Effects of beating on radiata pine kraft properties: effects of beaters†

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SUMMARY

The effects of four different laboratory beating treatments on several radiata pine kraft pulps are examined in terms of handsheet strength and optical properties.

When compared with PFI mill beating at 10 per cent stock consistency and at specific sheet densities, the Valley beater gives high breaking length, the Lampen mill low stretch and the PFI mill at 25 per cent consistency low breaking length and high stretch values. High consistency PFI mill beating gives handsheets with high tear factor for given breaking lengths, relative to the other beaters examined. Each beater appears to make fibres flexible to different degrees; Lampen mill ≥ Valley beater > PFI mill (10 per cent) > PFI mill (25 per cent).

Maximum handsheet strengths are attained at scattering coefficients of about 150 cm^2/g for Valley and PFI mill beaten pulps and at about 130 cm^2/g for Lampen mill processed stock. Valley and PFI mill processed pulps have similar density and stretch but different breaking length values at specific scattering coefficients (bonded areas). Factors other than bonded area and fibre dimensions appear to influence handsheet breaking length values.

The various paper properties obtained by processing pulps in different beaters are explained in terms of beater action, wood quality, fibre surface and intrawall structure, and fibre flexibility.

The effects of four laboratory beating treatments on the paper properties of a variety of radiata pine kraft pulps are examined. Pulps were beaten in a Valley beater, a Lampen mill, and in a PFI mill at 10 and 25 per cent consistency.

The effects of PFI mill beating at 10 per cent stock concentration on the paper properties of radiata pine kraft pulps made from earlywood, latewood, compression wood, young wood (rings 1 to 10) and mature wood (rings 20 to 30) are discussed in a previous paper (1). The present paper describes the effects of beaters on paper properties in terms of their deviation from PFI mill beating at 10 per cent consistency. Although most of the data presented refer to the young wood, mature wood and compression wood pulps, similar trends were obtained with the four earlywood and latewood samples (1)(2).

EXPERIMENTAL

Pulps were prepared from the various wood samples and beaten in a Valley beater at 1.6 per cent consistency, a Lampen mill at 3 per cent consistency and a PFI mill at 10 and 25 per cent consistency by methods described previously (3). High consistency PFI mill beatings were made on 24 g o.d. pulp with an applied 1.8 kg load. Methods of handsheet preparation and evaluation have been described elsewhere (1).

Fines indices were calculated from tabulated data which describe the effects of beating on fibre surfaces (4). Each fines index was calculated using the expression:

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

where S_n refers to specific wall lamellae on beaten fibre surfaces.

RESULTS

Handsheets prepared from pulps processed in the Valley beater and PFI mill have similar density — freeness relations. Separate curves are obtained with Lampen mill beaten stock. Each beater produces pulps with different handsheet tear properties (Figure 1).

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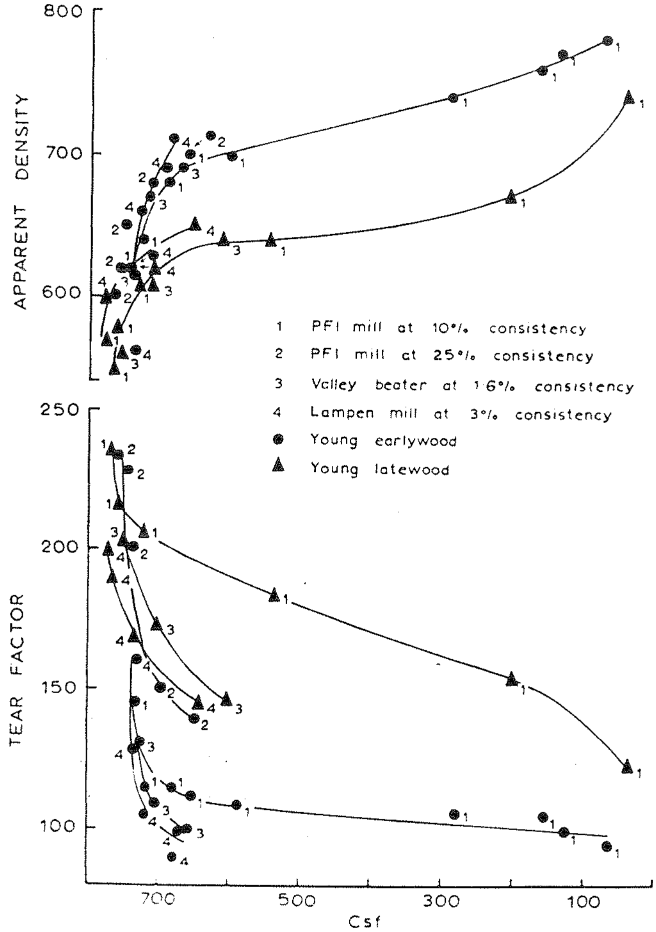

