" cut from photomicrographs of transverse sections of chips.

Measurements of lumen diameter, wall thickness, and fibre diameter were made using procedures developed for use with a Reichart Visopan screen with slide-wire attachment described elsewhere (Kibblewhite and Brookes, 1977d). Light-microscope transverse sections were prepared from each of 10 chips per wood sample. Within each growth layer examined, five cells adjacent to one another at their tangential surfaces were measured at intervals of 6 to 10 cells in the radial direction. The first and last set of fibre measurements in each growth layer were made as close as possible to the boundaries with adjacent layers. The number of sets of five cells measured in each growth layer depended on its overall width. A total of 50 fibres was measured for each of the 10 sections examined per wood sample.

Pulping

Kraft pulps were processed in a 20-litre Haato Oy laboratory recirculatory digester, with liquor : wood ratio of 4 : 1. Pulps were processed for 60 min at 170°C and the liquor contained 37.5 g/litre Na_2O at a sulphidity of 23%. Time to maximum temperature was 90 min. Pulped chips were defibred at about 2% consistency with a propeller stirrer operating at 1425 rev/min for 10 min. Pulps were screened in a 0.25-mm slotted Packer screen, dewatered to an o.d. (oven-dried) pulp content of about 20%, and stored at about —17°C.

Pulp and Fibre Characterisation

Fibre length, fibre diameter, fibre surface structure, and pulp chemical composition were determined using procedures described in detail elsewhere (Kibblewhite and Brookes, 1977a). Estimates of fibre kink were made from the measurement of angular bends in projected fibre images (Kibblewhite and Brookes, 1975). Cross-sectional fibre dimensions in undried pulps were obtained using a semi-automated procedure outlined previously (Kibblewhite and Brookes, 1977d).

Pulp Beating

Pulps were beaten in a PFI mill at 10 and 25% stock concentrations, and in a Lampen mill at 3% stock concentration. For the PFI treatments, pulps were beaten at a load of 1.8 kg/cm, a relative roll and housing speed of 6 m/s, a pulp charge of 24 g o.d., and a temperature of 21° ± 2°C. Pulps were beaten in a Lampen mill in accordance with Appita standard method P202 m-75. Handsheets were prepared, and strength and optical properties determined using standard procedures.

RESULTS AND DISCUSSION

Wood Properties

Wood structure: Chips of the red beech and the two silver beech wood samples had similar densities and similar anatomical properties (Table 1). Hard beech chips, on the other hand, were denser by more than 100 kg/m^3, and contained proportionately fewer rays and vessels, and more fibres than the silver beech and red beech chips. The high densities of the hard beech chips reflected their high proportions of large-diametered, thick-walled fibres. In hard beech the low values for the derived parameters of fibres per gram and geometric external specific surface corresponded with the high wood and fibre densities of this sample (Table 1). Differences between anatomical elements in the hard beech, and those in the silver beech and red beech chips were in general statistically significant (Table 1).

Wood properties presented in Table 1 reflect values obtained for composite material made up of wood from selected trees. For this reason, these values cannot be expected to relate to the more general anatomical data listed by Uprichard (1968) and Orman and Harris (1964).

Chemical composition: Methanol extractives, ash, lignin, and carbohydrate contents were similar for the silver beech and red beech samples. The high-density hard beech chips contained more methanol extractives and less lignin than the other species examined (Table 2).

The low lignin content of the hard beech wood sample (Table 2) confirmed results obtained by Kerr (1976). The similar carbohydrate values obtained for all the beech wood samples are in agreement with the more detailed studies of Harwood (1973) and Uprichard *et al.* (1975). The high proportion of methanol extractives in the hard beech sample accords with Lloyd and Bristow (1975), Uprichard *et al.* (1975), and Kerr (1976).

Pulp Composition, and Fibre and Vessel Dimensions

Pulp yields, fibre and vessel lengths, fibre and vessel diameters, and chemical compositions were in general similar for the red beech and the two silver beech pulps (Table 3). The hard beech pulp, on the other hand, had the highest yield and the longest and widest fibres and vessels. In contrast, lignin and carbohydrate contents of the hard beech pulp were similar to those of the silver beech and red beech pulps. Many of the differences between the hard beech, and the silver beech and red beech pulps were statistically significant, viz, fibre and vessel lengths, and fibre diameters.

Measurement of the cross-sectional dimensions of undried pulps showed that wall thicknesses, lumen diameters, and fibre diameters were similar for the unbeaten red beech and silver beech pulps (Table 4). The values for hard beech differed as wall thicknesses and fibre diameters were higher, and lumen diameters were lower than those of the silver beech and red beech pulps. Relative cross-sectional dimension trends, but not absolute magnitudes, were similar to those obtained for fibres measured *in situ* in wood chips (Table 1).

Beating Effects on Fibre and Vessel Properties

Fibre dimensions: PFI mill beating at 10 and 25% stock concentration, and Lampen mill beating, did not change significantly the lengths and diameters of the silver beech and hard beech pulp fibres (Table 5). Cross-sectional fibre dimensions were, however, modified by pulp beating (Table 4). Wall thicknesses were increased and lumen diameters were correspondingly decreased by pulp beating and, in particular, by pulp beating at high stock concentration. Corresponding fibre diameters, on the other hand, were unchanged by pulp beating except for the hard beech sample (Table 4). These hard beech diameter values contradicted those obtained using an alternative measurement procedure (Table 3).

Effects of beating on fibre dimensions were in general as expected, with fibre

TABLE 1—Wood chip samples — Wood element dimensions and proportions

Beech species	Chip density (kg/m³)	Volume (%) Rays	Vessels	Fibres	Fibre dimensions Diameter (μm)	Lumen (μm)	Lumen to diameter ratio	Wall thickness (μm)	Fibres per gram of pulp	Geometric external fibre specific surface (cm²/g)
Silver	439	11.3	33.7	54.9**	15.8	9.1	0.58	3.4*	3.3×10^6	1262
Silver	477	9.8	33.7	56.5	15.4*	8.7	0.56	3.3*	3.4×10^6	1271
Red	455	10.1	33.0	54.9**	15.7**	8.7	0.55	3.4*	3.2×10^6	1225
Hard	584	7.4	27.5	65.1	18.1	7.5	0.41	5.3	1.7×10^6	889

* Differs from hard beech value at 95% level of confidence
** Differs from hard beech value at 90% level of confidence

TABLE 2—Wood chip samples — Chemical composition

Beech species	Chip density (kg/m³)	Methanol extractives* (%)	Ash* (%)	Acid-soluble lignin* (%)	Klason lignin* (%)	Carbohydrates (% of total) Rhamnan	Arabinan	Xylan	Mannan	Galactan	Glucan
Silver	439	5.1	0.25	5.0	22.1	0.4	1.7	22.6	2.0	1.7	71.6
Silver	477	4.9	0.25	4.9	21.8	0.2	1.2	22.8	1.8	1.3	72.7
Red	455	5.0	0.28	4.8	18.9	0.5	1.0	24.8	2.1	1.2	70.4
Hard	584	7.3	0.28	4.4	15.9	0.4	1.0	24.6	1.9	1.3	70.8

