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# Surface mechanical treatment of TMP pulp fibers using grit material

PHICHIT SOMBOON AND HANNU PAULAPURO

**ABSTRACT:** The authors studied surface mechanical treatments of thermomechanical pulp fibers using a grit material after first-stage refining and the treatment's impact on second-stage refining. The surface mechanical treatment was performed using an ultra-fine friction grinder. The grit size of the grinding stone, the intensity of treatment and the rotational speed were optimized to accomplish rapid development and minimization of pulp fiber shortening. The second stage of refining was carried out using a wing defibrator operated under typical TMP refining conditions. Surface mechanical treatment using a grinding stone with a grit diameter of 297-420 µm, operated at a contact point of the stones and a high rotational speed of 1500 rpm, provided an efficient disruption of pulp fibers with minimized cutting. A promising degree of fiber cell wall fracture was obtained when the energy applied during disruption was approximately 20% of the total refiner energy consumption. During second stage refining the disrupted pulp developed freeness more quickly while requiring 37% less energy. Laboratory sheets showed no significant differences in properties between the disrupted and non-disrupted pulps at a given freeness.

***Application:*** This study presents a method of increasing disruption of fiber cell walls in refiner-based mechanical pulping. This technique could be applied for the development of refiner segments and refining processes to reduce electric energy consumption.

## INTRODUCTION

In the refining of wood chips, the underlying mechanism of the development of fibers proceeds in two stages. In the initial stage, called the defibration stage, the wood chips are broken down into coarse fibers. In the second stage, called the fibrillation stage, they are further developed; i.e., delaminated, peeled off, and fibrillated, to the extent necessary for papermaking. These processes consume more than 90% of the total electric energy used in mechanical pulp production [1, 2]. Theoretically, the energy input required in refining is relatively low [3-6]. The high energy consumption in refining is the result of inefficient work during the defibration and fibrillation stages, according to the nature of the wood raw material.

Wood is a viscoelastic material. The mechanical breakdown of the structure of the wood matrix in refining fundamentally begins from the application of cyclic stresses to the wood matrix. The repeated viscoelastic deformation caused by cyclic stresses results in plastic deformation, which continues until the breaking point of the structure is reached. The repeated viscoelastic deformation consumes a high amount of energy without producing any development of wood fibers [2, 3, 7, 8, 9]. In addition, the friction of fibers over the refiner bars plays an important role in energy loss. According to Sundholm [10], the friction force between the wood material and refiner bars is relatively small, resulting in the sliding of wood chips and fibers off the bars, and thus less treatment.

Several researchers have attempted to overcome these problems by applying a combination of grinding and refining, using a modified refiner plate with an abrasive surface [11-14]. This technique has shown potential for reducing the energy consumption. However, it has not been successful in practical applications because of problems with the operation of refiners and the intensive destruction of pulp fibers. In order to make possible the grinding technique in wood chip refining, it is necessary to determine where this technique should be applied, and how the fibers can be efficiently broken down and fibrillated.

In our research project, we focused on reducing the energy consumption in the fibrillation stage (the second stage of refining). Our research hypothesis was that repeated viscoelastic deformation can be reduced by increasing the disruption and opening the fiber wall structure during the defibration stage by applying grit material through the grinding method, thereby promoting the development of pulp fibers and reducing the energy consumption. In a previous study [15], high-freeness thermomechanical pulp (TMP) from a reject line was disrupted with grit material and subsequently refined under TMP refining conditions. The results showed the potential for reducing the energy consumption. However, the pulp fibers were weakened and shortened during grit treatment and refining. To solve these problems a deeper understanding must be gained of the parameters involved in the use of grit material and appropriate raw materials.

Our study was designed to gain a better understanding of mechanical treatment using grit material on the first-stage TMP pulp fibers, with the aim of achieving efficient disruption of the fiber wall structure while minimizing the degradation of fiber quality, and to evaluate the potential for reducing the energy consumption in the second stage of treatment.

## EXPERIMENTAL

Our experiments were divided into two parts. The first part was designed to find out how to achieve efficient disruption of pulp fibers, while minimizing fiber shortening. The second part was intended to evaluate the potential for reducing the energy consumption, and to examine the pulp and paper properties of the disrupted pulp produced during subsequent refining.

### Raw materials

Our raw material was first-stage TMP pulp from Norway spruce (*Picea abies L. Karst.*) with a CSF of 580 mL produced at Stora Enso's Summa Mill near Hamina, Finland.

### Surface mechanical treatment

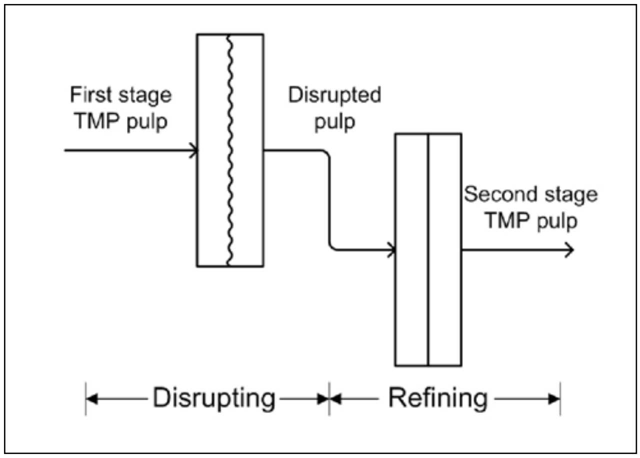
We carried out mechanical treatment of the surface of TMP pulp fibers using an ultra-fine friction grinder [15]. At the beginning of the study, we analyzed the key process parameters of the grinder, to optimize the treatment in order to achieve fast disruption of pulp fibers, while minimizing fiber shortening. Our analysis was based on a statistical model of a single replication of a $2^3$ factorial design [16]. The intensity of treatment, rotational speed and grit size of the grinding stone were considered.

