EFFECTS OF BEATING, BEATERS, AND WOOD QUALITY ON WET WEB STRENGTH

R. P. KIBBLEWHITE
Forest Research Institute, New Zealand Forest Service, Rotorua

(Received for publication 2 April 1974)

ABSTRACT

Effects of beating, beater type, and fibre quality on the wet web strength of several radiata pine (**Pinus radiata** D. Don) kraft pulps were examined.

Wet strength increased linearly with increasing dry strength except for unbeaten and heavily beaten pulps. Wet/dry strength ratios were unaffected by changes in wood density although beating developed wet strength more rapidly in long-fibred than in short-fibred pulps.

Beating effects which influenced dry handsheet properties also affected corresponding wet web properties. Lampen mill beating gave lower wet and dry stretch than either PFI or Valley beating. The wet web behaviour of compression wood and Lampen mill beaten pulps indicated that the internal structure of fibres may influence wet web properties as well as dry handsheet properties.

INTRODUCTION

Kraft pulps exported from New Zealand, Sweden, and elsewhere have lower wet strengths than those obtained from Howe Sound in Canada (Stephens and Pearson, 1970). Stephens *et al.* (1971) found that pulps containing 40% of unbeaten New Zealand kraft or 20% of refined New Zealand kraft or less than 10% of Howe Sound kraft are required for satisfactory newsprint production at the Australian Newsprint Mills. More recent work (Stephens *et al.,* 1973) showed that the wet strength of New Zealand kraft beaten at high consistency is similar to that obtained with Howe Sound provided the pulp is dispersed at consistencies below 1.5%.

Wet web studies described here and elsewhere (Kibblewhite, 1974b, c; Kibblewhite and Brookes, 1974) are designed to characterise the wet web properties of New Zealand krafts and to explain differences in the wet web strength of New Zealand and Howe Sound pulps. The wet web properties of a wide variety of well-characterised radiata pine (*Pinus radiata* D. Don) kraft pulps (Kibblewhite, 1972a, b; 1973a, b; 1974a) are described in the present report. Effects of beating, wood quality, and different laboratory beaters are examined.

EXPERIMENTAL

Young-wood, mature-wood, and compression-wood pulps, and earlywood and latewood pulps, were prepared, beaten, and evaluated by methods described previously (Kibblewhite, 1972a, b; 1973b). Roundwood billets containing 10 (young-wood), and the outer 10 of 30 (mature-wood) growth layers were taken from two 44-year-old radiata pine trees located in Kaingaroa Forest. The compression-wood sample was taken from the butt sweep of a tree on the same site and consisted of the outer 10 of 35 growth layers in the roundwood billet.

Wet web stress, strain, and tensile energy values obtained using the techniques of Stephens and Pearson (1970) were in qualitative rather than absolute units. For this reason, experimental wet web values were modified by suitable factors to convert them to conventional units and allow comparison with dry handsheet values (Kibblewhite, 1973c).

RESULTS

Wet breaking length, stretch, and tensile energy increase with beating although the stretch of lightly beaten pulps is often less than that of unbeaten stock (Table 1,