* Values refer to percentage of original o.d. wood

TABLE 3—Pulp and fibre characteristics

Beech species	Chip density (kg/m³)	Pulp yield (%)	Fibre length* Unbeaten (mm)	Fibre length* Beaten (mm)	Fibre diameter** Unbeaten (μm)	Fibre diameter** Beaten (μm)	Vessel length† (mm)	Vessel diameter‡ (μm	Pulp chemical composition: Klason lignin (% o.d. pulp)	Acid-soluble lignin (% o.d. pulp)	Carbohydrates in hydrolysates (%) Arabinan	Xylan	Mannan	Glucan
Silver	439	47	0.77	0.74	19.6	20.2	0.61	70.6	1.0	1.3	0.2	16.9	0.2	82.7
Silver	477	49	0.78	0.78	18.9	19.0	0.59	62.8	0.8	1.2	0.2	15.9	0.1	83.8
Red	455	49	0.78	0.80	19.5	19.0	0.64	72.7	0.9	1.2	0.6	17.7	0.1	81.6
Hard	584	52	0.92	0.91	21.4	21.7	0.75	73.6	1.0	1.2	0.3	16.4	0.1	83.2

* Different at 95% level if fibre lengths differ by more than 0.06mm
** Different at 95% level if fibre diameters differ by more than 1.9 μm
† Different at 95% level if vessel lengths differ by more than 0.048 mm
‡ Different at 95% level if vessel diameters differ by more than 6.4 μm

lengths and diameters remaining unchanged, and wall thicknesses increasing into fibre lumens (Tables 3, 4, 5) (Fig. 1). These trends were in agreement with those obtained with softwood radiata pine (*Pinus radiata* D. Don) kraft and bisulphite fibres (Kibblewhite and Brookes, 1977a; d).

Fibre kinking: Fibres in the unbeaten hard beech pulp were kinked to a slightly greater extent than those in the corresponding silver beech pulp (Table 6). Beating at high stock concentration caused fibre kink to be substantially increased (Table 6). The

TABLE 4—Dimensions of beech fibres in undried pulps

Beech species	Chip density (kg/m^3)	Beating conditions	Beating revs	Wall thickness (μm)	Lumen diameter (μm)	Fibre diameter (μm)	Wall volume per unit length of fibre
Silver	439	Unbeaten	0	4.67	8.85	18.2	65.9
		PFI mill (10%)	8000	4.89	8.41	18.2	70.9
		PFI mill (25%)	8000	5.60	7.13	18.3	74.8
Red	455	Unbeaten	0	4.82	8.86	18.5	69.2
		PFI mill (10%)	8000	5.18	8.12	18.5	73.4
Hard	584	Unbeaten	0	6.15	8.13	20.4	93.1
		PFI mill (10%)	8000	6.33	6.20	18.9	83.2
		PFI mill (25%)	8000	6.46	5.83	18.8	85.2

NOTE: (1) Mean wall thicknesses were different at the 95% level if they differed by more than 0.44 μm
(2) Mean lumen diameters were different at the 95% level if they differed by more than 0.98 μm
(3) Mean fibre diameters were different at the 95% level if they differed by more than 1.40 μm
(4) Mean wall volumes were different at the 95% level if they differed by more than 11.7 units

TABLE 5—Pulp fibre dimensions — Beater effects

Beech species	Chip density (kg/m^3)	Beating conditions	Beating revs	Fibre length* (mm)	Fibre diameter** (μm)
Silver	439	Unbeaten	0	0.77	19.6
		PFI mill (10%)	8000	0.74	20.2
		PFI mill (25%)	8000	0.75	18.6
		Lampen mill	8000	0.77	20.6
Hard	584	Unbeaten	0	0.92	21.4
		PFI mill (10%)	8000	0.91	21.7
		PFI mill (25%)	8000	0.92	21.3
		Lampen mill	8000	0.91	21.6

* Different at 95% level if fibre lengths differ by more than 0.06 mm
** Different at 95% level if fibre diameters differ by more than 1.9 μm

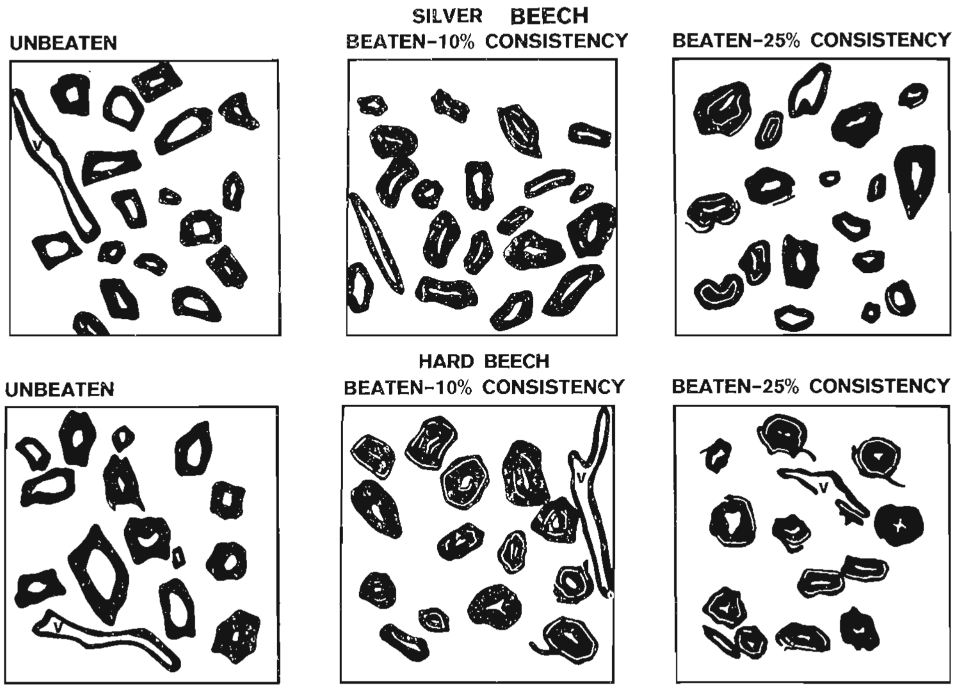


FIG. 1—Fibre cross-sections in unbeaten and beaten (PFI mill at 8000 rev) hard beech and silver beech pulps. Vessel fragments are indicated (v).