Fig. 1 — Effects of wood quality and beaters — sheet density, tear factor and freeness.

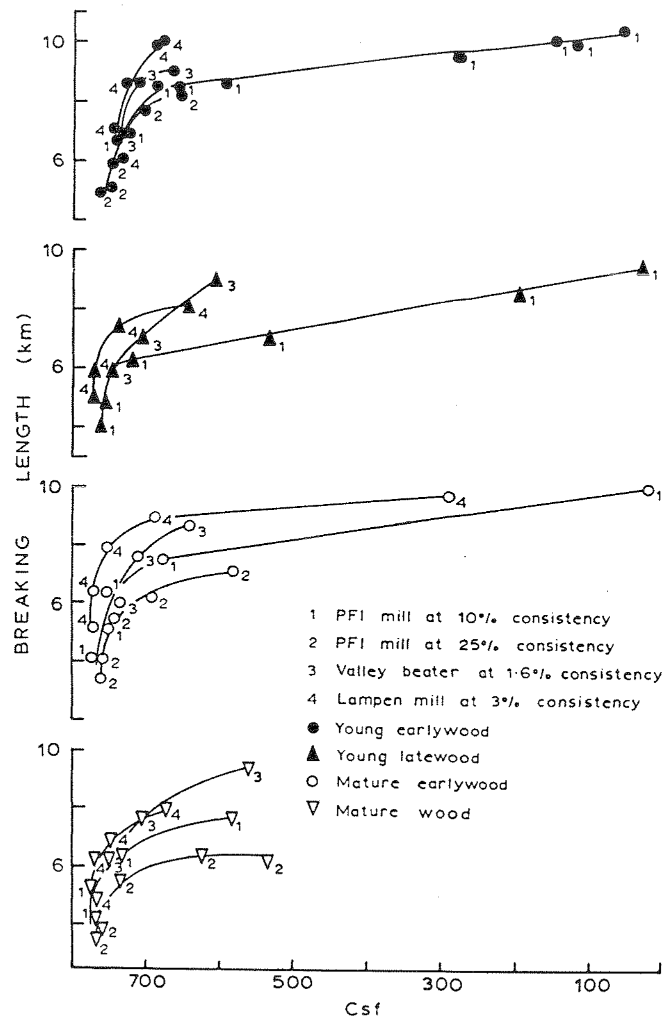

Fig. 2 — Effects of wood quality and beaters — breaking length and freeness.

Breaking length — freeness relations are affected by changes in wood quality (Figure 2). The breaking lengths of Valley beaten young earlywood pulps are lower than those obtained when the same pulp is processed in the Lampen mill. Young latewood, mature wood and compression wood pulps behave differently. For these pulps the breaking lengths of Valley beaten stock can exceed those obtained with Lampen mill processed pulp (Figure 2) (1)(2).

