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Disrupting the wall structure of high-freeness TMP pulp fibres and its effect on the energy required in the subsequent refining

By P. Somboon, T. Kang and H. Paulapuro

Abstract: A treatment disrupting the wall structure of high-freeness TMP pulp fibres and its effect on the energy consumption in the subsequent refining were studied. Subjecting the pulp fibres to an abrasive material resulted in the disruption, opening, peeling-off, and weakening of fibre cell walls. In the subsequent refining, the pulp quickly developed to the desired quality for the making of paper, while the energy consumption in refining was reduced. Laboratory sheets showed no significant degradation of mechanical and optical properties.

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Reducing the energy consumption in refining is one of the most important aims of research related to the production of mechanical pulps. Among mechanical pulping techniques, refiner-based processes require considerably more energy than stone grinding [1]. Several researchers have attempted to reduce the energy consumption in refining by modifying the surface of refiner segments to make them resemble the pulpstone surface, for example, making abrasive surfaces on the outside of refiner plates [2, 3], filling the plate grooves with a pulpstone-like matrix [4] and coating the plate bars with an abrasive material [5]. According to some of this research, this kind of modification offers potential for reducing the consumption of energy in refining. However, these techniques have not been successful in practical applications because of problems with the modification of segments, the operation of refiners, and the intensive destruction of pulp fibres [2-7].

In the present research, the focus was on the application of abrasive treatment to TMP refining and the modification of refiner segments as a means to bring about a disruption of fibre cell walls. To be able to develop this technique for industrial use, the underlying mechanism in the development of wood fibres, which involves a combination of grinding and refining, needs to be better understood. The objectives of this study were to examine the change in the wall structure of high-freeness TMP pulp fibres and their critical properties when pretreated by an abrasive material, and to evaluate the potential for reducing the energy consumption in the subsequent refining of the pretreated pulps under typical TMP refining conditions.

EXPERIMENTAL

The experiment consisted of two stages of treatments on high-freeness TMP pulp fibres. In the first stage, the pulp fibres were pretreated with an abrasive material to various levels of pulp freeness to examine the changes in fibre structure. In the second stage, the pretreated fibres were further refined under TMP refining conditions to evaluate the required energy, and examine the pulp and paper properties. The experimental schematic is shown in Fig. 1.

Raw materials: High-freeness TMP pulp made from Norway spruce (*Picea abies L. Karst.*), having CSF of 574 ml, collected from a reject line at UPM-Kymmene's Kaipola mill, was used as raw material.

Abrasive treatments: Abrasive treatments (pretreatments) were carried out using an ultra-fine friction grinder [8, 9] equipped with abrasive stones, Fig. 2, having a grit size number of 46 in both the rotor and stator. The grinder was operated with a peripheral speed of 1500 rpm. The grinding position was controlled at the contact point of the stones in the motion stage [10]. The pulp slurry feed was controlled at a low consistency of 4%. The degrees of pretreatment were targeted at a freeness of 400 ml (slight disruption), 300 ml (low disruption), and 200 ml (high disruption). After the pretreatments, all pulps were sampled for testing and thickened for refining in the subsequent stage.

Subsequent refining: Subsequent refining of pretreated pulps was carried out using a wing defibrator at Helsinki University of Technology. Figure 3 shows the construction of the wing defibrator. The defibrator was operated under typical TMP refining conditions, with a peripheral speed of 750 rpm. The pulp feeds were controlled at a consistency of 23% and dry weight of 150 g. The pulps were refined under various specific energy consumptions from 1 to 5 MWh/t and a temperature of 130°C without preheating. The input of electric energy in the wing defibrator was measured using a frequency inverter and computational units. No-load power was measured before refining for each sample under testing conditions.