TABLE 6—Fibre kinking

Beech species	Beating revs	Beating consistency %	Chip density (kg/m^3)	Number of kinks Per fibre	Number of kinks Per mm of fibre	Angle of kink-percentage of total kinks 10-19	20-44	45-89	90-180	Kink index Per fibre	Kink index Per mm of fibre*
Silver	0	—	439	3.18	4.13	66.0	30.5	3.5		3.36	4.37
	8000	10	439	3.66	4.95	68.3	30.9	0.8		3.59	4.85
	8000	25	439	5.07	6.85	46.3	50.9	2.8		5.83	7.88
Hard	0	—	584	3.67	3.99	59.6	36.0	4.4		4.89	5.31
	8000	10	584	3.98	4.37	68.6	29.4	2.0		4.82	5.30
	8000	25	584	5.79	6.36	47.7	47.8	4.5		8.24	9.06

* Different at the 95% level if differ by more than 1.54 units

significant extent of kink brought about by high consistency beating is evident in the series of micrographs in Fig. 2 and 3. The greater length of the hard beech fibres is also apparent in these micrographs.

The marked increase in fibre kinking brought about by pulp beating at high stock concentration (Table 6) was surprising in view of the general absence of such an effect with softwood fibres (Kibblewhite and Brookes, 1975). More recent studies (R. P. Kibblewhite, unpublished data) have shown, however, that extents of fibre kink developed in softwood fibres depend on the magnitude of the load applied to the PFI mill. A degree of fibre kink was developed in the softwood pulps when the applied load was increased from 1.8 to 5 kg/cm. The large extent of kink developed in the beech fibres by high-consistency pulp beating was apparently related to their short lengths and narrow diameters compared with those of softwood fibres. The numbers of fibre-to-fibre interactions were, therefore, very high in the beech pulps during beating.

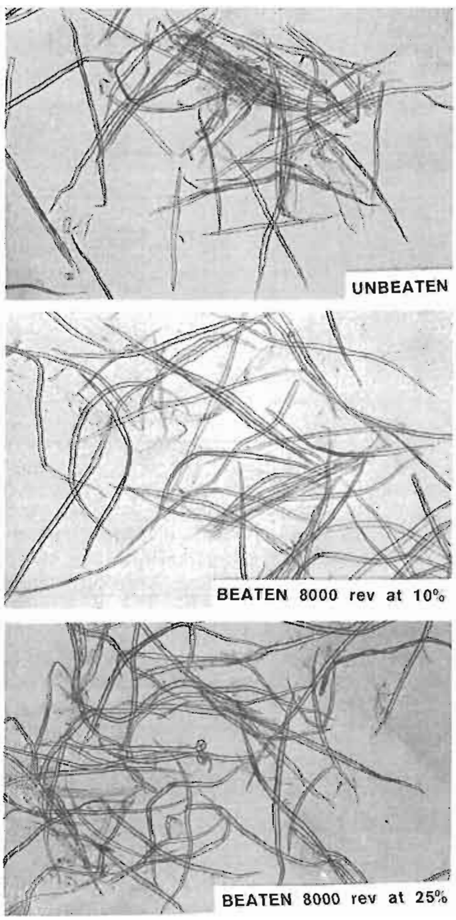


FIG. 2—Effects of beating hard beech pulps.

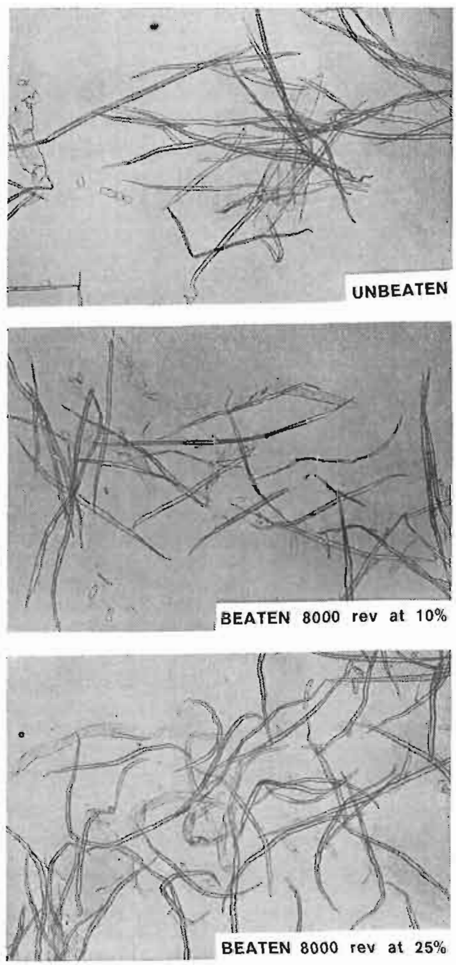


FIG. 3—Effects of beating silver beech pulps.

Fibre wall organisation: Numbers of wall dislocations were greatest in the hard beech fibres, and increased with pulp beating and with increasing stock concentrations at which the pulps were beaten (Fig. 4). These differences were visually obvious and quantitative measurements were not made.

Extents of wall delamination were also greatest in the hard beech pulps, and increased with pulp beating as well as with increased stock concentrations at which pulps were beaten (Fig. 1 and 5). The increased extents of wall delamination developed by pulp beating corresponded with the measured expansion of fibre walls into fibre lumens (Table 4).

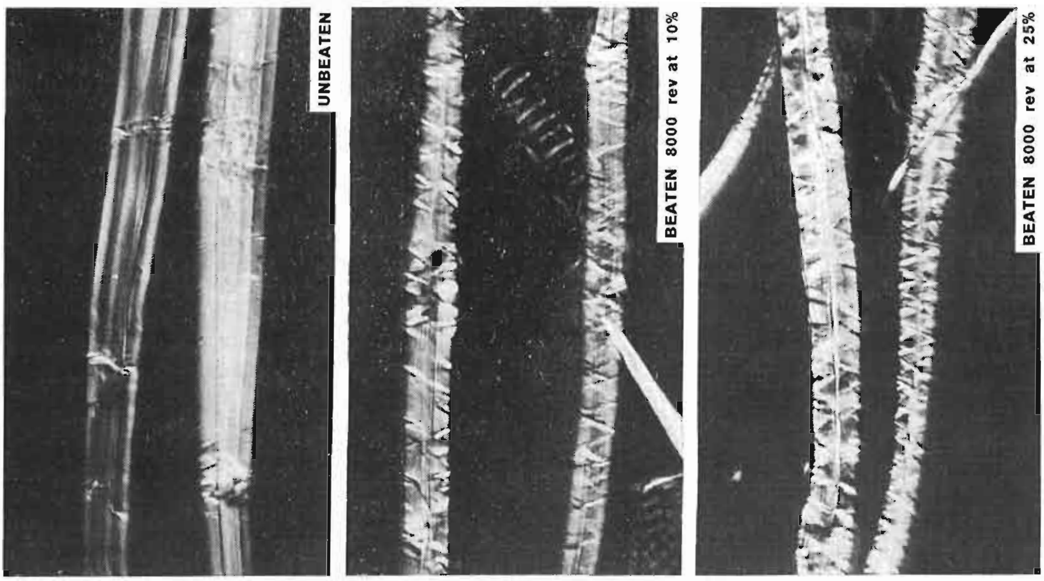


FIG. 4 (right)—Effects of beating on the development of wall dislocations and wall delaminations in hard beech fibres.

