Paper II

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Effect of External Fibrillation on Paper Strength

By T. KANG and H. PAULAPURO

Abstract: Using an ultra-fine friction grinder, it was possible to promote mostly external fibrillation while keeping the internal fibrillation constant, which made it possible to examine the effect of external fibrillation on paper strength. Although sheet density was strongly dependent on internal fibrillation, it could also be increased by promoting mostly external fibrillation, which resulted in a further improvement in tensile and Scott bond strength.

Beating of chemical pulp is an essential step in improving the bonding ability of fibres, causing a variety of simultaneous changes in fibres, such as internal fibrillation, external fibrillation, fibre shortening or cutting, and fines formation [1-2]. The simultaneous occurrence of these effects in conventional industrial refiners and laboratory-scale refiners makes it difficult to assess the relative importance of these effects for paper strength. Among the effects, the internal fibrillation of fibres plays a major role in the development of paper strength, because it improves the flexibility and collapsibility of fibres, which are essential for inter-fibre bonding — an aspect which seems to be gaining more attention. Furthermore, the solute exclusion technique has been widely used for measuring the level of internal fibrillation of fibres [3], which makes it easier to assess the effect of internal fibrillation on paper strength.

An effort has been made to separate the effect of internal and external fibrillation of fibres, and fines formation on paper strength [4]. According to this research, the breaking length of a sheet depends on the internal fibrillation of fibres and on the amount of fines added to the furnish, but is not affected by external fibrillation, though sheet density is increased. The increased density may improve some other properties than breaking length. External fibrillation is closely related to fines formation [5-6], and external fibrils attached to the fibre can be expected to play a similar role as fines in the fibre network, improving certain strength properties of paper. There is no commonly accepted technique available to quantify the degree of external fibrillation, though several efforts [5, 7-9] have been made to develop such a technique. This also makes it difficult to understand the relative importance of external fibrillation for paper strength. However, the potential role of external fibrillation in improving paper strength cannot be ignored.

The objective of the present study was to evaluate the effect of external fibrillation on paper strength. This was done using an ultra-fine friction grinder, controlling the degree of internal and external fibrillation of fibres separately.

EXPERIMENTAL

Once-dried bleached kraft softwood pulp, consisting of a mixture of Scots pine (56%) and Norway spruce (44%), was obtained from a Finnish pulp mill. The pulp was disintegrated for 10 min, and then beaten for 10 min and 30 min in a Valley beater (ISO 5264-1:1979). These pulps were used as reference pulps. The disintegrated pulp was refined separately in an ultra-fine friction grinder (super masscolloider®, Masuko Sangyo Co.Ltd., Japan) under the conditions shown in Table I.

The ultra-fine friction grinder shown in Fig. 1 consists of two grinding stones having a diameter of 250 mm: a lower rotating one and an upper stationary one. The gap clearance between the two stones can be adjusted by operating a handle which moves the rotating stone vertically in 20 µm increments. The pulp passing through the gap between the stones is subjected to compressive and shear forces. The gap varies between 0 and 230 µm. A smaller gap results in closer contact. The grinding stones are composed of either Al_2O_3 (grit class 80) or SiC (grit class 46). The surface of the outer periphery of the stone is rather flat and the tapered inner part is grooved, which allows the gap to be narrowest at the outlet of the grinder and widest at the inlet or inner part. Treated pulp is discharged by centrifugal force and can be recirculated manually to the inlet of the grinder, if necessary. The rotating speed can be raised to about 3000 rpm with a frequency converter [6].

The long-fibre fraction (>100 mesh) was collected using a Bauer-McNett classifier and used for measuring the fibre properties and for handsheet preparation. The fines content of whole pulp was measured using a Bauer-McNett classifier according to SCAN-M 6:69. In this study, fines are defined as the fraction passing through a 100 mesh screen. The curl index was measured using a FiberLab 3.0 (Metso Automation). The degree of internal fibrillation was measured as the fibre saturation point (FSP) with solute exclusion [3] using a 2×10^6 Dalton dextran polymer (Amersham Biosciences AB, Uppsala, Sweden). The degree of external fibrillation was calculated based on images taken by a light microscope in phase contrast mode (DM LAM, Leica). At least 20 images each containing several fibres were further analyzed, using an image processing tool to

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TABLE I. Conditions in an ultra-fine friction grinder.