Sample testing: The drainability of pulp fibres and laboratory sheets were tested with the whole pulp according to SCAN and ISO standards. Drainability was analysed using a Canadian standard freeness tester. Laboratory sheets were formed with a circulated white water and dried

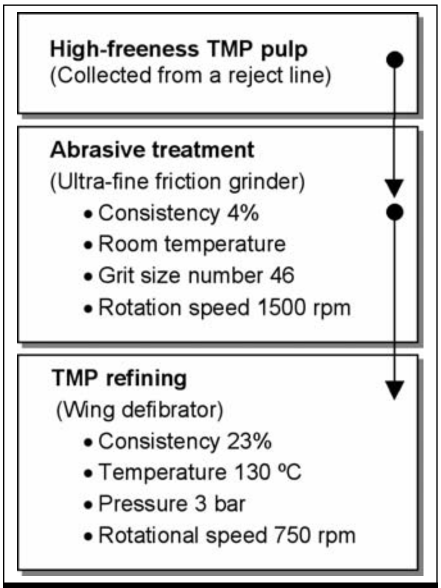


FIG. 1. Experimental schematic of the treatment of high-freeness TMP pulp fibres with a combination of abrasive treatment and TMP refining.

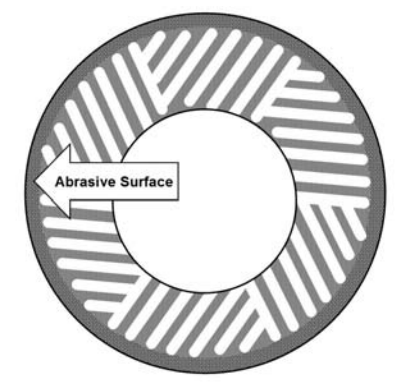


FIG. 2. View of the abrasive plate of an ultra-fine friction grinder with a grit size number of 46 (grit diameter 297- 420 μm).

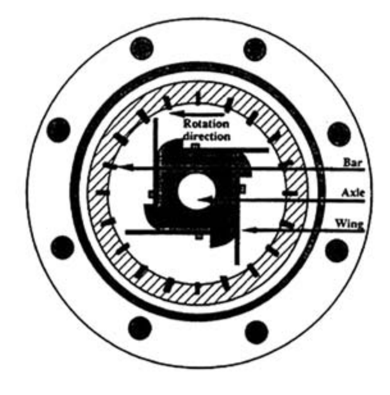


FIG. 3. Construction of a wing defibrator [11].

on a drum dryer. The physical properties of laboratory sheets were determined according to ISO standards.

Fibre length and fibre coarseness were measured using the Kajaani FiberLab according to TAPPI standards. Fibre length was measured with fractionated pulp collected from a Bauer McNett classifier with a 200-mesh screen (R200). The pulp used for analysing fibre coarseness was collected from a 50-mesh screen (R50).

To analyze the breaking of the fibre wall structure, the micropore volume in the cell wall of fractionated fibres (R200) was analyzed. The measurement was made at the Helsinki University of Technology using a differential scanning calorimeter based on the thermoporosimetry method with an isothermal step melting technique [12].

The strength of wet fibres (R50) was determined based on derivation of the breaking stress of wet paper strips at a zero span, and the number of fibres bearing the load [13].

The morphological changes in fibres were observed with long fibres and fines. The long fibres were collected from a Bauer McNett classifier with a 30-mesh screen. The fines were separated using a dynamic drainage jar with a 200-mesh screen. External fibrillation and splitting of the long fibres were analyzed based on the KCL method. The images of long fibres and fines were taken using a scanning electron microscope (SEM) at the Institute of Biotechnology of the University of Helsinki. The fibres for SEM observation were dehydrated through a series of graded ethanol concentrations and critical-point-dried using liquid carbon dioxide before the taking of images.

RESULTS AND DISCUSSION

Effects of abrasive treatment on fibre properties: Figure 4 shows the surface morphology of high-freeness TMP pulp fibres collected from a reject line. Two fibre layers can be clearly distinguished: a thin covering layer and an interior layer with exposed (band-like) fibrillation along the fibre surface. In the magnified pictures, the exterior layers consist of randomly oriented fibrils, indicating that it is probably a primary wall or a secondary wall S1. The interior layers with an oriented fibrillar structure suggest that it is a secondary wall S2 [14-16].

Figure 5 shows the effect of abrasive treatment on high-freeness TMP fibres, with a clear increase in external fibrillation. Figure 6 shows fines material in the treated pulp at CSF of 269 ml consisting of flake-like particles whose shape is similar to the outer layer of high-freeness fibres, as in Fig. 4. This implies that the flake-like particles are probably derived from the primary wall and the S1 layer. The fines also contain band-like materials, which are the same as the interior layer of the high-freeness fibres, Fig. 4. This suggests that they might have been generated from the S2 layer.