Each beater makes fibres flexible to different degrees; Lampen mill ⩾ Valley beater > PFI mill (10 per cent) > PFI mill (25 per cent). Relative estimates of the degree to which each beater makes fibres flexible are obtained by comparing pulp freeness and fines, and handsheet tear and breaking length values (Figures 1 and 2, Table 1).

Breaking length and stretch increase linearly with sheet density (Figures 3 and 4). Regression lines are drawn through what appear to be closely related data. A similar series of curves is obtained with mature and young, earlywood and latewood values (1)(2). Valley beating gives handsheets with the highest, and PFI mill beating at high consistency the lowest breaking lengths when compared at similar densities. The PFI mill at 25 per cent consistency gives the highest and the Lampen mill the lowest handsheet stretch values. Only the PFI mill at 25 per cent gives separate stretch — density curves for young and mature wood pulps. Tensile energy — density curves vary with the type of beater (Figure 5).

The development and retention of tear factor with beating is greatest in pulps processed at high consistency in the PFI mill and least in those treated in the Lampen mill or Valley beater (Figure 6).

Maximum handsheet strength develops at scattering coefficients of about 150 cm^2/g for pulps processed in the PFI mill and the Valley beater, and at about 130 cm^2/g for those beaten in the Lampen mill (Figures 7, 8 and 9).

TABLE 1

Effects of beaters on the surface structure of mature earlywood fibres

Beater and beating time	Canadian Standard Freeness (Csf) 740-759	680-699	660-679	640-659	Fines index
PFI mill (10%)					
8,000 rev	Primary wall remnants and outer S_1 lamellae				75
15,000 rev			Outer and inner S_1 to S_2 lamellae		210
PFI mill (25%)					
8,000 rev	Primary wall remnants and the outermost S_1 lamella				53
15,000 rev		Outer and inner S_1 to S_2 lamellae			190
Lampen mill					
8,000 rev	Primary wall remnants and the outermost S_1 lamella				81
15,000 rev		Outer S_1 lamellae			148
Valley beater 45 min				Primary wall remnants to S_2 layer. Evenly distributed	153

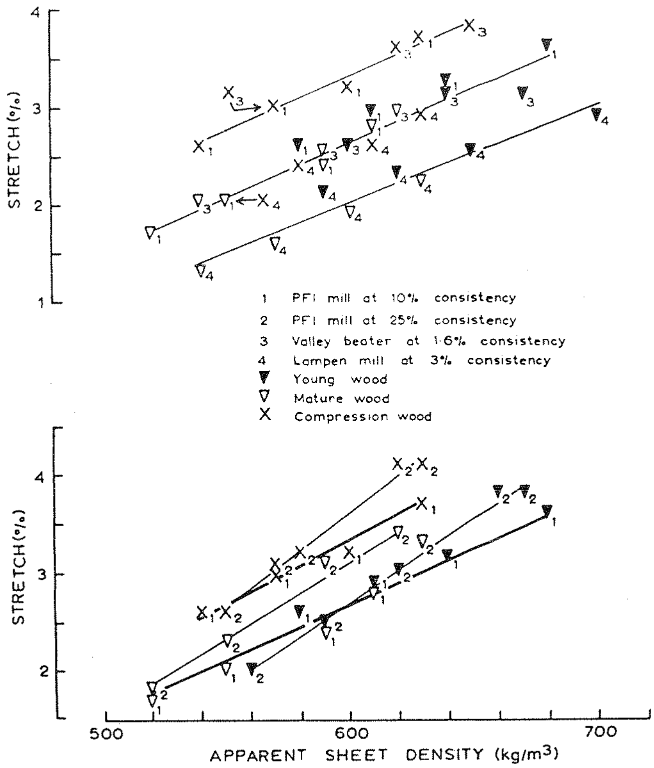

Fig. 4 — Effects of beaters — stretch and sheet density.