TABLE 1: Wet and Dry Strength

Wood Sample	Beater	Beating Conditions	Breaking length (km) Wet	Dry	Wet/dry	Stretch (%) Wet	Dry	Wet/dry	Tensile energy (J/kg) Wet	Dry	Wet/dry
Young wood	Unbeaten	0	0.05	3.0	0.017	3.5	1.7	2.1	12.3	363	0.034
	PFI (10%)	2000 rev	0.07	5.2	0.013	3.9	2.6	1.5	18.5	970	0.019
		4000 "	0.08	6.1	0.013	4.0	2.9	1.4	20.2	1147	0.018
		8000 "	0.10	7.6	0.013	5.0	3.2	1.6	31.1	1605	0.019
		15000 "	0.11	8.8	0.012	5.8	3.6	1.6	43.0	2070	0.021
	PFI (25%)	2000 rev	0.05	3.7	0.013	3.9	2.0	1.9	12.8	538	0.024
		4000 "	0.05	4.3	0.012	4.2	2.5	1.7	14.0	785	0.018
		8000 "	0.05	5.5	0.009	4.7	3.0	1.6	17.0	1172	0.014
		15000 "	0.08	7.0	0.011	6.3	3.8	1.7	32.5	1843	0.018
		20000 "	0.09	7.3	0.012	6.1	3.8	1.6	40.1	1930	0.021
	Lampen	2000 rev	0.08	5.8	0.014	3.5	2.1	1.7	17.5	830	0.021
		4000 "	0.08	7.3	0.011	3.7	2.3	1.6	18.9	1117	0.017
		8000 "	0.08	8.4	0.009	4.0	2.5	1.6	20.9	1450	0.014
		15000 "	0.09	9.8	0.009	4.8	2.9	1.6	29.2	1903	0.015
	Valley	15 min	0.08	6.7	0.012	3.1	2.6	1.2	14.9	1247	0.012
		30 "	0.11	8.6	0.013	4.4	3.1	1.4	29.3	1767	0.017
		45 "	0.12	9.5	0.013	5.1	3.1	1.6	37.6	1973	0.019
Mature wood	Unbeaten	0	0.03	2.2	0.014	2.9	1.1	2.6	6.1	158	0.039
	PFI (10%)	2000 rev	0.04	4.2	0.009	3.1	1.7	1.8	9.2	473	0.019
		4000 "	0.06	5.1	0.012	3.6	2.0	1.8	13.5	705	0.019
		8000 "	0.08	6.4	0.012	4.4	2.4	1.8	22.5	1060	0.021
		15000 "	0.11	7.6	0.014	5.8	2.8	2.1	41.0	1480	0.028
	PFI (25%)	2000 "	0.04	3.4	0.012	3.1	1.8	1.7	8.8	442	0.020
		4000 "	0.05	4.0	0.012	3.9	2.3	1.7	13.0	625	0.021
		8000 "	0.06	5.4	0.011	4.8	3.1	1.5	19.3	1282	0.015
		15000 "	0.10	6.4	0.016	7.6	3.4	2.2	53.8	1503	0.036
		20000 "	0.11	6.2	0.018	8.4	3.3	2.5	64.7	1395	0.046
	Lampen	2000 rev	0.04	4.8	0.008	2.5	1.3	1.9	7.0	433	0.016
		4000 "	0.05	6.2	0.008	2.6	1.6	1.6	8.2	705	0.012
		8000 "	0.08	6.8	0.012	3.5	1.9	1.8	17.1	913	0.019
		15000 "	0.09	7.9	0.011	4.7	2.2	2.1	28.8	1255	0.023
	Valley	15 min	0.06	6.2	0.010	2.9	2.0	1.4	10.6	842	0.013
		30 "	0.09	7.7	0.012	4.8	2.5	1.9	27.8	1282	0.023
		45 "	0.12	9.3	0.013	6.1	2.9	2.1	49.4	1860	0.026
Compression wood	Unbeaten	0	0.04	2.2	0.018	4.6	1.5	3.1	11.7	233	0.050
	PFI (10%)	2000 rev	0.05	4.0	0.012	4.1	2.6	1.6	13.1	728	0.018
		4000 "	0.05	4.5	0.011	3.7	3.0	1.2	11.4	922	0.012
		8000 "	0.08	5.6	0.014	4.8	3.2	1.5	23.5	1280	0.018
		15000 "	0.10	6.4	0.016	5.5	3.7	1.5	34.6	1617	0.021
	PFI (25%)	2000 rev	0.04	3.4	0.012	4.3	2.6	1.6	11.9	660	0.018
		4000 "	0.05	3.9	0.013	4.7	3.1	1.5	14.3	880	0.016
		8000 "	0.07	4.1	0.017	5.5	3.2	1.7	20.6	943	0.022
		15000 "	0.11	5.6	0.020	6.6	4.1	1.6	31.5	1637	0.019
		20000 "	0.14	6.0	0.023	8.6	4.1	2.1	64.7	1722	0.037
	Lampen	2000 rev	0.04	4.4	0.009	3.0	2.0	1.5	8.8	577	0.015
		4000 "	0.05	5.4	0.009	3.2	2.4	1.3	10.0	842	0.012
		8000 "	0.05	6.2	0.008	3.2	2.6	1.2	10.7	1077	0.010
		15000 "	0.07	7.2	0.010	4.0	2.9	1.4	18.8	1389	0.013

Kibblewhite, 1973c). Wet stretch of unbeaten pulps usually decreases more with Lampen mill than with PFI mill or Valley beating.