Table I shows the effects of the abrasive treatment on fibre properties. The treatment lowers freeness and reduces fibre length. The micro-pore volume of the cell wall is increased. Fibre coarseness is clearly reduced by the degradation of the strength of the wet fibres. Based on these results, it is postulated that abrasive treatment with an ultra-fine friction grinder has an impact on high-freeness TMP pulp fibres collected from the reject line. The treatment causes disruption of the wall structure, opening of the outer layers, peeling-off of the cell wall, weakening of the fibres, and a reduction of fibre length.

Effects of abrasive treatment on the subsequent refining: Figure 7 shows the development of drainability of pulp fibres as a function of energy consumption in the subsequent refining. The pulps pretreated to CSF of 269 ml and 152 ml display a steeper slope, indicating that a certain freeness level can be achieved with lower energy consumption. However, the trend-line slope of the slight disruption (CSF 474 ml) is almost similar to that of the reference pulp (CSF 574 ml).

The disruption caused by a very low level of abrasive treatment from CSF 574 ml to 474 ml did not show any potential for reduced energy consumption. It could be speculated that the raw material taken from the reject line has been treated intensively before the experiments. The pulp might be easily refined with a wing defibrator. Therefore, a rather high level of abrasive treatment is required to reveal the differences in energy consumption in the subsequent refining. However, these findings imply that in order to reduce the energy consumption, the pulp has to be disrupted to a level which causes the wall structure of fibres to be sufficiently fractured in order to allow easier development in further refining.

The potential for reduced energy consumption can be simply assessed from the differences in the trend-line slope of pulp freeness, as illustrated in Fig. 8. The energy consumption of the reference pulp is compared with the pulps disrupted to a CSF of 269 ml. Refining of the non-disrupted pulp is assumed to start at the same freeness as disrupted pulp from a freeness level of 269 ml to the desired freeness of 50 ml. This consumes 2.5 MWh/t of electric energy, whereas 2.1 MWh/t of energy is needed to develop the disrupted pulp. This means that the energy consumption in the subsequent refining is reduced by 16 %. The potential for reduced energy consumption of all treatments, calculated in the same way, is shown in Fig. 9.

Fibre and paper properties: Figure 10 shows the length-weighted fibre length of reference and pretreated pulps plotted

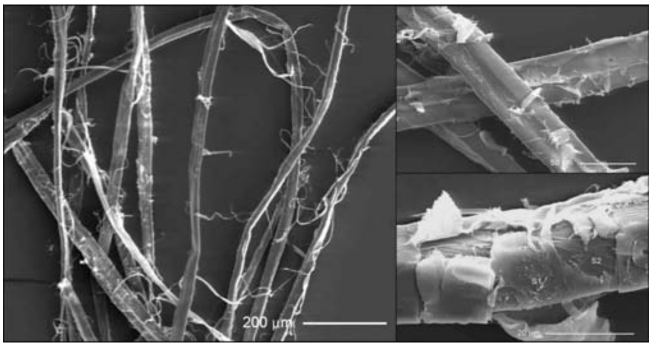


FIG. 4. High-freeness pulp fibres (R30) collected from reject line.

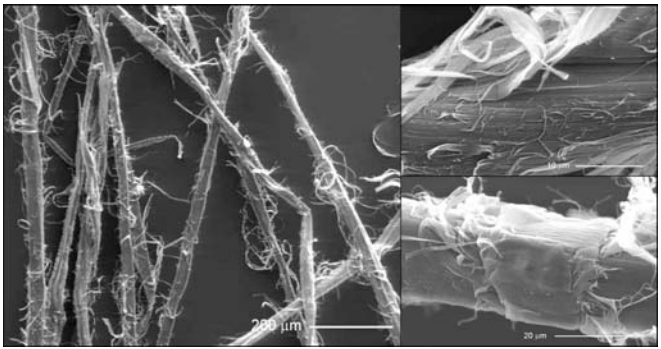


FIG. 5. Long fibres (R30) of disrupted pulp at CSF of 269 ml.