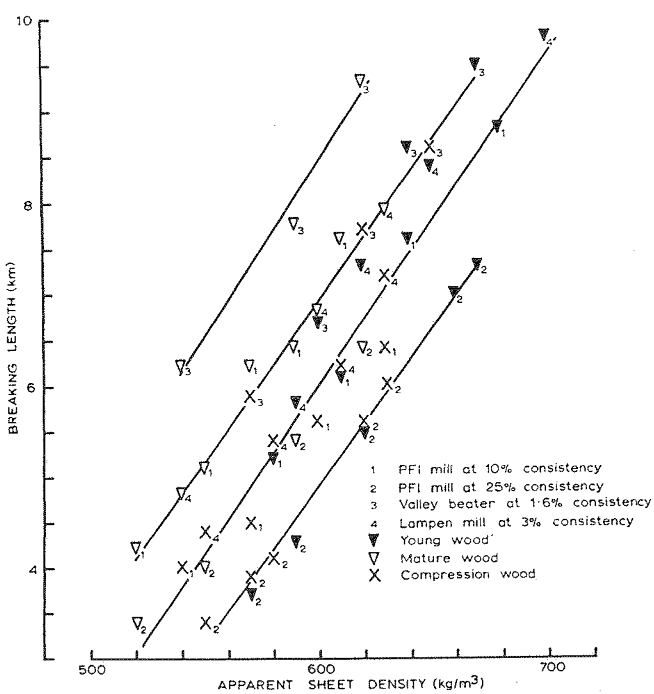

Fig. 3 — Effects of beaters — breaking length and sheet density.

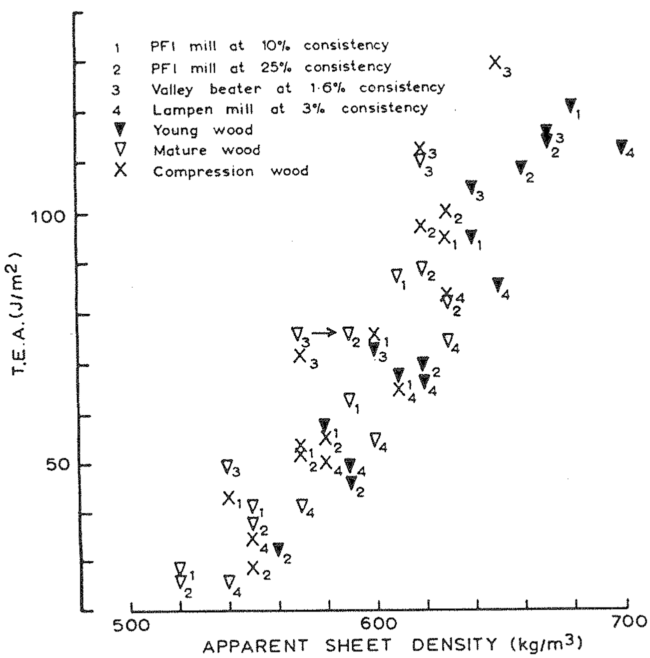

Fig. 5 — Effects of beaters — tensile energy and sheet density.