Pulp wet strength normally increases linearly with increasing dry strength and is unaffected by changes in fibre diameter and fibre wall thickness (Table 1, Figs. 1, 2). For given dry values, beating develops wet strength more rapidly in the mature-wood pulps than in the young-wood pulps (Figs. 1, 2).

Beating effects which influence dry handsheet properties also appear to affect wet web breaking length, stretch, and tensile energy. PFI mill beating at 10% consistency normally develops lower wet and dry stretch, and higher wet and dry breaking lengths, than does PFI mill beating at 25% consistency (Table 1, Kibblewhite, 1973c). However, similar wet/dry strength ratios are obtained using the two beating treatments (Table 1, Figs. 1 and 2). Wet/dry strength ratios are used throughout the text to show that for each beating treatment changes in wet strength usually correspond to changes in dry strength.

Lampen mill beating gives low wet stretch values when compared to other methods at similar handsheet densities and beating revolutions (Table 1). Wet/dry stretch ratios are, however, similar to those obtained with PFI mill beating because Lampen mill beating also gives handsheets with low stretch properties (Fig. 3, Table 1). In contrast, while wet breaking lengths are low after Lampen mill beating, dry breaking lengths are high so that the ratios between the two are lower than those obtained with PFI and Valley beating (Fig. 3, Table 1, Kibblewhite, 1973c).

Compression-wood pulps have higher wet stretch, and more distinct drops in wet stretch with initial beating, than the young and mature normal-wood pulps (Table 1). Lampen mill beating causes the largest drop in wet stretch, which corresponds to the low dry-stretch values obtained when the mature and young normal-wood pulps are processed in this beater.

DISCUSSION

Beating develops paper strength by making wet fibres flexible so that they are able to collapse and bond to one another's surfaces during the papermaking process (Kibblewhite, 1973a). Wet strength (about 30% solids), on the other hand, apparently develops without the formation of molecular bonds and can be related to the extent of interaction of fibres and fibre elements within essentially unbonded webs (Robertson, 1959, 1963; Kibblewhite, 1973a). The development of wet strength by beating must therefore be related to degrees of fibre, fibril, and molecular fibril contact and entanglement, and the resistance of such entangled networks to deformation by stress.

Many fibre morphological changes normally developed by beating can be expected to affect the tensile properties of a wet paper web (Robertson, 1963; Kibblewhite, 1973a):

1. *Fibre morphology:* Interaction of fibres within a wet web is probably affected by variations in pulp fibre length, fibre diameter, and fibre wall thickness. Amount of extensibility within fibres as well as interactions of fibres in a wet web are also affected by the extents of fibre twisting and fibre kinking.
2. *Fibre flexibility:* This is a measure of extent of fibre collapse and intrafibre wall dislocation, delamination, and microcompression. The more flexible the fibres, the greater the amount of fibre collapse and conformability within a wet web. Therefore,