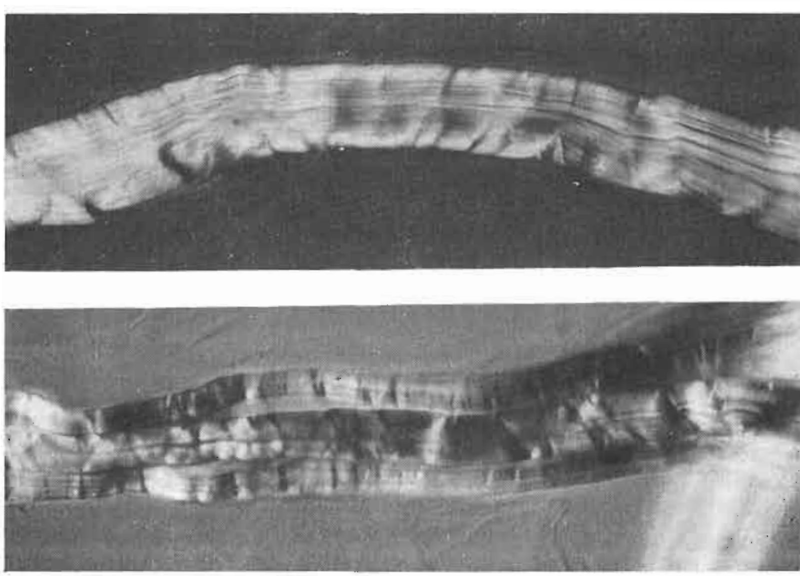


FIG. 5 (below)—Wall delamination in hard beech fibres beaten for 8000 rev at 25% stock concentration.

Fibre surface structure: Over 94% of the unbeaten red beech and silver beech fibres examined were covered or partly covered with the primary wall layer, whereas the hard beech fibres were virtually void of the primary wall layer on their surfaces (Table 7). Only 20% of the hard beech fibres examined showed primary wall fragments attached to their surfaces. This virtual absence of primary wall material on the surfaces of the hard beech fibres was surprising. A likely explanation is that this layer was more readily removed from the thick-walled and relatively stiff hard beech fibres during pulping and/or subsequent defibration, washing, and screening operations.

TABLE 7—Beating effect on fibre surfaces* — Percentage of fibres examined

Beech species	Wood density (kg/m³)	Beating revs PFI mill (10%)	P	P-S_1	S_1	S_{1-70}	S_{70-30}	S_T	S_2	Fines index†
Silver	439	0	82	16	1	1	0	0	0	3
		1000	2	31	51	13	1	2	0	88
		2000	0	18	65	11	6	0	0	105
		4000	0	10	49	30	8	2	1	146
		8000	0	4	43	29	18	3	3	182
		12000	0	3	23	30	28	10	6	237
Silver	477	0	85	11	3	1	0	0	0	5
		1000	1	37	51	9	2	0	0	75
		2000	4	48	38	9	0	0	1	161
		4000	0	16	55	17	12	0	0	125
		8000	0	4	46	28	13	6	3	180
		12000	0	7	31	43	16	0	3	180
Red	455	0	78	16	3	2	1	0	0	10
		1000	0	40	45	14	1	0	0	76
		2000	0	12	66	19	3	0	0	113
		4000	0	3	49	37	11	0	0	156
		8000	0	10	33	40	13	1	3	171
		12000	1	12	38	32	8	4	5	167
Hard	584	0	0	20	56	24	0	0	0	104
		1000	0	9	68	20	3	0	0	117
		2000	1	14	55	23	5	1	1	125
		4000	0	6	42	21	23	5	3	188
		8000	0	0	30	36	17	7	10	231
		12000	0	4	20	19	23	13	21	284

* P Primary wall largely intact

P-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_T Transition between S_{70-30} and S_2. Microfibrils at angles of less than 30 degrees to fibre axes but general wall textures not those of true S_2 layer

S_2 S_1 layer removed to reveal S_2 layer

† Calculated from: $[S_1 + (S_{1-70} \times 2) + (S_{70-30} \times 3) + (S_T \times 4) + (S_2 \times 5)]$

Effects of pulp beating were to progressively remove wall lamellae from fibre surfaces (Table 7). Fines indices are a measure of the extents of removal of wall material from the surfaces of pulp fibres (Kibblewhite, 1975); they were greatest for hard beech, and least for the red beech and the high-density (477 kg/m^3) silver beech pulps (Table 7, Fig. 6). The differences in the hard beech pulps can be related to the high initial fines index of the unbeaten fibres (Table 7). In Fig. 6 the slopes for the hard beech pulp, and the red beech and silver beech pulps, were statistically similar (Kibblewhite and Brookes, 1977c) and, therefore, similar quantities but different qualities of wall material were removed from fibre surfaces by the beating treatment.

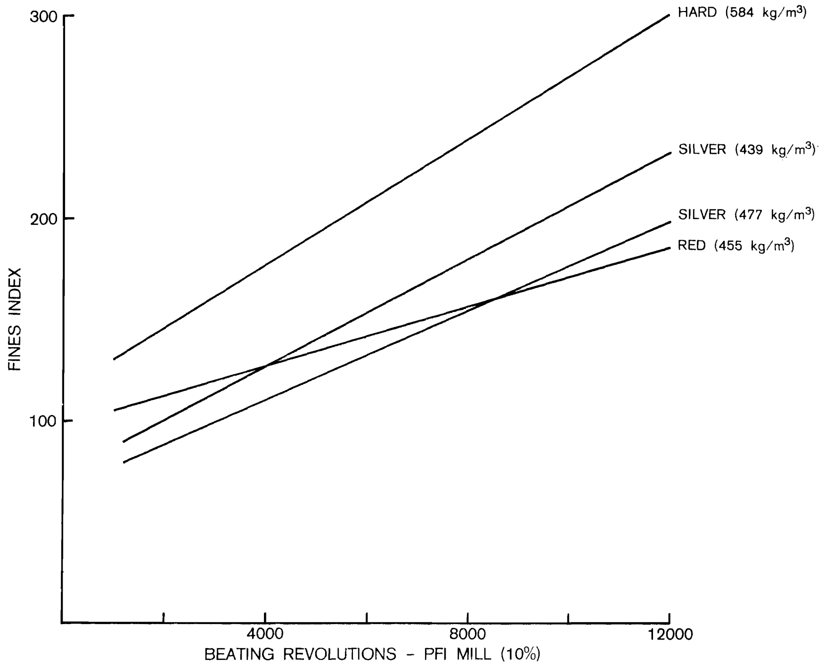


FIG. 6—Beech pulps — Beating effects on fines indices.