Variables	Condition
Gap [µm]	230 & 250
Rotating speed [rpm]	1500
Pulp consistency [%]	5
Grit class of the grinding stones	46 (grit size 297-420 µm)

TABLE II. Curl index.

Pulp passage (230 µm)	Curl (%)	Pulp passage (250 µm)	Curl (%)	Valley beating (min)	Curl (%)
0	22.4	0	22.4	0	22.4
1	22.1	1	22.5	10	18.4
7	21	6	21.6	30	17.5
14	21.1	14	21.6		
20	20.9	22	20.6		
30	19.7	30	20.2		

FIG. 1. An ultra-fine friction grinder [6].

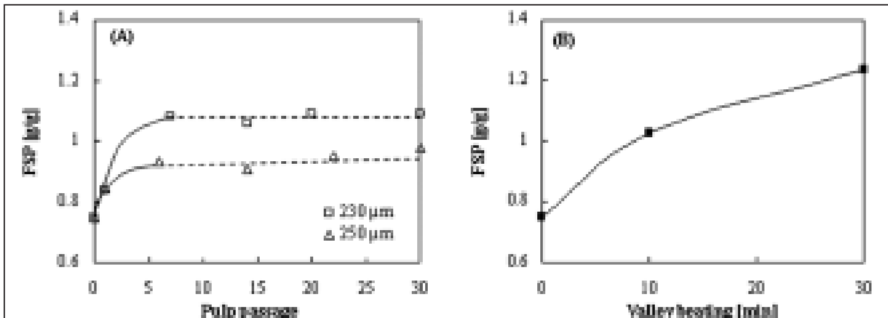

FIG. 2. Development of internal fibrillation of fibres. In Fig. 2 (A), the solid line represents the region where internal fibrillation is dominant, the dotted line the region where external fibrillation is dominant. Pulp passage is the number of pulp recirculations through the gap.

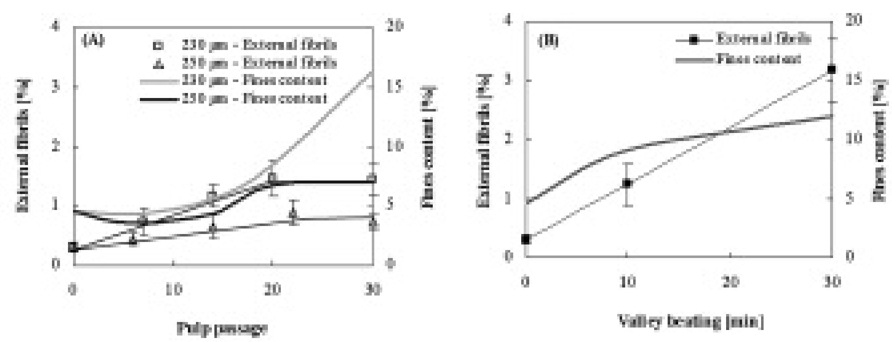

FIG. 3. Development of external fibrillation of fibres (R100) and fines formation (P100). Error bar are shown at 95% confidence level.

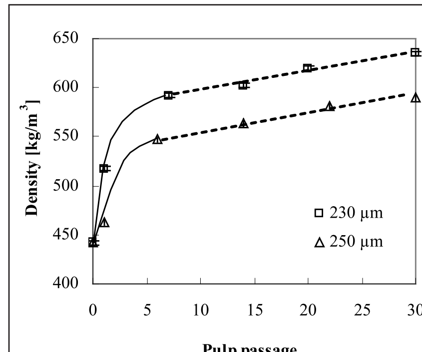

FIG. 4. Effect of fibrillation on density.

calculate the ratio between the area of external fibrils and the fibres, which allowed a quantitative measurement of the degree of external fibrillation. A sheet surface coated with platinum was observed using a scanning electron microscope (SEM, DSM 962, Zeiss) at 10 kV. Paper properties were evaluated according to standard methods.