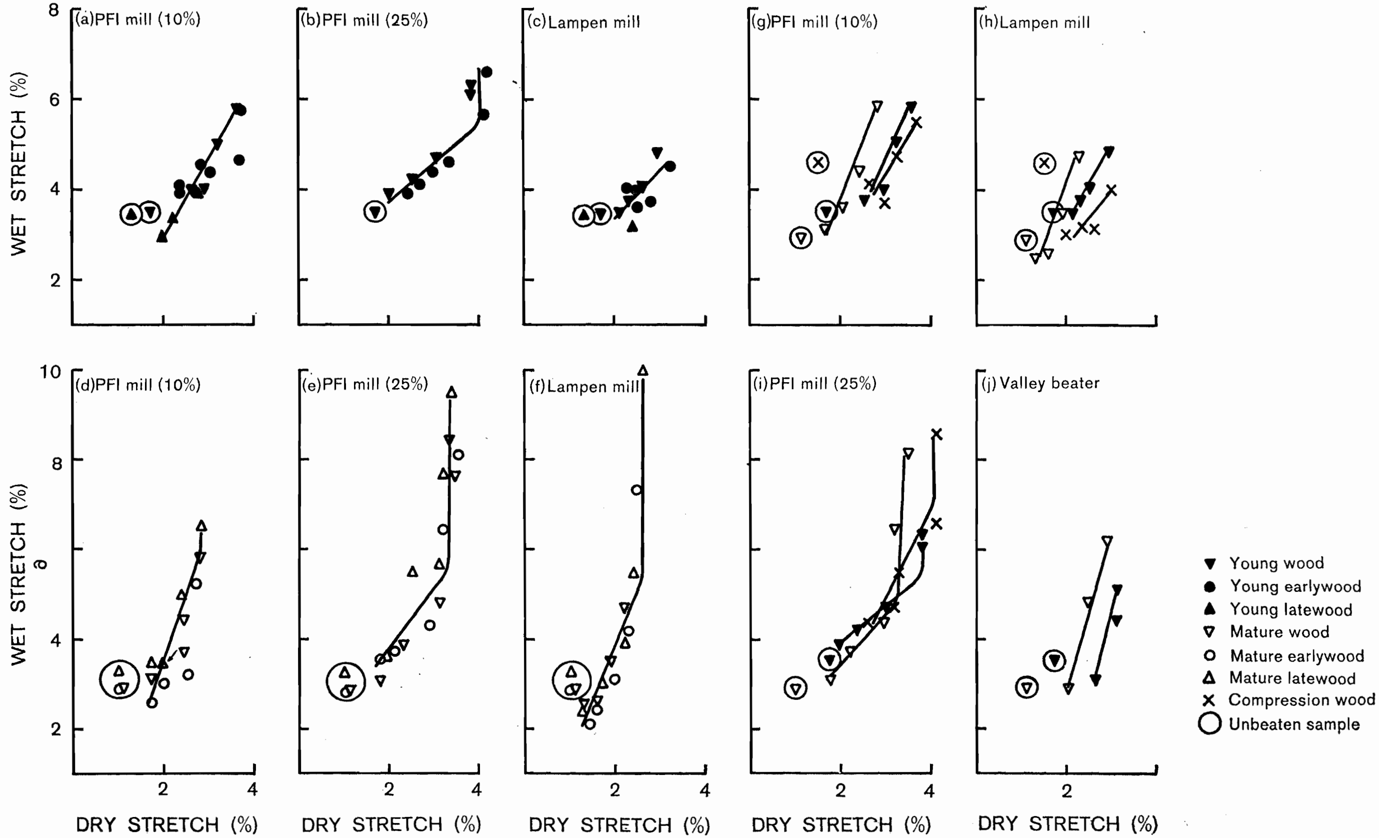

FIG. 1—Wood quality effects on wet and dry stretch properties

a-f: Comparison of young-wood pulps and mature-wood pulps beaten in a PFI mill at two consistencies and also in a Lampen mill.

g-j: Comparison of composite young-, mature-, and compression-wood pulps beaten in a PFI mill at two consistencies, and in a Lampen mill and a Valley beater.