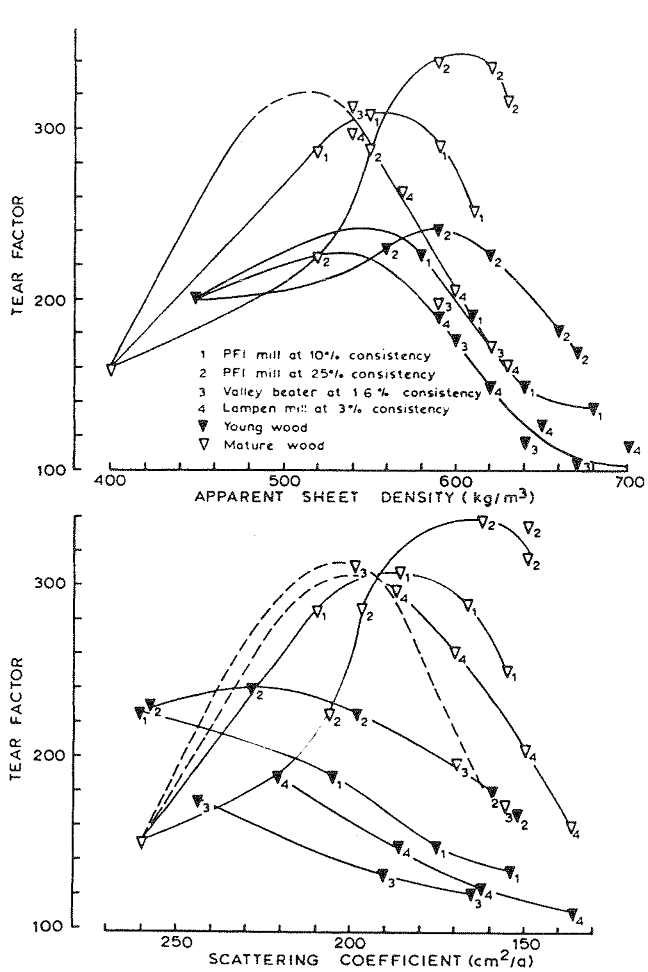

Fig. 6 — Effects of beaters — tear factor, sheet density and scattering coefficient.

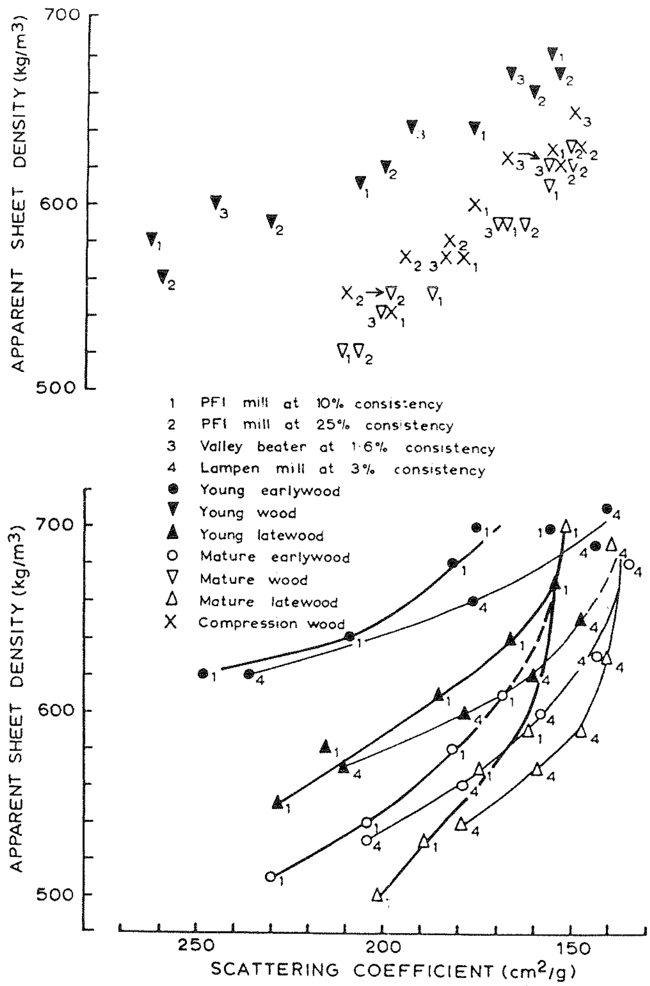

Fig. 7 — Effects of beaters — sheet density and scattering coefficient.

DISCUSSION

Fibre characteristics

Each beater shortens fibres to a similar extent (3) but removes different amounts of material from fibre surfaces (4).