RESULTS AND DISCUSSION

Control of external fibrillation and its characteristics

The gap clearance in the ultra-fine friction grinder is a very important variable in controlling the internal and external fibrillation of fibres separately. In the previous work [6], the FSP was found to reach a plateau after increasing initially at the gap of 230 µm. This plateau of the FSP was believed to be a region where mainly external fibrillation develops, without affecting the internal fibrillation of fibres.

Figure 2 shows the development of fibrillation of long fibres (R100 fraction). The FSP increases initially and thereafter remains constant, despite additional treatment in the grinder as shown in Fig. 2 (A). The region where internal fibrillation seems to be dominant is shown as a solid line, and the region where external fibrillation is dominant as a dotted line. These are shown in selected figures in this paper. The external fibrillation may develop mostly in the plateau of the FSP curve, since the shear forces generated at the gap of 230 µm and 250 µm in the ultra-fine friction grinder seem to fibrillate fibres mainly externally after 6 to 7 pulp passages. Figure 2 (B) shows the FSP curve of Valley-beaten fibres, which rises continuously as beating increases.

The degree of external fibrillation of fibres treated in the grinder and the Valley beater, and its relationship with fines formation are shown in Figs. 3 (A) and (B), respectively. As the pulp is increasingly recirculated through the gaps of 230 µm and 250 µm in the grinder, external fibrillation increases. Although the FSP reaches the plateau shown in Fig. 2 (A), external fibrillation is further increased in the plateau, increasing more at a smaller gap, as shown in Fig. 3 (A). External fibrillation and fines formation caused by the shear forces in the grinder are minor effects in the beginning of FSP development. Fines formation increases continuously along with the increase in external fibrillation, except for 30 pulp passages at the gap of 230 µm, for which a higher fines content is shown at a given degree of external fibrillation.

In contrast to beating in the grinder, in the Valley beater internal and external fibrillation increase simultaneously. This is shown in Fig. 2 (B) and Fig. 3 (B). Fines formation correlates well with the degree of external fibrillation. The increase in fines content slows down in the later stage of beating in the Valley beater, while external fibrillation continues to increase.

It is well known that fibres are straightened in beating, enhancing the mechanical properties of paper [1, 10-12]. Therefore, minimizing the changes in curl would be ideal for the purposes of this study, because this would allow evaluating the effect of external fibrillation on paper strength. Table II shows the changes in curl index as beating increases in the grinder and the Valley beater. Although the fibres treated in the grinder are only slightly straightened, they can all be considered rather curly, whereas the fibres treated in the Valley beater are more straightened under compressive and shear forces. A curl index of about 10% is considered to indicate a straight fibre, and an index of about 20% a curly fibre [10].

The collapsibility and conformability of fibres caused by internal fibrillation play an important role in the development of sheet density. Although sheet density (sheet consolidation) is caused mostly by internal fibrillation of fibres, it can also be increased further by promoting mainly external fibrillation, as shown in Fig. 4. The external fibrils evidently increase Campbell's forces, resulting in improved consolidation of the sheet, as suggested by Giertz [12-13].

Figure 5 shows SEM images of a handsheet surface. The increase in external fibrils is clearly seen between 7 and 30 passages, which have a similar FSP. This confirms that external fibrillation becomes dominant in the plateau of the FSP curve shown in Fig. 2 (A). As the number of external fibrils increases, a film-like structure becomes apparent. Nanko and Ohsawa [14] have suggested that this structure increases the contact area between fibres and distributes the stress concentration evenly, resulting in improved bond strength.