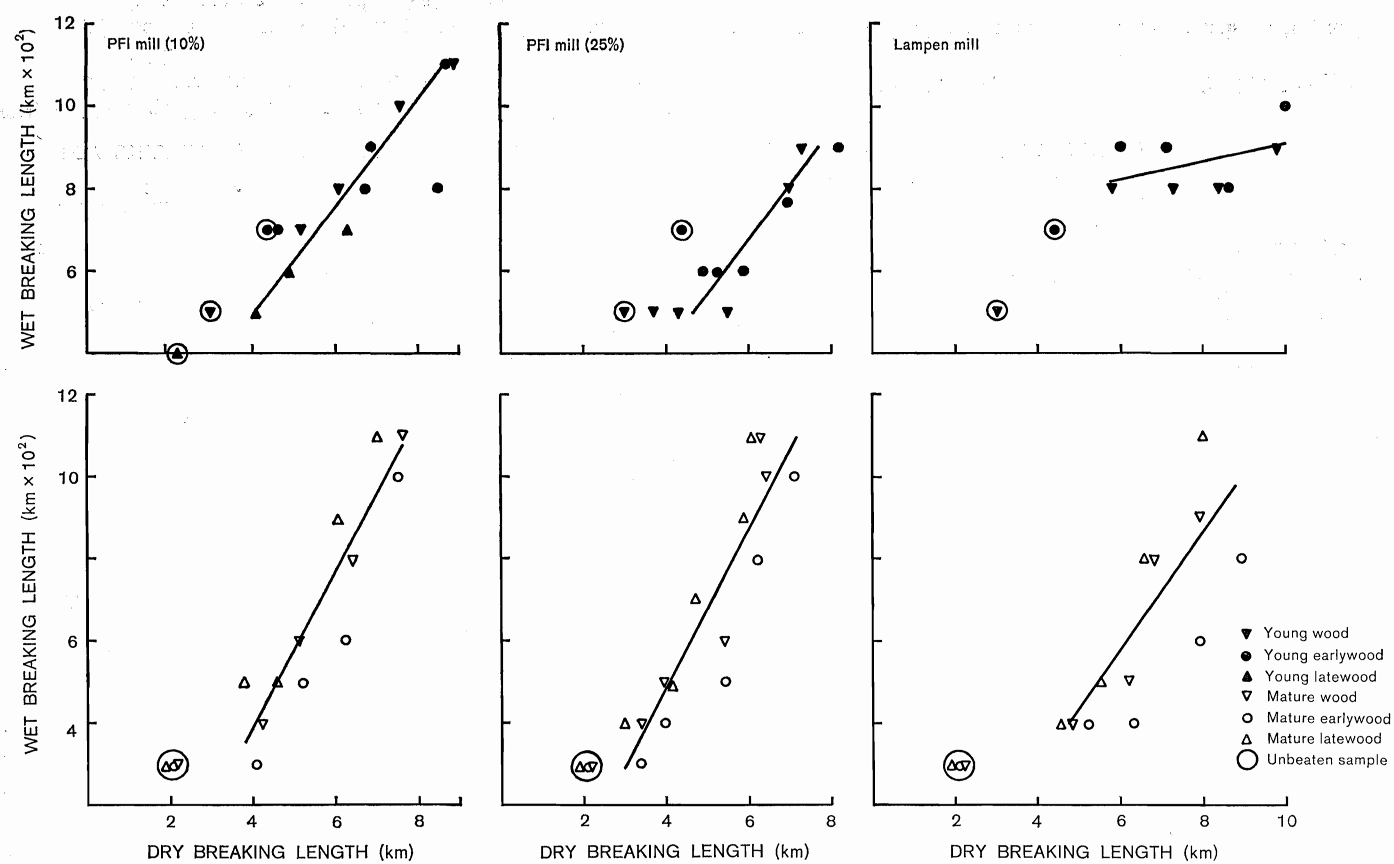

FIG. 2—Wood quality effects on wet and dry breaking length properties. Comparison of young-wood pulps and mature-wood pulps beaten in a PFI mill at two consistencies and in a Lampen mill.