Beating decreases pulp freeness by producing fines and causing fibres to become flexible (5). Mature earlywood pulps at 740 to 759 Csf have similar fines contents after beating in the PFI and Lampen mills (Table 1). Within this freeness range the relatively high freeness and high breaking length of Lampen mill processed pulps (Figure 2) indicate that this beater makes fibres more flexible than the PFI mill. For similar reasons, the PFI mill at 10 per cent consistency makes fibres more flexible than at 25 per cent consistency. At lower freeness values (660 to 699 Csf), Lampen mill fines contents are low relative to the PFI mill, which supports the conclusion that the ball mill produces the more flexible fibres. Tear factor values are highest for PFI mill (25 per cent) and lowest for pulps processed in the Lampen mill (Figure 1). The low Lampen mill tear factor is probably also related to flexible fibres.

The fines index (Table 1) and the tear factor and breaking length data (Figures 1 and 2) indicate that the Valley beater makes fibres more flexible than the PFI mill and less flexible than the Lampen mill. The high breaking length of Valley beaten young latewood and mature wood (Figure 2) and compression wood pulps (1)(2) may be associated with high fines indices relative to those obtained with Lampen mill beating. Valley beaten compression wood pulp at 700 Csf has a fines index of 212 while Lampen mill processed stock at 704 Csf has an index of 119 (1)(2)(4).

Valley beaten pulps contain a range of fibre surface structures which include the primary wall and lamellae of the S_1 and S_2 layers of the secondary wall (4). Such a range of fibre surfaces suggests that, during Valley beating, some fibres are caught between beater bars and bed plate more often than others. Consequently, a wide range of fibre flexibilities probably develops in Valley beaten pulps.

The flexibility series Lampen ⩾ Valley > PFI (10 per cent) > PFI (25 per cent) is slightly different from that observed by qualitative microscopy (6). Although microscopic analysis shows flexibility differences between unbeaten and beaten, and earlywood and latewood fibres, the method is apparently not sensitive enough to show differences between beaters.

Tensile properties

Lampen mill: The similar breaking length — density relations of Lampen and PFI (10 per cent) mill processed pulp (Figure 3) is surprising in view of the scattering coefficient data (Figures 7 and 8). For given densities and breaking lengths, Lampen processed pulps give low handsheet scattering coefficients and therefore high degrees of intra and/or interfibre bonding. Among the beaters examined, the Lampen mill is unique because maximum strength develops at lower scattering values (Figures 7, 8 and 9). This suggests a greater bonded area which can be related to the flattening and crushing action of the Lampen mill (3). Because both the Lampen and PFI mills have similar density — breaking length curves (Figure 3), the low minimum scattering coefficient (130 cm^2/g) obtained with the ball mill indicates that the area of intrafibre rather than interfibre bonds may be increased relative to PFI mill beating.

The low stretch of Lampen beaten pulps is probably caused by the apparent high degree of intrafibre bonding which minimizes fibre elongation in strained sheets (Figures 4 and 9). Ball mill beating produces few dislocations in fibre walls (6). The low Lampen stretch values are reflected in the low tensile energy relation (Figure 5). Although the integrated stress — strain curve may be independent of wood quality (1), it is strongly affected by beater type (Figure 5).

Valley beater: Sheet density and stretch but not breaking length appear to be related to scattering coefficient for all beaters except the Lampen mill (Figures 7, 8 and 9). Relative to the PFI mill, handsheets prepared from Valley beaten pulps have high breaking lengths at low densities (Figure 3). Because each beater shortens fibres to a similar extent (3), factors other than bonded area and fibre dimensions appear to be responsible for the breaking length variation between Valley beater and PFI (10 per cent) mill processed pulps. Present evidence suggests that Valley beaten pulps contain fibres ranging from lightly beaten and stiff to heavily beaten and flexible. The stiffer fibres may form a network about which the more flexible fibres are distributed. Other factors which may influence breaking length and not bonded area are the relatively high degree of intrafibre disorganization and the wide variation in fibre surface structure in Valley beaten pulps (4). The surface structure variation could possibly increase bond strength although this is unlikely.