Figure 6 shows the effect of fibrillation on the light scattering coefficient. In the region where external fibrillation is dominant, light scattering decreases slightly. According to Retulainen [15], light scattering decreases only slightly when kraft fines are added to the long-fibre fraction of kraft pulp. External fibrils were found to increase in the region where external fibrillation is dominant and seemed to act in the same way as pulp fines.

Effect of external fibrillation of fibres on paper strength

Figures 7 (A) and (B) show the relationship between internal and external fibrillation, and tensile strength. It is evident that an increased degree of internal fibrillation strongly promotes tensile strength. However, the strength of pulp

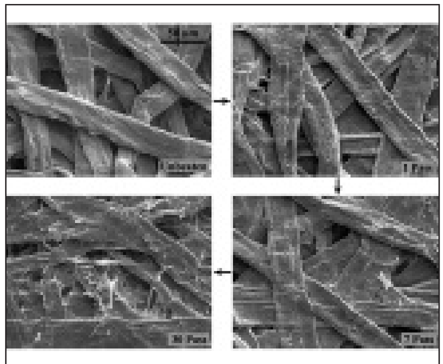

FIG. 5. SEM images of a handsheet surface. Pulp treated at 230 µm in ultra-fine friction grinder.

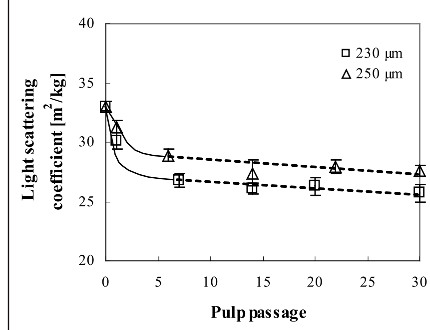

FIG. 6. Effect of fibrillation on light scattering coefficient.

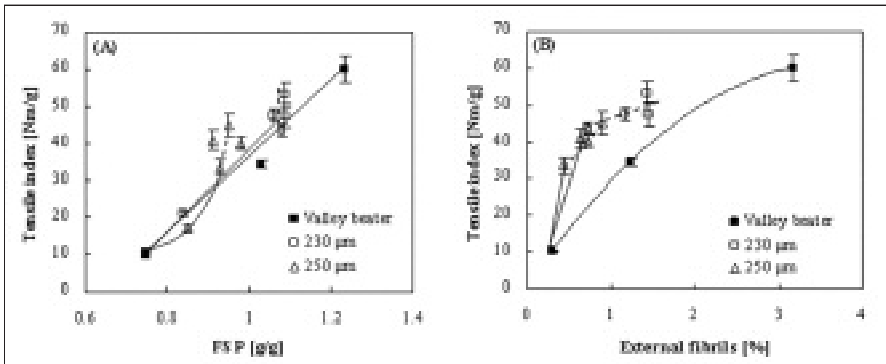

FIG. 7. Effect of fibrillation on tensile strength of long-fibre fraction (R100) beaten in a Valley beater and an ultra-fine friction grinder.

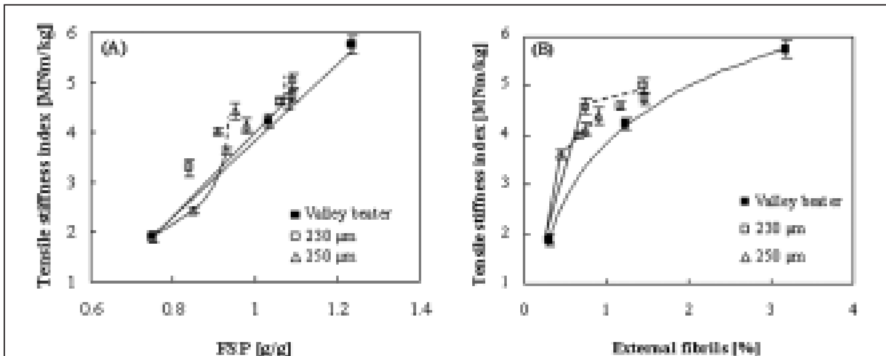

FIG. 8. Effect of fibrillation on tensile stiffness of long-fibre fraction (R100) beaten in a Valley beater and an ultra-fine friction grinder.

