Paper IV

Kang, T., Somboon, P. and Paulapuro, H., Fibrillation of Mechanical Pulp Fibers. *Paperi ja Puu*. 88(2006)7, p.409-411**.**

PEER-REVIEWED

Taegeun Kang, Phichit Somboon, Hannu Paulapuro[1]

Fibrillation of mechanical pulp fibers

Keywords:
Fibrillation, ultra-fine friction grinder, Lampen mill, shear forces, compressive forces, mechanical pulp.

Abstract

The objective of this study was to expand the knowledge of the mechanism governing fibrillation of mechanical pulp under compressive and shear forces, and to examine its effect on pulp and paper properties. The compressive forces generated in a Lampen mill promoted neither internal nor external fibrillation of mechanical pulp fibers. However, the shear forces generated in an ultra-fine friction grinder fibrillated fibers mainly externally, resulting in increased density, bond strength and light scattering of the sheet. Shear forces seem to be more important than compressive forces in improving the strength of mechanical pulp.

Introduction

Mechanical treatment in post-refining or reject refining plays an important role in developing mechanical pulp to its desired quality level, involving fibrillation of fibers which is essential for promoting the bonding between fibers. However, the fibrillation of mechanical pulp is different from that of chemical pulp. Swelling develops well in chemical pulp fibers, while in mechanical pulp fibers it is restricted by the lignin-rich structure of the fiber wall /1–3/. Instead, the peeling-off mechanism is believed to dominate in the development of mechanical pulp fibers during mechanical treatment /4/. Therefore, external fibrillation appears to play an important role in developing the strength of a mechanical pulp fiber network.

Pulp fibers are developed under complicated cyclic compressive and shear forces during refining. In a previous study /5/, an attempt was made to separate the contribution of different forces to chemical pulp quality, concluding that compressive forces contribute to internal fibrillation and shear forces to external fibrillation; the effects of changes in pulp quality on paper properties were also examined. These findings prompted a need to expand the knowledge of the mechanism governing the fibrillation of mechanical pulp by examining the separate forces involved.

In the present study, a Lampen mill which generates compressive forces /6–7/ and an ultra-fine friction grinder which generates shear forces at a larger gap /8/ were used to fibrillate mechanical pulp fibers. The objective was to provide a better insight into the mechanism governing fibrillation and its effect on pulp and paper properties.

Experimental

Pulp used

Thermomechanical pulp (TMP) with a freeness of 545 ml was taken from the reject line of the first-stage refiner in a Finnish pulp mill. The pulp, made from Norway spruce (*Picea abies*), was supplied at 40% dry solids and stored at -25 °C before use.

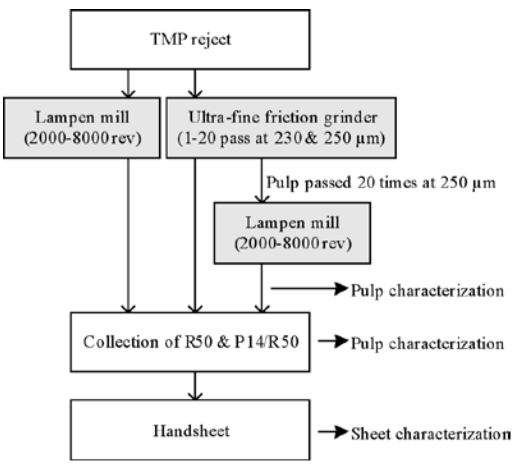

Fig. 1. Experimental design for fibrillation of TMP.

Fibrillation of mechanical pulp

Fig. 1 shows the experimental design for fibrillation of TMP. An ultra-fine friction grinder /8/ and a Lampen mill /6/ were used to fibrillate mechanical pulp fibers. Pulp heated to about 60 °C was used in both devices. This temperature is used in the reject refiner at the Finnish pulp mill where the pulp was obtained from.

The operating principle of the grinder is described in an earlier publication /8/. The rotating speed was 1500 rpm. The grit class of the grinding stone was 46 (grit size 297– 420 µm). The pulp was circulated up to 20 times through gaps of 230 µm and 250 µm at a consistency of 5%.