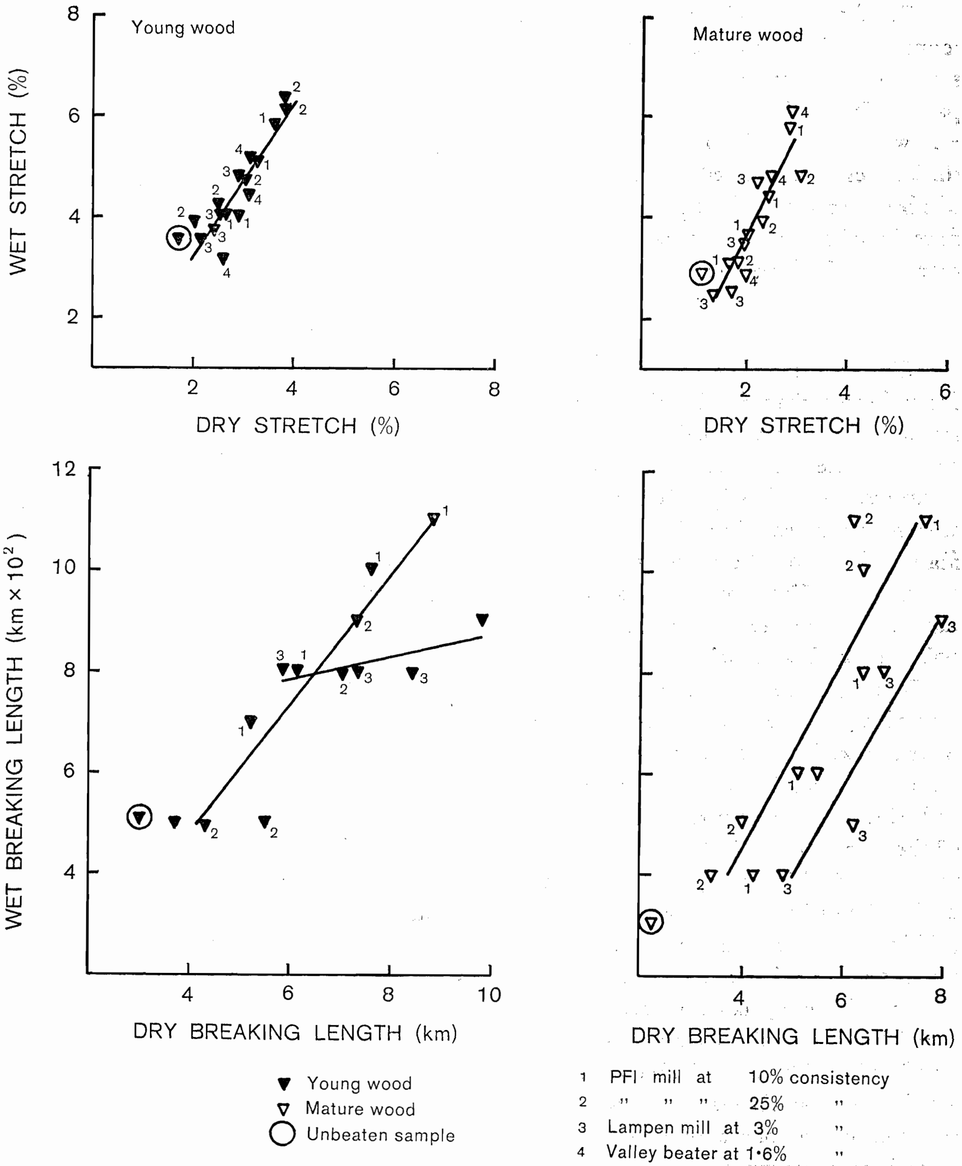

FIG. 3—Beater effects on wet web stretch and breaking length properties.

the more flexible the fibres in wet webs the greater is the area of interaction and friction between adjacent fibre surfaces in contact.

3. *Fibre fibrillation:* Entanglement of interfibre fibrils and fibrillar fines increases frictional forces between fibres which increase wet web tensile properties. The interaction of molecular fibrils on the surfaces of adjacent fibres in close proximity must also improve wet web strength. This would be particularly true of fibres which conform strongly to one another's surfaces.

The discussion which follows attempts to interpret experimental wet web data in terms of both fibre characteristics and dry handsheet properties. Fibre properties of the seven pulps examined are described and related to dry handsheet properties in an earlier paper (Kibblewhite, 1973b). The young-wood pulps, young-latewood pulps, and young-earlywood pulps all contain fibres with similar lengths but different diameters, wall thicknesses, and geometric specific surfaces. The three pulps also have similar numbers of fibres per gram of pulp. Similar trends occur with the three mature-wood pulps, but fibre lengths are 3.0 mm rather than 2.5 mm and the pulps contain 5×10^5 rather than 7×10^5 fibres per gram (Kibblewhite, 1973b).

Beating Effects

Wet/dry ratios for stretch, breaking length, and tensile energy are often higher for unbeaten than for lightly beaten stock and are related to a rapid increase in dry strength and a corresponding slow increase in wet strength with initial beating (Table 1). This effect is particularly evident with stretch and with the mature-wood and compression-wood pulps. Except for the initial effects, beating normally causes wet web strength to increase linearly with increasing handsheet values and shows that mechanical fibre modification affects wet web properties and dry handsheet properties proportionately (Figs. 1, 2). The slower development of wet strength by initial beating is probably caused by a decrease in entanglement between fibres and a loss of fibre rigidity at points of kink and twist.