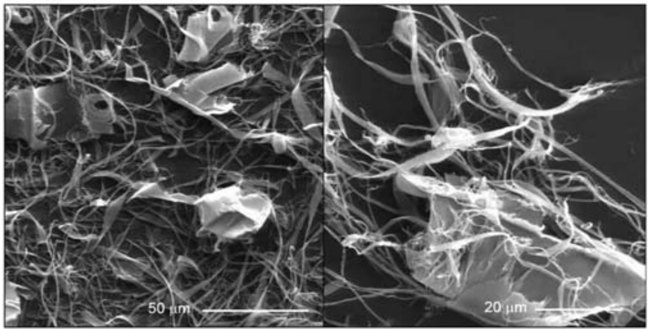


FIG. 6. Fines (P200) of disrupted pulp at CSF of 269 ml separated using a dynamic drainage jar.

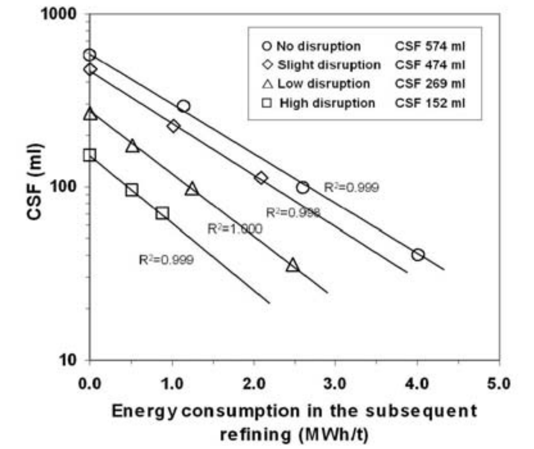


FIG. 7. Drainability of pulps in the subsequent refining (a wing defibrator) as a function of specific energy consumption.

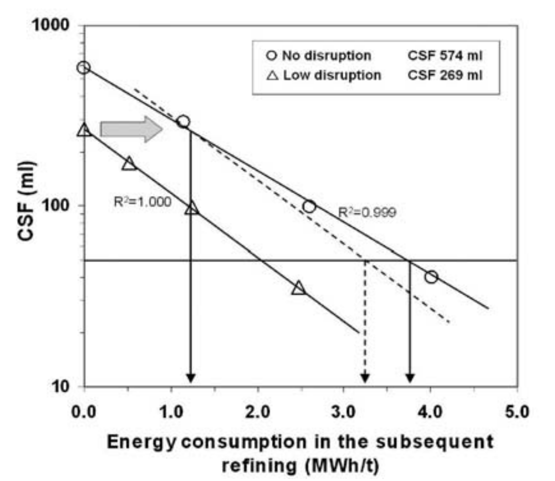


FIG. 8. Comparison of energy consumption in the refining of disrupted and non-disrupted pulps.

TABLE I. Effects of abrasive treatment on fibre properties.

Degree of abrasive treatment		No	Slight	Low	High
Freeness	(ml)	574	474	269	152
Long fibre fraction (R30)	(%)	71.3	68.6	61.9	56.2
Fines content	(%)	7.1	8.7	13.3	18.6
Fibre length	(mm)	2.24	2.17	2.04	2.03
Micropore volume	(µl/g)	721	-	742	778
Non-fibrillated fibre	(%)	13.3	-	14.0	8.0
Fibre splitting	(%)	10.3	-	32.3	31.1
Fibre coarseness	(mg/m)	0.330	0.291	0.251	0.238
Wet fibre strength	(mN)	159	130	122	119

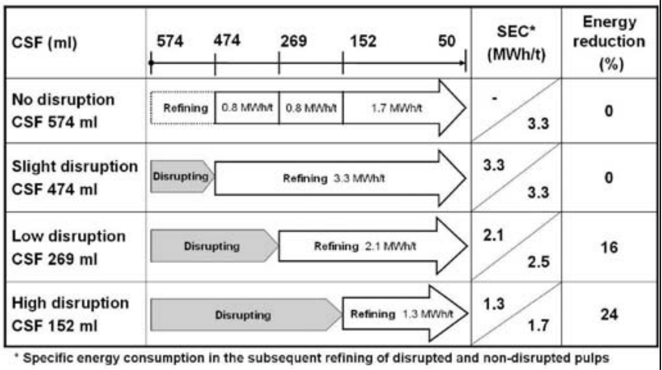
against specific energy consumption in refining with a wing defibrator. The trendline slopes of the pulps ground to CSF of 474 ml and 269 ml are similar to that of the non-pretreated pulp, which means there are no differences in the cutting of fibres. For the high level of abrasive treatment, the slope is steeper, which means the fibres are cut rapidly. This phenomenon indicates that the weakening of highly disrupted fibres, subjected to abrasive treatment, might result in severe shortening of fibres in the subsequent refining.