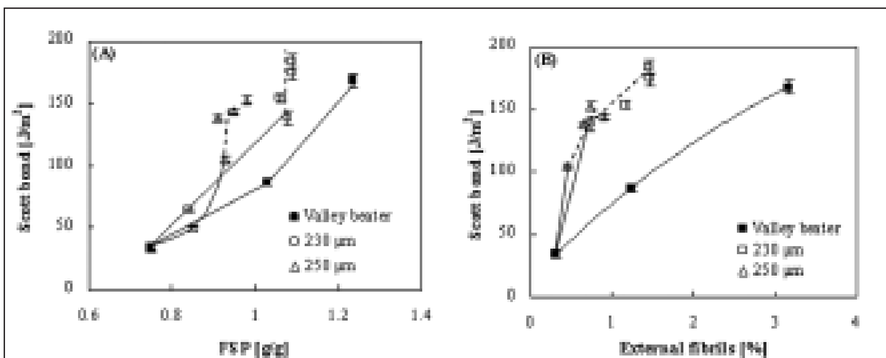

FIG. 9. Effect of fibrillation on internal bond strength of long-fibre fraction (R100) beaten in a Valley beater and an ultra-fine friction grinder.

treated at both 230 μm and 250 μm in the grinder is further promoted by external fibrillation, with the tensile index increasing by about 20% (shown as a dotted line). This result does not agree with Hartman's work [4], according to which external fibrillation results in increased density without affecting tensile strength. Internal and external fibrillation increase simultaneously throughout beating in a Valley beater. This makes it difficult to assess their relative importance for strength development.

The increase in the tensile stiffness index caused by external fibrillation shows a similar trend as the tensile index, as shown in Figs. 8 (A) and (B). The tensile stiffness caused mostly by external fibrils increases by about 9% and 14% for fibres treated at 230 μm and 250 μm, respectively, although internal fibrillation of fibres plays a major role in activating the sheet.

Figures 9 (A) and (B) show the relationship between the fibrillation of fibres and the internal bond strength of a sheet. As expected, fibre swelling improves the bond strength for all sheets. Fibres treated in the grinder show higher strength than Valley-beaten fibres at a given degree of internal and external fibrillation. The quality of fibrils attached to fibres treated in the grinder probably differs from that of fibrils attached to Valley-beaten fibres. The strength produced by external fibrils increases by 33% and 46% (shown as a dotted line) for pulp treated at 230 μm and 250 μm, respectively. The increase in internal bond strength produced by a higher degree of external fibrillation is greater than the increase in tensile strength. Therefore, it is apparent that external fibrils contribute more to internal bond strength than tensile strength.

CONCLUSIONS

Promoting mostly external fibrillation while keeping the internal fibrillation constant made it possible to examine the role of external fibrillation for the development of the strength of the fibre network. External fibrils still attached to the fibres further improved the consolidation of the sheet. The light scattering caused by the increase in external fibrils decreased slightly. The increase in external fibrils seemed to act in the same way as pulp fines added separately.

Although paper strength properties such as tensile strength and Scott bond strength were strongly influenced by internal fibrillation, these could also be increased further by promoting mostly external fibrillation. In this experiment, the tensile index was increased by about 20% and Scott bond strength by 46% by promoting mostly external fibrillation.

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Résumé: La présente étude examine l'effet de la fibrillation externe des fibres de pâte chimique sur la résistance du papier. À l'aide d'un broyeur à friction ultra-fin, il a été possible de favoriser surtout une fibrillation externe tout en maintenant la fibrillation interne constante, ce qui a permis d'examiner l'effet de la fibrillation externe sur la résistance du papier. Bien que la densité de la feuille dépendait largement de la fibrillation interne, nous avons aussi pu l'augmenter en favorisant surtout la fibrillation externe, ce qui a permis d'améliorer encore davantage la résistance à la traction et la cohésion interne Scott.

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