The Lampen mill /6/ is a rotating-ball mill consisting of a 10-kg ball and a housing. Pulp with consistency of 3% was treated in the Lampen mill with 2000, 5000 and 8000 revolutions. In addition, pulp circulated 20 times through the 250 µm gap in the grinder was treated separately in the Lampen mill under the same conditions as the untreated pulp.

After treatment in the grinder and the Lampen mill, the long-fiber fraction (R50) was collected using a Bauer-McNett classifier and used for measuring the fiber saturation point (FSP) and water retention value (WRV), and for handsheet preparation. The long-fiber fraction (P14/R50), excluding shives, was also collected and used for preparing a shive-free sheet.

Fiber and sheet characterization

The CSF (ISO 5267-2:2001), fiber length distribution (Bauer-McNett classifier; SCAN M 6:69) and PFI mini shives (SCAN-M 13) were measured. The degree of internal fibrillation was measured in terms of WRV (SCAN-C 102 XE) and FSP with the solute exclusion method /2/ using a 2×10^6 Dalton dextran polymer (Amersham Biosciences AB, Uppsala, Sweden).

To observe the external fibrils using a scanning electron microscope (SEM), fibers were dehydrated through a series of graded ethanol concentrations for 10–15 min each in 50, 70, 96 and 100% ethanol, and critical-point-dried using liquid CO_2 (BAL-TEC CPD030, Bal-Tec Union Ltd., Liechtenstein). SEM observation was carried out on both platinum-coated surfaces of fibers and a sheet using a DSM 962 (Zeiss, Germany) operated at 10 kV.

To observe the cross section of a sheet using a confocal laser scanning microscope (CLSM), the sheet was embedded in an epoxy resin, cured and polished, and then an appropriate amount of resin was removed ☛

1. Taegeun Kang, Phichit Somboon, Hannu Paulapuro, Laboratory of Paper Technology, Department of Forest Products Technology, Helsinki University of Technology, P.O.Box 6300, FI-02015, Finland. e-mail: tkang@cc.hut.fi

Table 1. Properties of pulps treated in the grinder.

Gap, µm	Pulp passage	Net refining energy, kWh/t	CSF, ml	Bauer McNett fractions, %			Shives, %
				R50	R200	P200	
	0	0	545	84.9	8.8	6.3	4
230	1	248	451	81.5	9.6	8.9	2.8
	3	498	339	-	-	-	-
	6	823	214	-	-	-	0.7
	10	1156	118	68	12.6	19.4	0.5
	15	1557	78	-	-	-	-
	20	1895	47	61.3	13.9	24.8	0.1
250	1	164	489	82.7	9.1	8.2	3.1
	3	379	401	-	-	-	-
	6	670	267	-	-	-	1.4
	10	904	167	71.7	11	17.3	1.1
	15	1245	110	-	-	-	-
	20	1536	80	67.7	12.1	20.2	0.6

Table 2. Properties of pulps treated in Lampen mill.

Rev	CSF, ml	Bauer McNett fractions, %			Shives, %
		R50	R200	P200	
0	545	84.9	8.8	6.3	4
2000	505	86.6	8.9	4.5	2.9
5000	508	-	-	-	-
8000	492	81.3	9.1	9.6	3.5
0*	80	67.7	12.2	20.2	-
2000	76	67.1	13.2	19.6	-
5000	74	-	-	-	-
8000	69	64.4	14.4	21.2	-

* Pulp ground at 250 µm circulated 20 times.

from the surface of the resin block. Further details of the sample preparation procedure are given elsewhere /9/. CLSM observation of the cross section of the sheet was carried out using a TCS SP II (Leica, Germany).

Standard 60 g/m^2 laboratory sheets were prepared from the R50 and P14/R50 fractions separately, and the paper properties were evaluated according to standard methods.

Results and discussion

Pulp properties

The changes in the weights of pulp fractions caused by mechanical treatment using the grinder and the Lampen mill are shown in Table 1–2. Shear forces generated in the grinder increased the fines content (P200) probably due to the fibrillation of the fiber surface, while the compressive force generated in the Lampen mill had little effect on the fines content. Shives were effectively disintegrated into fibers in the grinder while they remained unchanged in the Lampen mill. The degree of fibrillation seemed to be sensitive to changes in the gap clearance between the plates. A smaller gap in the grinder was found to produce more external fibrillation of fibers, resulting in more fines.