Beating in the PFI mill at 10% stock concentration removed more material from fibre surfaces than PFI mill beating at 25% stock concentration (Fig. 7). Lampen mill beating removed the least amount of material. The removal of more material from fibre surfaces by pulp beating at 10% than at 25% stock concentration was in agreement with earlier studies of radiata pine kraft fibres (Kibblewhite, 1972), but contrasted with trends obtained for similar bisulphite fibres (Kibblewhite and Brookes, 1977a). The relatively small amount of fines produced by Lampen mill beating was in agreement with trends shown for similar studies of softwood fibres (Kibblewhite, 1972; Kibblewhite and Brookes, 1977a).

The incidence of removal of "intact" layers (Kibblewhite, 1975) from fibre surfaces was similar for the silver beech and hard beech pulps, and for Lampen mill beating and PFI mill beating at 10 and 25% stock concentrations (Kibblewhite and Brookes, 1977c).

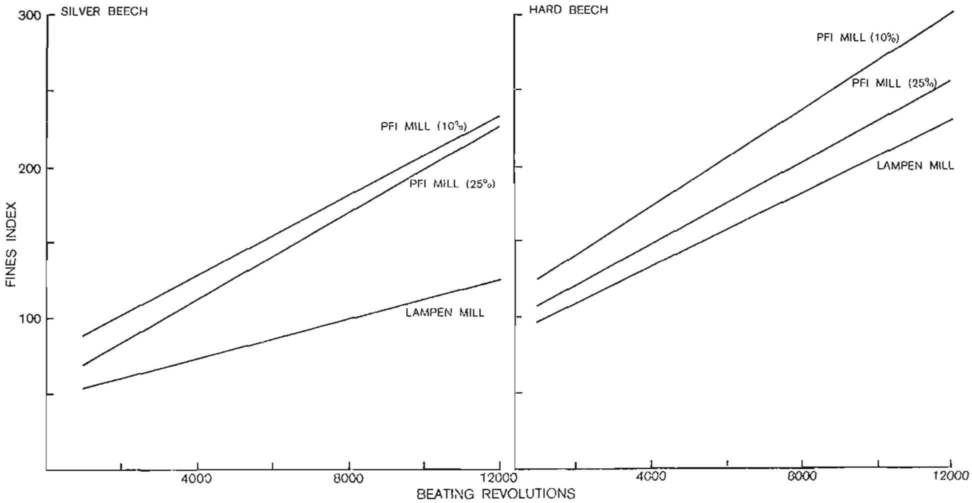


FIG. 7—Beater effects on beech pulps — Fines index and beating revolutions.

Vessels: Pulp beating in the PFI mill at 10 or 25% stock concentration caused vessels to become more fibre-like as their diameters were decreased (Fig. 8) and their appearance became "ropy" (Fig. 9). Beating at high stock concentration was most effective in making the vessels more fibre-like.

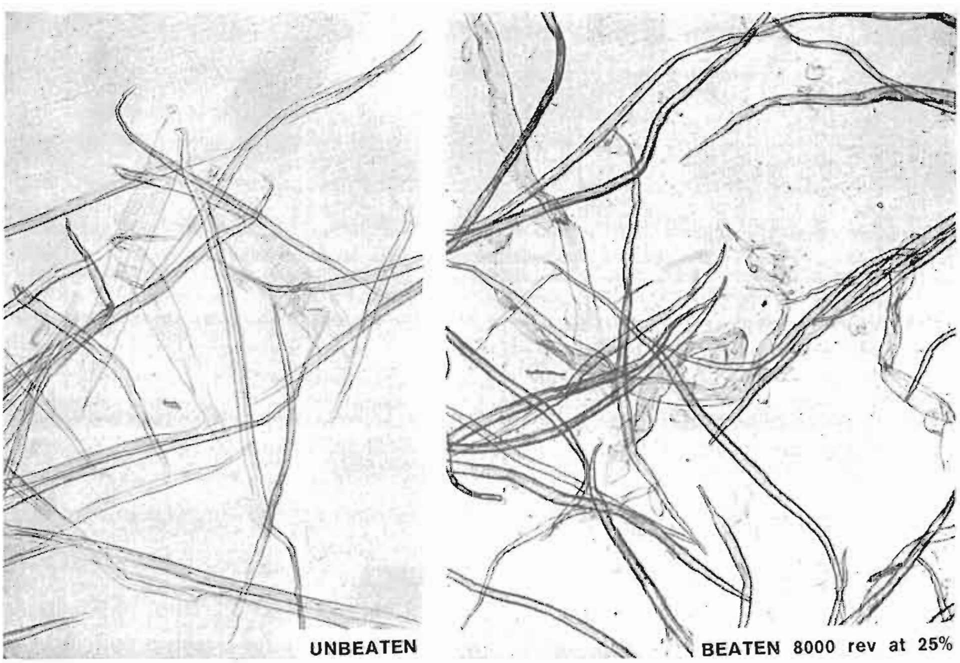


FIG. 8—Effects of beating on vessel morphology. Note the narrower diameters and the more fibre-like appearance of vessels in the beaten pulp.