Beating causes a change of state in wet, unbeaten fibre networks by straightening twisted and kinked fibres (Kibblewhite and Brookes, 1975) and by apparently making points of kink and twist flexible. If this was the only effect of light beating, a drop in pulp wet strength would be expected. However, beating also increases fibre flexibility and, therefore, the amount of collapse and conformability of fibres within a wet web (Robertson, 1963; Kibblewhite, 1973a), which in turn promotes an improvement in wet strength. Therefore, the parallel development of more flexible and straighter fibres during the early stages of beating probably accounts for the slow increase in wet strength (Table 1). Fibre flexibility is a continuous beating effect and accounts for much of the progressive increase in wet strength after initial beating (Table 1).

The above explanation accounts for the absence of a drop in wet stretch with initial beating in the young-wood pulps and the very definite drop in the compression-wood pulps (Table 1, Kibblewhite, 1973c). The beaten young-wood and young-earlywood fibres contain many thin-walled, large-diametered fibres which are able to collapse and conform to one another (Kibblewhite, 1972c). The high potential for collapse in these beaten earlywood fibres possibly cancels the effect of fibre-straightening and the loss of fibre rigidity with initial beating. On the other hand compression-wood earlywood fibres are thick-walled (Kibblewhite, 1973b), have a low potential for collapse, and show a slower development of wet stretch with beating (Table 1). The high wet stretch of the unbeaten compression-wood pulp may be related to the unique intra-wall structure of compression-wood fibres (Kibblewhite, 1973b).

The non-linearity of the wet and dry strength relations of heavily beaten pulps (Figs. 1, 2) is probably related to the extensive entanglement of fibrils and fibrillar fines in wet webs, particularly when the long fibrils of the S_2 layer are available for entanglement (Kibblewhite, 1972a). Up to 25% of the fibres in a pulp beaten for

15,000 rev can show the S_2 layer on their surfaces (Kibblewhite, 1972b), and this would account for the more rapid increase in wet stretch values than in dry stretch values at this beating level. The presence of fines and fibrillar elements increases the tensile properties of dry handsheets, but only slightly (Giertz, 1967).

Wood Quality Effects

Latewood, earlywood, and composite pulps from young or mature wood fit the same wet strength-dry strength regression (Figs. 1, 2). This shows that for given dry strengths pulps with different fibre densities develop similar wet strengths with beating. Pulps with different fibre lengths on the other hand give different wet-dry strength relations. For given dry values, the long-fibred mature-wood pulps develop wet strength more rapidly than do the shorter-fibred young-wood pulps (Figs. 1, 2). Because corresponding young- and mature-wood pulps have similar fibre diameters, fibre wall thicknesses, and fibre specific surfaces (Kibblewhite, 1973b), the more rapid development of mature-wood pulp wet strength can be related to differences in fibre length.

Beater Effects

Unbeaten pulps usually have higher wet stretch than those lightly beaten in the Lampen mill (Table 1, Kibblewhite, 1973c). For compression-wood, this effect is also apparent after PFI mill and Valley beating though the Lampen mill gives the lowest values (Table 1). Valley and PFI mill beating of the young- and mature-wood pulps apparently also cause the wet stretch of unbeaten pulps to decrease, but this is usually obscured by the rapid and parallel development of wet stretch with beating (Table 1, Kibblewhite, 1973c). Wet/dry stretch ratios for Lampen mill beating are similar to those obtained with the other beaters because both wet and dry stretch values obtained after Lampen mill beating are low.

The definite initial drop in wet stretch which occurs when unbeaten pulps are processed in the Lampen mill is difficult to explain. In fact, present evidence suggests that this low wet-stretch is related to wet intrafibre extensibility. Although such an explanation may appear improbable, it accounts for the experimental facts that:

1. Lampen mill beating develops greater fibre flexibility and bonding in dry handsheets than do either the PFI mill or the Valley beater (Kibblewhite, 1974a);
2. Lampen mill beating gives wet/dry stretch ratios which are almost identical to those of PFI mill and Valley beating (Fig. 3, Table 1), which suggests that wet and dry stretch are determined by the same fibre characteristics;
3. Compression-wood dry stretch values are higher than those of normal-wood pulps and are related to the unique wall structure of compression-wood fibres (Kibblewhite, 1973b). Wet stretch values are also high for the compression-wood pulps and are directly related to dry values (Table 1), which suggests that intrafibre structure affects both wet and dry stretch properties.