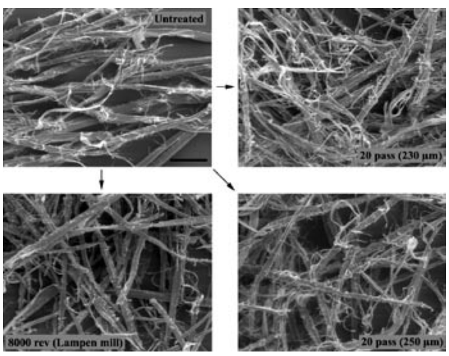

Fig. 2. SEM micrographs of fiber surface (R50 fraction). Fibers were dried using the critical-point-drying technique. Scale bar of 200 µm is shown in the top left image.

Fig. 2 shows SEM images of the surfaces of fibers treated under different forces in the grinder and the Lampen mill. The increase in external fibrillation is clearly seen in the fibers treated in the grinder, while the fibers treated in the Lampen mill show little change. As external fibrillation increases with mechanical treatment in the grinder, it is likely to reduce the coarseness of the fibers and to generate more collapsible and flexible fibers, as shown in an earlier study by Karnis /4/ and Corson /10/.

The swelling of the fiber fraction caused by shear or compressive forces is shown in Fig. 3. The restricted fiber swelling seems to remain unchanged even after treatment in the grinder and the Lampen mill. External fibrils still attached to the fibers can be considered as fibrillar fines, which have been shown to result in increased swelling /11/, but an increase in fibrillation caused by grinding action does not improve the overall swelling of the fiber fraction.

The WRV shows a higher value than the FSP, which may be due to external fibrils between the fibers. This overestimation of the cell wall water measured in terms of the WRV has also been found in another study /12/.

Paper properties

Fig. 4–5 shows images of the surface and cross section of a sheet. As the peeling action increases in the grinder, a denser structure becomes apparent in the surface and in the cross section. In contrast, compressive forces generated in the Lampen mill do not seem to change the structure of fibers. This might be due to the elastic deformation behavior of the coarse fibers under compressive forces /13/. In other words, the compressive forces generated in the Lampen mill might not be enough to cause plastic deformation of the fibers at the given temperature. It is apparent that the temperature plays a key role for the plastic deformation of wood fibers caused by compressive forces /13–15/, but in this study a temperature well below the lignin softening temperature was used both for the grinder and the Lampen mill. The reason for using the lower temperature was to ensure fibrillation conditions similar to those used in some pulp mills.

Although the sheet structure becomes denser as the peeling-off mechanism proceeds in the grinder, the increase in external fibrils contributes to light scattering, as shown in Fig. 6. However, fibers treated in the Lampen mill do not affect light scattering.

The shear forces generated in the grinder are likely to be favorable for the peeling-off mechanism, which improves the density of the sheet, resulting in improved internal bond and tensile strength. This is shown in Fig.7–8. However, the compressive forces in the Lampen mill do not improve these properties. It was expected that fibers treated in the grinder before beating in the Lampen mill would be more susceptible to deformation by the compressive forces in the Lampen mill, but no further changes were found.

The shear forces have been found to remove shives and to increase the external fibrillation of fibers, and as a consequence of this development paper strength increases. To eliminate the effect of shives on paper strength, a shive-free sheet made from the P14/R50 fraction was evaluated, as shown in Table 3. The increase mostly in external fibrillation caused by the shear forces further increases the density of the sheet, resulting in improved tensile and internal bond strength. External fibrillation of mechanical pulp therefore appears to be an important factor in controlling the quality of mechanical pulp fibers.

Conclusions

The compressive forces generated in the Lampen mill promoted neither internal nor external fibrillation of mechanical pulp fibers, causing no changes in the FSP, density or Scott bond strength, nor any changes in

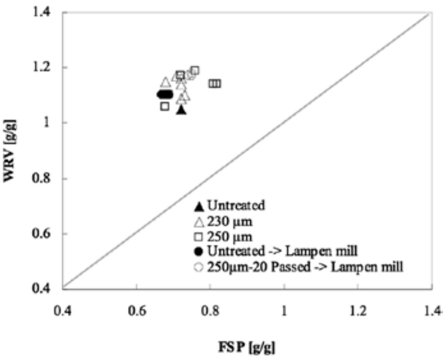

Fig. 3. Internal fibrillation of long-fiber fraction (R50).