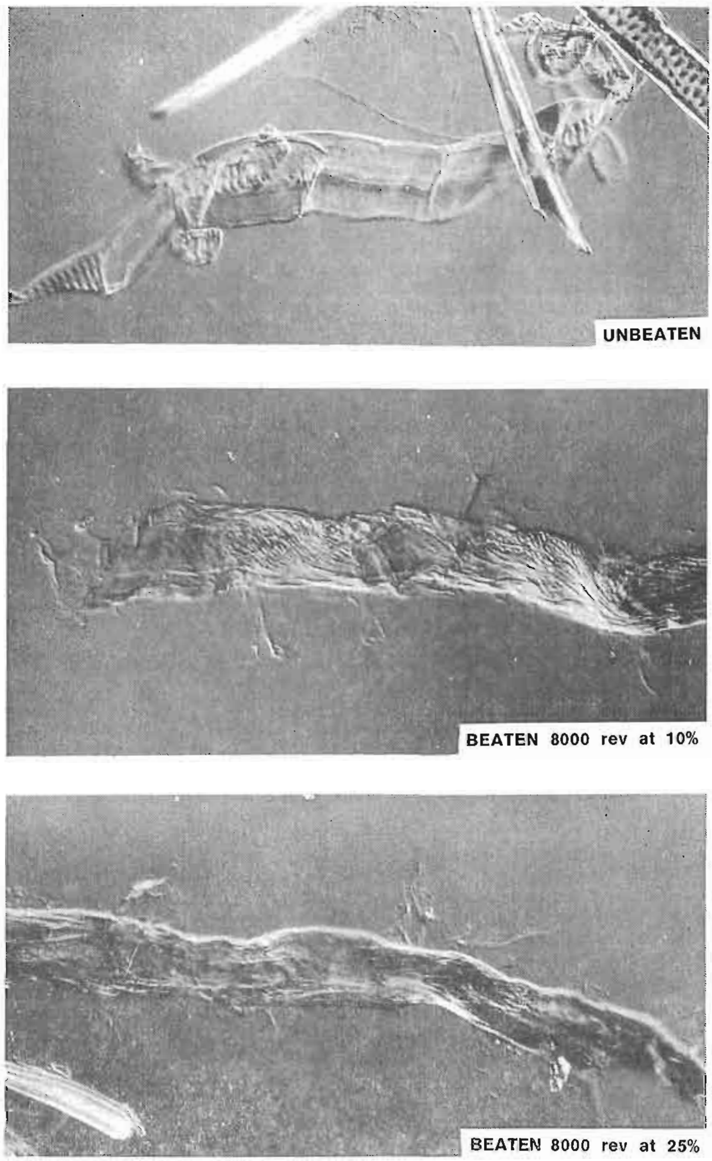
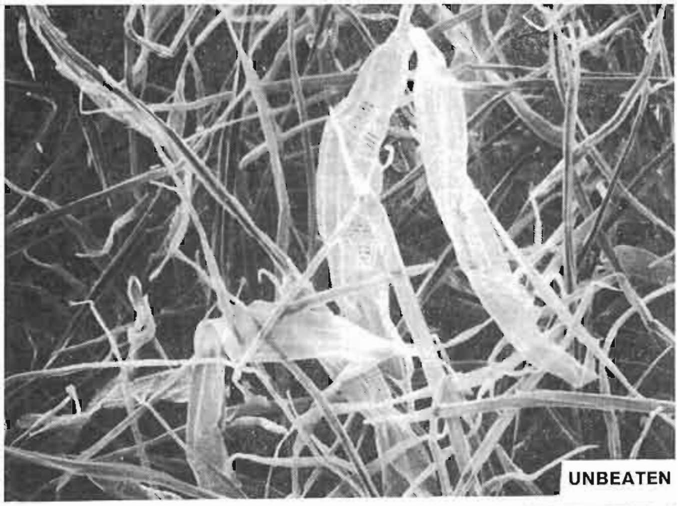
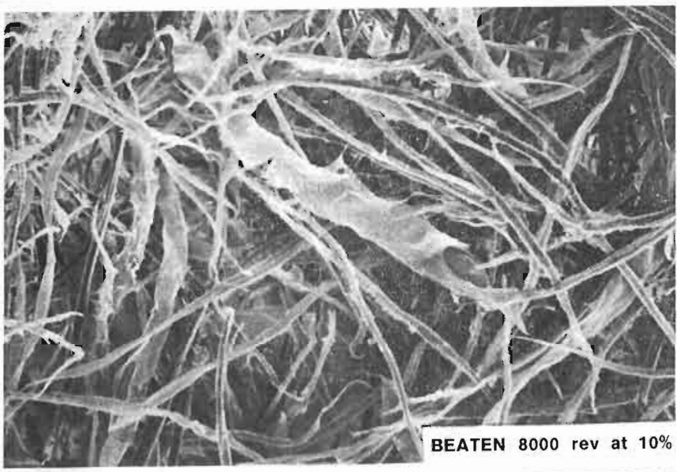


FIG. 9—Effects of beating on vessel morphology. Beating at 25% stock concentration was most effective in making vessels fibre-like and "ropy" in appearance.

Web organisation and behaviour: Fibre and vessel modifications brought about by pulp beating were evident through the examination of undried, unpressed PBW webs (Kibblewhite, 1972) (Fig. 10). Unbeaten fibres appeared straight, inflexible, and unfibrillated when compared with those in webs produced from beaten pulps. Fibre entanglement and interaction were greatest in the beaten pulps. Vessel diameters were contracted and their appearance became "ropy" through pulp beating.


UNBEATEN


BEATEN 8000 rev at 10%

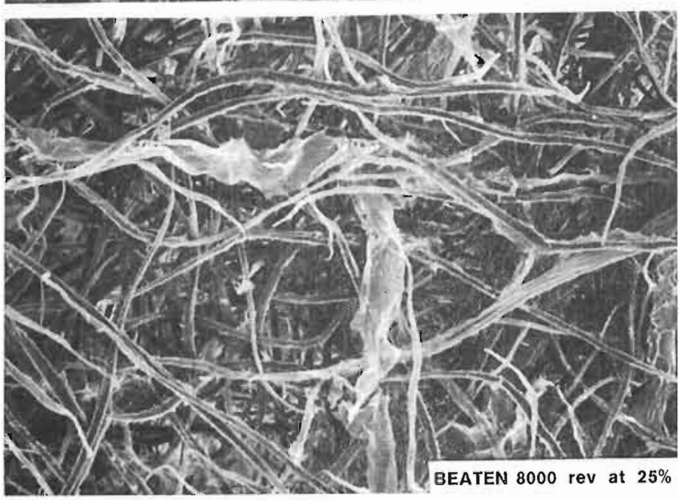

BEATEN 8000 rev at 25%

FIG. 10 (left)—Configuration of beaten and unbeaten fibres and vessels in unbonded (PBW — Kibblewhite, 1972) paper webs. Vessels become progressively more fibre-like with pulp beating at the higher stock concentrations.

Effects of pulp beating on web consolidation by the development of fibre flexibility were examined through the study of air-dried, unpressed PBA webs (Kibblewhite, 1972). Lightly beaten pulps gave PBA webs which were unconsolidated and contained fibres with very little interfibre contact and bonding (Fig. 11). Similar effects occurred