Figures 11-14 illustrate the mechanical and optical properties of non-disrupted and disrupted pulps in the subsequent refining, plotted against pulp freeness. At a given freeness level, no significant differences can be seen in light scattering coefficient, tensile strength, or bonding strength (Scott bond). An exception is tear strength; the low- and high-pretreated pulps subjected to abrasive treatment have somewhat lower tear strength than the reference pulp at a given freeness level. This is probably due to their shorter fibre length [17, 18]. However, at a pulp freeness below 100 ml there are no significant differences in tear strength.

DISCUSSION

This research is a first attempt to examine the changes in the wall structure of pulp fibres disrupted by an abrasive material and the effect of this treatment on the energy consumption and pulp quality in the subsequent refining. The main purpose of this research was to carry out fundamental work for developing an energy-efficient TMP refining process, including the reinventing of refiner plates.

The results showed that it is possible to preliminarily disrupt TMP pulp with an abrasive material and refine the pulp further to the desired quality for the making



CSF (ml)	574 474 269 152 50	SEC* (MWh/t)	Energy reduction (%)
No disruption CSF 574 ml	Refining 0.8 MWh/t 0.8 MWh/t 1.7 MWh/t	- 3.3	0
Slight disruption CSF 474 ml	Disrupting Refining 3.3 MWh/t	3.3 3.3	0
Low disruption CSF 269 ml	Disrupting Refining 2.1 MWh/t	2.1 2.5	16
High disruption CSF 152 ml	Disrupting Refining 1.3 MWh/t	1.3 1.7	24

* Specific energy consumption in the subsequent refining of disrupted and non-disrupted pulps

FIG. 9. Evaluation of energy consumption in the subsequent refining (a wing defibrator, WD) using disrupted and non- disrupted pulps.

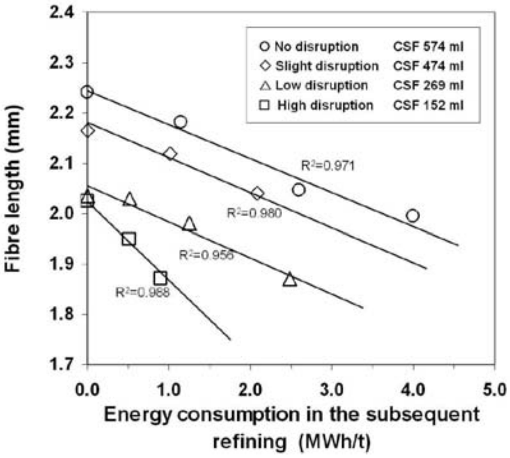


FIG. 10. Fibre length as a function of specific energy consumption.

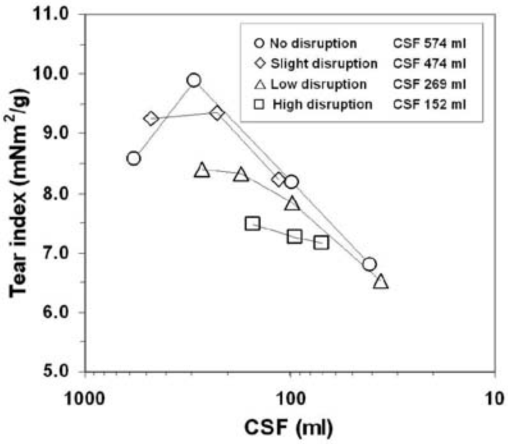


FIG. 11. Tear strength as a function of pulp freeness.