PFI mill at 25 per cent stock concentration: Although pulps processed in the Valley beater and PFI mill give similar sheet density — scattering coefficient curves (Figure 7) handsheets prepared from pulps beaten at

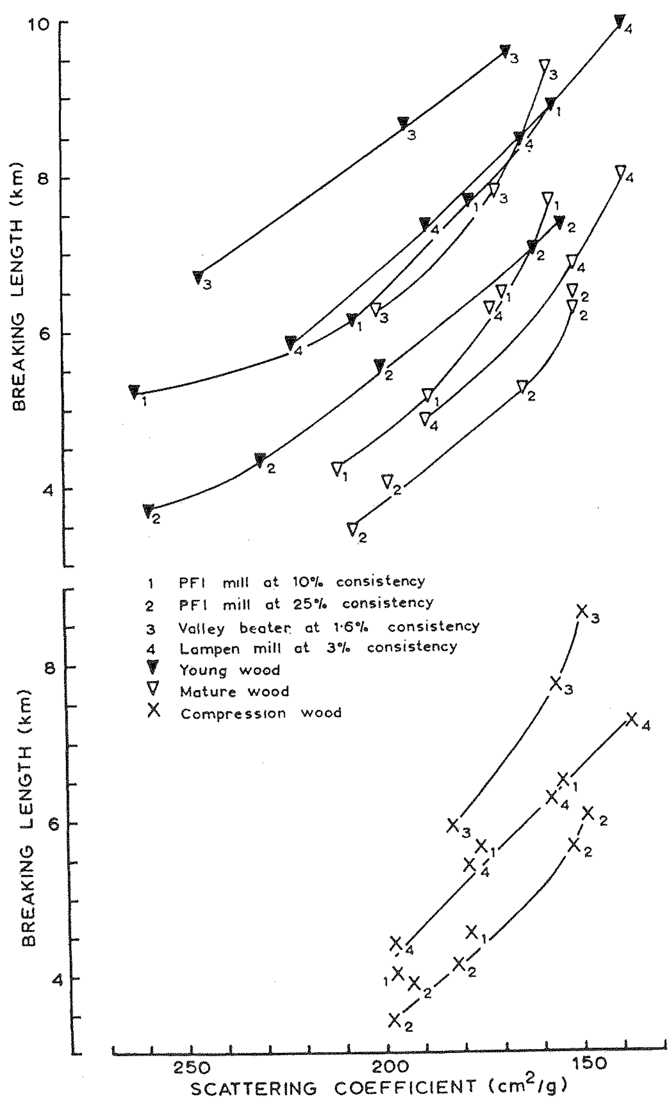

Fig. 8 — Effects of beaters — breaking length and scattering coefficient.

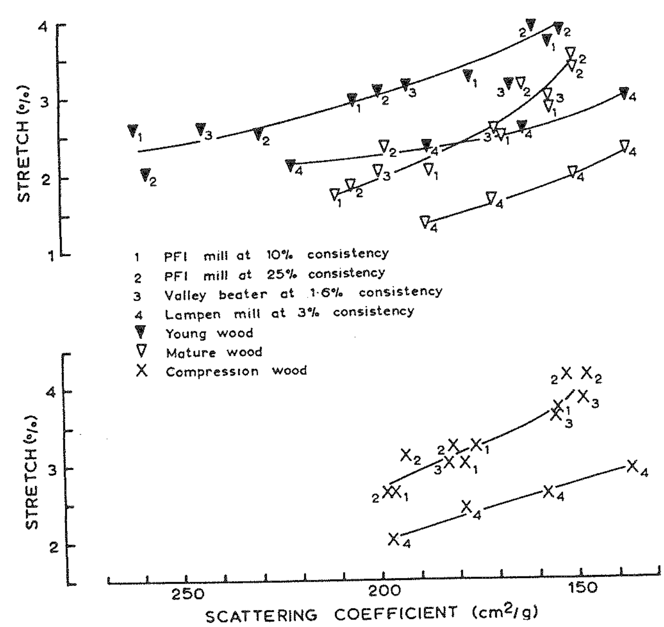

Fig. 9 — Effects of beaters — stretch and scattering coefficient.