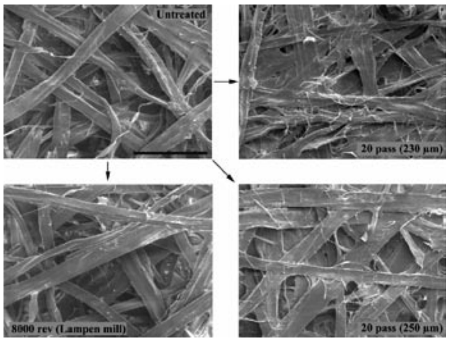

Fig. 4. SEM micrographs of a handsheet surface made of R50 fraction. Scale bar of 200 µm is shown in the top left image.

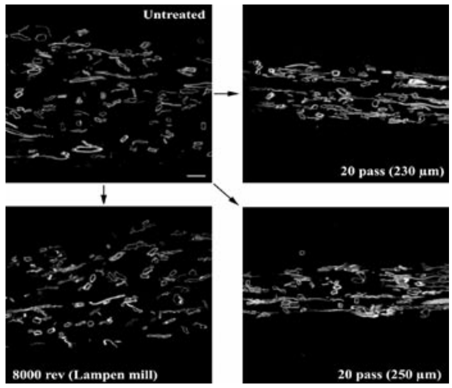

Fig. 5. CLSM micrographs of the cross section of a sheet made of R50 fraction. Scale bar of 80 µm is shown in top left image.

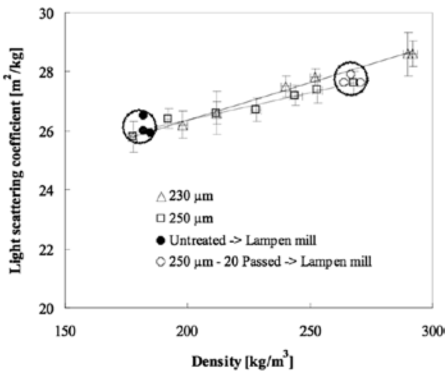

Fig. 6. Effect of fibrillation on light scattering coefficient of long-fiber fraction (R50).

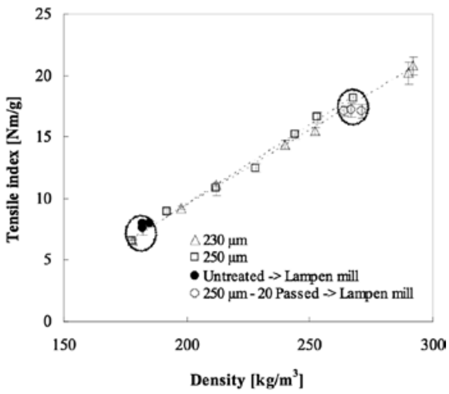

Fig. 7. Effect of fibrillation on tensile index of long-fiber fraction (R50).

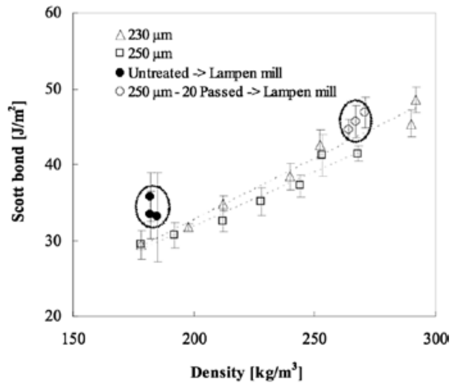

Fig. 8. Effect of fibrillation on internal bond strength of long-fiber fraction (R50).

Table 3. Properties of a sheet made from P14/R50 fraction. 95% confidence interval limits are included.