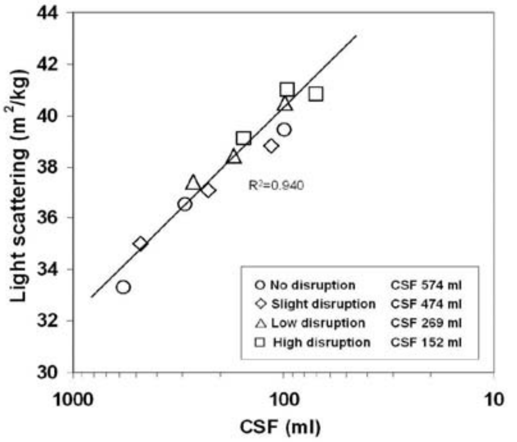


FIG. 12. Light scattering coefficient as a function of pulp freeness.

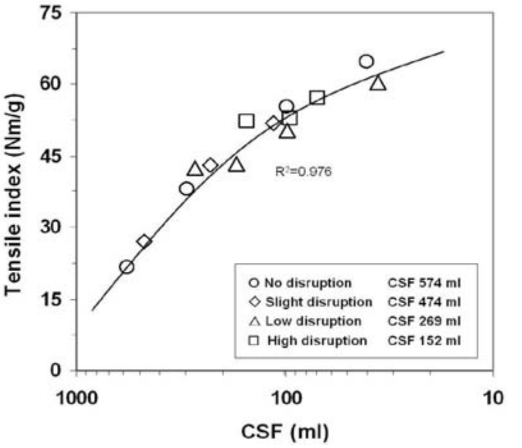


FIG. 13. Tensile strength as a function of pulp freeness.

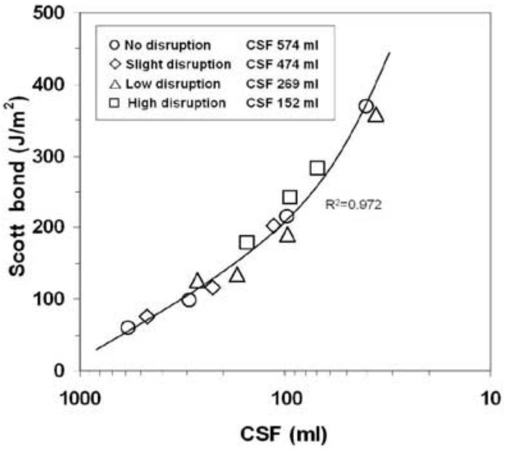


FIG. 14. Bonding strength (Scott bond) as function of pulp freeness.

of paper. The disruption could be performed at a low degree of treatment in order to minimise fibre shortening. The disrupted pulp allows fast development in the subsequent refining, while reducing the energy consumption in refining. According to these results, it could be postulated that a higher amount of broken fibres obtained by the grit treatment should provide for faster fibrillation in the subsequent refining stage.

Although a net saving in energy consumption appears to be possible, great care would have to be taken in controlling the degree and intensity of the abrasive treatment stage in order to minimise fibre damage and the resultant drop in tear strength. To solve these problems, a deeper understanding must be gained of the parameters involved in the use of abrasive material and appropriate raw materials. The next step of this work will focus on the application of the disruption technique to further development of refiner plates.

CONCLUSIONS

Mechanical pretreatment of high-freeness TMP pulp fibres using an abrasive material causes disruption, opening and peeling-off of fibre wall surfaces. At a low degree of abrasive treatment, it can disrupt the fibre cell wall without causing any severe damage to fibres. A high level of disruption causes serious shortening and weakening of pulp fibres. In the subsequent refining, the disrupted pulps were found to consume less energy when refined to a given freeness level compared with non-disrupted pulp. However, slightly disrupted pulp did not show any potential for reducing energy consumption. A high level of disruption was found to cause severe fibre shortening in the subsequent refining. The laboratory sheet properties of disrupted pulps were found to be almost similar to those of non-disrupted pulp.