high consistency have low breaking lengths (Figures 3 and 8). The large number of microcompression dislocations (6) and the low flexibility of fibres processed in the PFI mill (25 per cent) possibly account for the low breaking lengths. Where microcompressions are located within the bonded surfaces of moderately stiff fibres, they are probably points of bond failure in sheets under stress. Such bond discontinuities would probably not be detected by light-scattering techniques. The development of microcompression dislocations by beating apparently does not necessarily increase fibre flexibility (6).

The above explanation is supported by the stretch, density and scattering coefficient relations (Figures 4, 7 and 9). Although relative bonded area is directly related to stretch and sheet density, the 25 per cent PFI mill stretch — density curves deviate from those of the other beating treatments (Figure 4). The different slopes of the PFI mill (25 per cent) curves are possibly related to bond discontinuities caused by moderately stiff fibres with many microcompression dislocations.

The PFI mill at high consistency is the only beating treatment which gives separate stretch-density curves for young and mature wood pulps (Figure 4) (2). Although stretch is apparently unaffected by changes in fibre dimensions and fibre density, it is strongly affected by changes in intrafibre structure (1). The development of microcompression dislocations in the stiff high consistency beaten pulps modifies intrafibre structure and separate young and mature wood curves are obtained. The longer mature wood (1) fibres probably have more microcompressions throughout their length than the shorter young wood fibres.

Tear factor

PFI mill beating at 25 per cent consistency produces extensive microcompression dislocation of moderately stiff fibres. The low apparent "bond strength" of such fibres may decrease fibre fracture and increase frictional forces between fibres when paper is torn. This explanation could account for the extremely high tear factors obtained with pulps processed at high consistency (Figure 6). The low tearing strength obtained with Valley and Lampen beaten pulps is probably associated with flexible fibres.

High consistency PFI mill beating gives handsheets with high tear factors for given breaking lengths, relative to the other beating treatments examined (Figure 10).

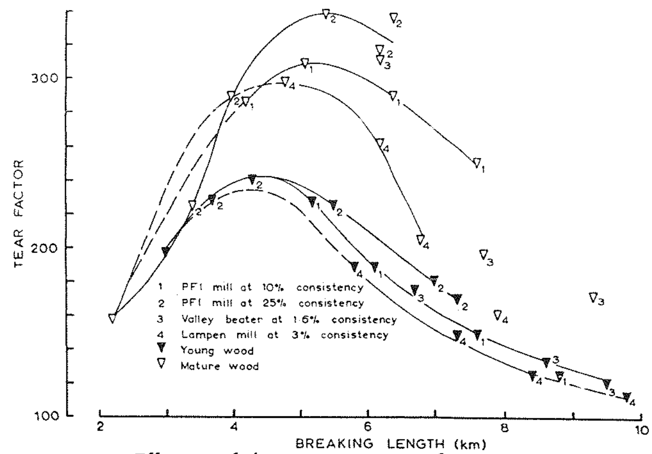

Fig. 10 — Effects of beaters — tear factor and breaking length.

CONCLUSIONS

Fibres are modified in different ways by a Valley beater, a Lampen mill, and a PFI mill at 10 and 25 per cent stock concentration. In each case, different paper properties are obtained which can usually be explained in terms of the beating action, wood quality, fibre surface and intrawall structure, and fibre flexibility.

Factors other than bonded area (estimated by scattering coefficient) and fibre dimensions can influence handsheet breaking length values).

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