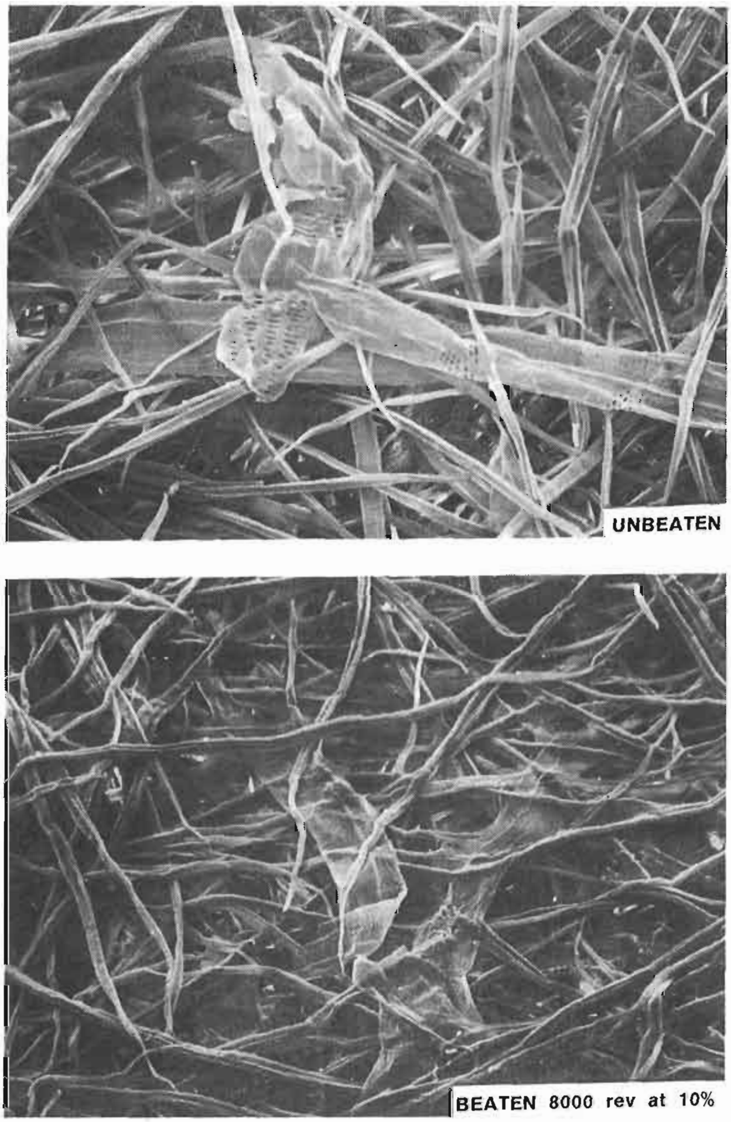


FIG. 11—Configurations of unbeaten and beaten fibres and vessels in unpressed, air-dried (PBA — Kibblewhite, 1972) paper webs. Hard beech pulps show effects of beating on web consolidation.

in the vessels, and the largest proportions of their surfaces were not bonded to adjacent fibres and vessels. The converse occurred in beaten pulps and improvements in the extents of bonding were evident (Fig. 11). Web pressing during papermaking vastly improved the extents of bonding, as expected (Fig. 12). The more heavily beaten pulps showed high degrees of fibre and vessel bonding within the surfaces of paper webs. The effectiveness of pulp beating at high stock concentration in causing vessel diameters to be contracted should be important in reducing vessel picking from paper surfaces during printing operations. It was generally difficult to identify vessels in the surfaces of sheets prepared from pulps processed at high stock concentration (Fig. 12).

Paper Strength and Optical Properties

Graphical and regression analyses data, and analyses of variance and tests of significance of differences between regression slopes and intercepts have been presented in an internal report of the Forest Research Institute (Kibblewhite and Brookes, 1977c). Much of this information has been excluded from the present paper but is available on request.

Effects of species: Differences in the paper strength and optical properties of the four beech pulps were as expected (Uprichard, 1976b), and were confined to differences between hard beech and the other pulps examined. For given sheet densities hard beech pulps gave the highest stretch values and the lowest scattering coefficients (Table 8). Similar trends were obtained for tear indices and scattering coefficients when compared at the same tensile strengths. An exception to these trends was the apparent low tensile strength of handsheets prepared from the red beech pulp (Table 8). The tensile/density, elastic modulus/density, and burst/tensile relations of the hard beech pulps were generally similar to those of the red beech and silver beech pulps. The low scattering coefficients and the high handsheet-stretch values obtained with the hard beech pulps can be respectively related to low fibre specific surfaces (Table 2), and high extents of fibre wall disorganisation (Fig. 1, 4, 5).

Effects of beaters: Effects of PFI mill beating at stock concentrations of 10 and 25%, and Lampen mill beating at 3% stock concentration, were similar to those obtained for softwood kraft pulps (Kibblewhite, 1974; Kibblewhite and Brookes, 1977b). Beating in the PFI mill at a stock concentration of 25% gave the lowest handsheet tensile strength and elastic modulus, and the highest stretch and tearing index (Table 8) (Kibblewhite and Brookes, 1977c). Lampen mill beating, on the other hand, gave handsheets with the lowest stretch and tear index, and probably the highest elastic modulus. Tensile strengths were generally similar for pulps beaten in the Lampen mill and in the PFI mill at 10% stock concentration. Different burst/tensile regressions were obtained for pulps processed using the three different beating conditions (Kibblewhite and Brookes, 1977c) (Table 8). This result was not unexpected, and can be related to the different beater effects on fibre wall structure and paper stretch properties (Kibblewhite, 1976) (Fig. 1, 4).

For given tensile strengths, handsheet light-scattering coefficients decreased most

FIG. 12 (right)—Configurations of silver beech fibres and vessels in standard handsheets. Progressive effects on vessel morphology of pulp beating are evident.