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LITERATURE

1. SALMEN, L., LUCANDER, M., HÄRKÖNEN, E., SUNDHOLM, J. *Fundamentals of mechanical pulping, Mechanical pulping* (Papermaking science and technology, Book 5) Fapet Oy, Finland:35-61 (2000).
2. Pat. US4372495. Process and apparatus for comminuting using abrasive discs in a disc refiner, The Research Foundation of State University of New York, USA (Marton, R. & Brown, A. F.) App. 144019, 28-04-1980, Publ. 02-08-1983.
3. STATIONWALA, M. I. Abrasive refiner plates for the production of mechanical pulp. *Tappi J.* 70(10):124-127 (1987).
4. MILES, K. B., MAY, W. D. A new plate for chip refining. *J. Pulp Pap. Sci.* 10(2):J36-J43 (1984).
5. STATIONWALA, M. I., MILES, K. B. Abrasive plates in high consistency second stage refining. *Pap. Puu* 76(8):561-520 (1994).
6. KANO, T., IWAMIDA, T., SUMI, Y. Energy saving in mechanical pulping, International symposium on wood and pulping chemistry, Japan TAPPI, vol.2:5-10 (1983).
7. PREGETTER, M., EICHINGER, R., STARK, K. Post refining of mechanical pulp using abrasive surface, 5th International paper and board industry conference, Pira International, UK:15 p (1999).
8. KANG, T., PAULAPURO, H. New mechanical treatment for chemical pulp, Progress in Paper Physics Seminar, NTNU and PFI, Norway:11-13 (2004).
9. KANG, T., SOMBOON, P., PAULAPURO, H. Fibrillation of mechanical pulp fibers, *Pap. Puu* 88(7):409-411 (2006).
10. Super Masscolloider MKZA10-15 J, Setting clearance, Instruction manual, Masuko Sangyo Co., Ltd., Japan:18-20 (2002).
11. SUNDSTRÖM, L., BROLIN A., HARTLER N. Fibrillation and its importance for the properties of mechanical pulp fiber sheets. *Nord. Pulp Pap. Res. J.* 8(4):379-383 (1993).
12. MALONEY, T. C., PAULAPURO, H. The formation of pores in the cell wall. *J. Pulp Pap. Sci.* 25(12):430-436 (1999).
13. SOMBOON, P., PAULAPURO, H. Measuring wet strength of wood fibers with a combination of a zero-span tensile apparatus and an automated optical analyzer, Progress in Paper Physics Seminar, Miami University, USA:45-48 (2006).
14. FORGACS, O. L. The characterization of mechanical pulps. *Pulp Pap. Mag. Can.* 64(C):T89- T118 (1963).
15. FERNANDO, D., DANIEL, G. Micro-morphological observations on spruce TMP fibre fractions with emphasis on fibre cell wall fibrillation and splitting. *Nord. Pulp Pap. Res. J.* 19(3):278-285 (2004).
16. KARNIS, A. The mechanism of fibre development in mechanical pulping. *J. Pulp Pap. Sci.* 20(10):J280-J288 (1994).
17. SHALLHORN, P., KARNIS, A. Tear and tensile strength of mechanical pulps, International Mechanical Pulping Conference, Technical section of Canadian Pulp and Paper Association:25-36 (1979).
18. LEVLIN, E. J. *General physical properties of paper and board, Pulp and Paper Testing* (Paper making science and technology, Book 17), Fapet Oy, Finland:138-160 (1999).

Résumé: Nous avons analysé un traitement et ses effets sur la structure des parois des fibres de PTM ayant un indice d'égouttage élevé et sur la consommation d'énergie lors d'un raffinage subséquent. La mise en contact de fibres de pâte avec une matière abrasive a entraîné la rupture, l'ouverture, le décollement, et l'affaiblissement des parois des cellules des fibres. Lors d'un raffinage subséquent, la pâte a rapidement présenté la qualité requise pour la fabrication du papier, et la consommation d'énergie de raffinage était moindre. Les propriétés mécaniques et optiques des formettes ne présentaient aucune dégradation importante.

Reference: SOMBOON, P., KANG, T., PAULAPURO, H. Disrupting the wall structure of high-freeness TMP pulp fibres and its effect on the energy required in the subsequent refining. *Pulp & Paper Canada* 108(10):T161-165 (October 2007). Paper presented at 93rd Annual Meeting in Montreal, QC, on February 5 to 9, 2007. Not to be reproduced with permission of PAPTAC. Manuscript received on November 17, 2006. Revised manuscript approved for publication by the Review Panel on July 24, 2007.

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