CONCLUSIONS

1. Beating increases the wet breaking length, stretch, and tensile energy of radiata pine kraft pulps, although the wet stretch of lightly beaten pulps is often less than that of unbeaten stock.
2. Wet strength increases linearly with increasing dry strength for moderate beating and is unaffected by changes in fibre diameter and fibre wall thickness.

3. For given dry values, beating develops wet strength more rapidly in mature-wood (fibre length 3.0 mm) than in young-wood (fibre length 2.5 mm) pulps.
4. Beating effects which influence dry handsheet properties also affect corresponding wet web strength values.
5. Lampen mill beating gives lower wet stretch values than PFI mill and Valley beating. The low wet stretch corresponds to low dry stretch values for Lampen mill beating.
6. Compression-wood pulps develop higher wet stretch than normal-wood pulps.
7. The effects of Lampen mill beating and the compression-wood wet stretch values indicate that the internal structure of pulp fibres can affect wet as well as dry stretch properties.
8. The wet/dry strength ratios for heavily beaten pulps deviate from the linear because extensive fibrillation causes wet strength to increase more rapidly than corresponding dry values.

ACKNOWLEDGMENTS

The determination of wet strength values for all pulps by staff of the Research Department of the Australian Newsprint Mills is gratefully acknowledged. The technical assistance of Miss Diane Brookes is also acknowledged.

REFERENCES

GIERTZ, H. W. 1967: A new approach in evaluating the effect of refining. **In** "Modern Concepts and Practices of Fibre Refining" (pp. 6-15). **Proc. 11th Ann. Pulp Pap. Conf.** (Michigan Univ., Michigan).

KIBBLEWHITE, R. P. 1972a: Effect of beating on fibre morphology and fibre surface structure. **Appita 26 (3):** 196-202.

——— 1972b: Effects of beaters and wood quality on the surface and internal structure of radiata pine kraft fibres. **Pap. ja Puu 54 (11):** 709-14.

——— 1973a: Effects of beating on wet web behaviour. **Appita 26 (5):** 341-2.

——— 1973b: Effects of beating and wood quality on radiata pine kraft paper properties. **N.Z. J. For. Sci. 3 (2):** 220-39.

——— 1973c: Behaviour of wet webs under strain 1. Beating, beater, and wood quality effects. **N.Z. For. Serv., For. Res. Inst., For. Prod. Branch Rep. 461** (unpubl.).

——— 1974a: Effects of beating on radiata pine kraft paper properties. Effects of beaters. **Appita 27 (6):** 418-23.

——— 1974b: Effects of fibre kinking and pulp bleaching on wet web strength. **Tappi 57 (8):** 120-21.

——— 1974c: Fibre and fibre network behaviour in strained wet webs. **N.Z. J. For. Sci. 4 (3):** 552-8.

KIBBLEWHITE, R. P. and BROOKES, D. 1975: Factors which influence the wet web properties of commercial pulps. **Appita** 28 (4): 227-31.

ROBERTSON, A. A. 1959: The physical properties of wet webs. 1. Fibre-water association and wet-web behaviour. **Tappi 42 (12):** 969-78.

——— 1963: The physical properties of wet webs. 2. Fibre properties and wet web behaviour. **Svensk PappTidn. 66 (12):** 477-97.

STEPHENS, J. R. and PEARSON, A. J. 1970: The control of pulp and papermaking processes by wet web evaluation. **Appita 23 (4):** 261-78.

STEPHENS, J. R., PEARSON, A. J. and LASSMAN, J. A. 1971: The control of newsprint furnish and paper machine operation. **Pulp Paper Mag. Can. 72 (4):** T143-T151.

STEPHENS, J. R., PEARSON, A. J. and LASSMAN, J. A. 1973: The effect of refining on the wet rupture energy of kraft pulps. **Appita 26 (5):** 361-367.