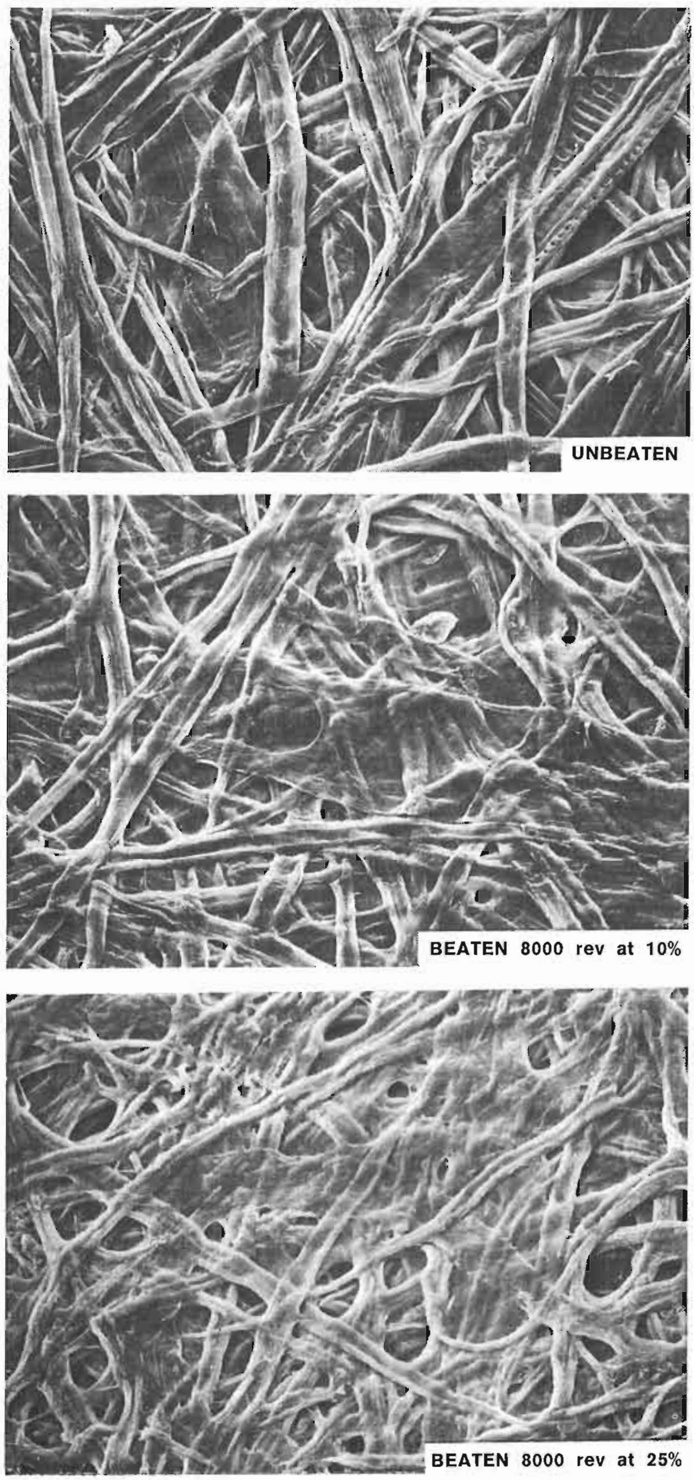

UNBEATEN
BEATEN 8000 rev at 10%
BEATEN 8000 rev at 25%

TABLE 8 - Physical evaluation data for beech pulps - Effects of beaters

BEECH SPECIES	CHIP DENSITY (kg/m^3)	BEATER AND PULP CONSISTENCY	BEATING (rev)	FREENESS (Csf)	TEAR INDEX (mN.m^2/g)	APPARENT DENSITY (kg/m^3)	SCATTERING COEFFICIENT (cm^2/g)	BURST INDEX (KPa.m^3/g)	AIR RESISTANCE (sec/100 cm^3)	TENSILE INDEX (N.m/g)	STRETCH (%)	t.e.a. (J/m^2)	ELASTIC MODULUS (MN/m^2)	BRIGHTNESS (%)
Silver	439	PFI mill @ 10%	1000	423	8.4	677	288	4.5	42	71	2.9	78	4800	28.8
			2000	347	9.0	714	258	4.9	78	79	3.4	100	5000	27.6
			4000	263	8.9	753	200	6.7	268	87	3.9	127	5100	24.9
			8000	133	9.3	785	157	7.8	>20 min	94	4.6	165	5400	22.2
			12000	94	9.2	811	127	8.0	>20 min	95	4.7	171	5300	20.1
Silver	439	PFI mill @ 25%	1000	532	8.0	712	264	3.7	23	55	3.4	77	4100	26.8
			2000	506	8.7	726	224	4.7	33	64	4.1	109	4100	25.6
			4000	419	9.4	750	190	5.8	65	73	4.7	138	4300	23.4
			8000	214	10.0	775	153	5.9	241	74	5.2	159	4800	20.7
			12000	173	9.2	788	145	6.4	1044	81	5.5	175	5000	20.4
Silver	439	Lampen mill @ 3%	1000	478	6.5	660	316	3.6	22	58	1.9	39	4400	29.9
			2000	467	6.9	691	275	4.2	28	69	2.3	60	4500	28.6
			4000	432	8.0	710	252	5.0	35	80	2.7	80	5100	27.1
			8000	371	8.4	723	221	5.9	50	84	3.1	99	5300	25.3
			12000	349	8.4	736	199	6.2	66	88	3.3	111	5300	24.3
Hard	584	PFI mill @ 10%	1000	597	6.6	557	221	2.1	<2	43	1.9	30	3300	25.6
			2000	565	8.3	608	221	3.4	3	54	2.5	51	3900	23.9
			4000	418	10.2	646	199	4.3	11	64	3.3	80	4100	22.4
			8000	199	10.7	677	169	5.2	115	74	3.9	111	4400	21.3
			12000	92	11.7	711	152	6.6	>20 min	77	4.3	126	4400	19.8
Hard	584	PFI mill @ 25%	1000	691	5.8	580	234	2.0	<2	38	2.3	35	2900	23.6
			2000	646	7.3	613	205	2.6	<2	44	3.0	53	3300	22.4
			4000	559	8.2	642	179	3.2	4	50	3.6	77	3500	21.1
			8000	357	9.7	672	160	3.7	20	53	4.1	90	3600	20.2
			12000	243	10.4	692	156	4.0	99	56	4.5	107	3700	19.8
Hard	584	Lampen mill @ 3%	1000	657	5.7	569	255	2.2	<2	43	1.5	22	3700	24.4
			2000	645	6.7	596	222	2.6	<2	50	1.9	36	3800	23.6
			4000	623	8.4	613	202	3.2	<2	57	2.2	48	4000	22.4
			8000	556	8.5	632	187	3.8	3	61	2.5	61	4100	21.1
			12000	489	9.0	643	179	3.9	3	63	2.6	63	4400	20.7
Silver	477	PFI mill @ 10%	1000	459	6.9	618	322	3.3	12	57	2.4	51	3800	32.4
			2000	418	8.5	668	268	4.6	24	71	3.0	81	4600	29.9
			4000	318	9.2	705	223	5.7	81	82	3.7	116	4800	27.8
			8000	143	9.0	740	195	7.0	551	86	4.1	134	5100	25.8
			12000	70	9.8	773	158	7.5	>20 min	88	4.6	154	4900	23.3
Red	455	PFI mill @ 10%	1000	426	8.7	677	264	4.6	28	65	2.7	67	4600	28.8
			2000	381	9.0	710	238	5.4	65	74	3.4	93	4900	26.7
			4000	290	9.4	731	212	6.2	150	82	3.8	119	5000	25.5
			8000	114	9.2	779	152	7.6	>20 min	90	4.6	159	5600	22.0
			12000	87	9.6	795	132	8.0	>20 min	80	4.3	147	5900	20.1

rapidly with PFI mill beating at 25% stock concentration (Table 8). Sheet density/scattering coefficient relationships, on the other hand, were only marginally different for the three beating treatments (Kibblewhite and Brookes, 1977c). This suggests that factors other than bonded area and fibre dimensions can influence handsheet tensile strength. Similar trends were obtained for softwood fibres (Kibblewhite, 1974). Explanations given for the interactions of beater effects and paper properties for softwood fibres (Kibblewhite, 1974) also appear to be valid for the shorter and narrower hardwood fibres of the present study.

CONCLUSIONS

1. The effects of beating the beech fibres were in general similar to those of softwood fibres. Ease of pulp beating was dependent on fibre dimensions, particularly fibre wall thickness, and on the conditions and types of beating.

2. Vessels in the beech pulps were selectively made more fibre-like and "ropy" through beating at high stock concentrations. Thus, pulps processed in this way should not be susceptible to vessel picking from paper surfaces during printing operations.

3. The trends of paper properties of the beech fibres were found to be generally predictable from a knowledge of their characteristics and the types of beating treatment given to the pulps. General trends for the different species and the different beating conditions were similar to those obtained with softwood fibres. The exception was paper tearing strength which was low for the beech pulps because of their short fibre lengths compared with those of softwood fibres.

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