Gap, µm	Pulp passage	Density, kg/m³	Tensile index, Nm/g	Scott bond, J/m²
	0	218 ± 3	11.2 ± 0.3	40.1 ± 0.9
230	1	212 ± 2	9.4 ± 0.4	42.2 ± 2.9
	6	249 ± 3	12.6 ± 0.5	47.9 ± 2.7
	10	265 ± 3	15.7 ± 0.6	47.9 ± 2.2
	15	294 ± 2	19.2 ± 0.4	50.0 ± 1.4
250	1	209 ± 3	8.9 ± 0.4	40.1 ± 1.8
	6	230 ± 1	11.4 ± 0.4	42.9 ± 2.3
	10	245 ± 2	12.5 ± 0.3	43.7 ± 2.3
	15	269 ± 2	15.3 ± 0.4	49.2 ± 2.3

these properties in fibers previously treated in the grinder before beating in the Lampen mill. These results are different from those obtained with chemical pulp treated in a Lampen mill /7/. To gain a better understanding of how mechanical pulp responds to compressive forces, further experiments should be carried out in which mechanical pulp is beaten under harsher conditions at a higher temperature in a Lampen mill.

The shear forces generated in the grinder were found to fibrillate fibers mainly externally, resulting in improved density, bond strength and light scattering of the sheet. Shear forces therefore seem to be more important than compressive forces in improving the strength of mechanical pulp.

Acknowledgements

We would like to thank Leena Nolvi for conducting the FSP measurements and Mika Siviö for the CLSM observations.

References

1. *Stone, J.E., Scallan, A.M.*: The effect of component removal upon the porous structure of the cell wall of wood. Part III. A comparison between the Sulphite and Kraft processes. Pulp Paper Mag. Can. 60(1968):12, 69–74.
2. *Stone, J.E., Scallan, A.M., Abrahamson, B.*: Influence of beating on cell wall swelling and internal fibrillation. Svensk Papperstidn. 19(1968):10, 687-694.
3. *Eriksson, I., Haglind, I., Lidbrandt, O., Salmen, L.*: Fiber swelling favoured by lignin softening. Wood Sci. Technol. 25(1991):2, 135–144.
4. *Karnis, A.*: The mechanism of fibre development in mechanical pulping. J. Pulp Pap. Sci. 20(1994):10, J280–J288.
5. *Hartman, R.R.*: Mechanical treatment of pulp fibres for property development. Doctoral Thesis. The Institute of Paper Chemistry, Appleton, USA. 1984, p.127.
6. *Cohen, W.E.*: The performance and use of the Lampen mill in Australia. Proceedings of the 2nd APPITA Annual Conference. Hobart, Australia. Apr. 13, 1948, p.84–117.
7. *Wang, X., Paulapuro, H.*: Effects of various refining on dry sheet properties of commercial never-dried and dried Kraft softwood pulps. Proceedings of 91st Annual Meeting. PAPTAC, Montréal, Canada. Vol.B, Feb. 7–10, 2005, p.13–21.
8. *Kang, T., Paulapuro, H.*: New mechanical treatment of chemical pulp. Proceedings of The 2004 Progress in Paper Physics Seminar. NTNU and PFI, Trondheim, Norway. June 21–24, 2004, p.11–13.
9. *Williams, G.J., Drummond, J.G.*: Preparation of large sections for the microscopical study of paper structure. J. Pulp Pap. Sci. 26(2000):5, 188-193.
10. *Corson, S.R., Ekstam, E.I.*: Intensive refining of radiata pine fibre. Pap. Puu. 76(1994):5, 334–339.
11. *Luukko, K., Maloney, T.C.*: The swelling of mechanical pulp fines. Cellulose. 6(1999):2, 123–135.
12. *Maloney, T.C., Laine, J.E., Paulapuro, H.*: Comments on the measurement of cell wall water. Tappi J. 82(1999):9, 125–127.
13. *Salmen, L., Dumail, J.F., Uhmeier, A.*: Compression behaviour of wood in relation to mechanical pulping. Proceedings of International Mechanical Pulping Conference. SPCI, Stockholm, Sweden, June 9–13, 1997, p.207–211.
14. *Uhmeier, A., Morooka, T., Norimoto, M.*: Influence of thermal softening and degradation on the radial compression behavior of wet spruce. Holzforschung 52(1998):1, 77–81.
15. *Salmén, L., Tigerström, A., Fellers, C.*: Fatigue of wood-characterization of mechanical defibration. J. Pulp Pap. Sci. 11(1985):3, J68–J73.

Received August 5, 2005