The intensity of treatment was based on the relative position of grinding stones. The position was controlled at below the contact point of the stones in the motion stage, at 5 µm (low intensity) and 30 µm (high intensity). The peripheral speed of the grinding stone was adjusted to 1200 rpm and 1500 rpm. The impact of the grit size was analyzed by using a stone No. 80 with a grit diameter of 149-210 µm and a stone No. 46 with a grit diameter of 297-420 µm. The pulp slurry feed was controlled at a low consistency of 4% and circulated through the grinder with four passes. After treatment, the pulps were sampled for measuring pulp drainability, fiber length and fiber coarseness for the factorial analysis.

### Second-stage refining

Feed pulps before second-stage refining were prepared and disrupted with grit material under optimized conditions. The degrees of grit treatment were targeted at 10%, 15%, and 20% of the total refining energy consumption. After the disruption, all disrupted pulps were thickened to high consistency and further refined under typical TMP refining conditions, as shown in **Fig. 1**.

We carried out second-stage refining using a wing defibrator at Helsinki University of Technology [15]. The feed pulps were controlled at a consistency of 23% and a dry weight of 150 g. The peripheral speed of the defibrator was set to 750 rpm. The pulps were refined at a temperature of 130 °C without preheating and under various specific energy consumptions from 1 to 5 MWh/t. After refining, we took pulp samples for testing fiber and paper properties and evaluated the specific energy consumption in the second stage of treatment, including disruption and refining.




***1. Experimental schematic of the second-stage treatment of TMP pulp with a combination of disruption and refining.***

### Sample testing

We tested the drainability of pulp fibers using a Canadian standard freeness tester according to ISO 5267-2. Laboratory sheets were formed using the whole pulp with white water recirculation, and dried with a drying plate in a conditioning room at 23°C and 50% RH according to ISO 5263. Basis weight, thickness, and density of laboratory sheets were tested according to ISO 536 and ISO 534. Tensile and tear strength of laboratory sheets were tested according to ISO 1924-2 and ISO 1974. Light scattering coefficient of laboratory sheets was tested according to ISO 2471.

We measured fiber length and coarseness with a Kajaani FiberLab apparatus, according to TAPPI T271 om-98. Fiber length was measured with the whole pulp. Fiber coarseness was analyzed from fractionated pulp using a Bauer-McNett classifier with the screen number 30 (R30). The wet strength of long fibers (R30) was determined based on derivation of the breaking stress of wet paper strips at a zero span and the number of fibers bearing the load [17, 18].

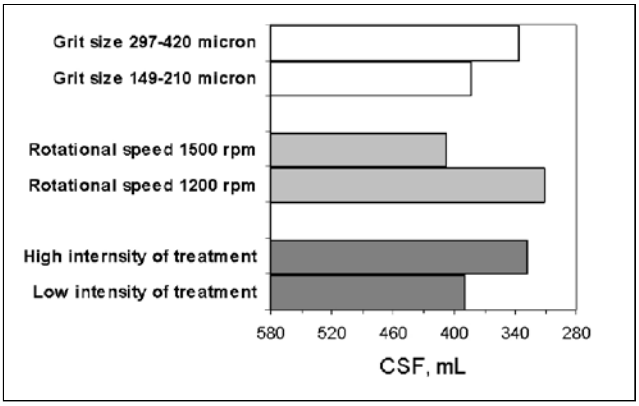
We measured breaks in the wall structure of fibers based on the micropore volume in the cell wall of fractionated fibers (R30). We made the measurement at the Helsinki University of Technology, using a differential scanning calorimeter based on the thermoporosimetry method with an isothermal step melting technique [19].

We observed the morphological changes in fiber cell walls based on an image analysis developed by KCL. External fibrillation and splitting of long fibers (R30) were analyzed. The images of long fibers were captured using a scanning electron microscope (SEM) at the Institute of Biotechnology of the University of Helsinki. The samples were dehydrated through a series of graded ethanol concentrations and dried using a critical point dryer before taking images.

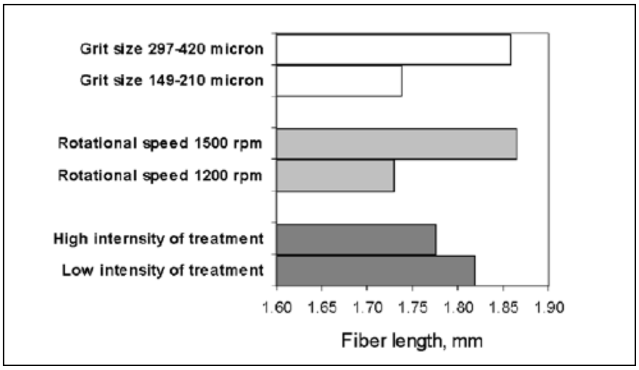
## RESULTS

### Surface mechanical treatment

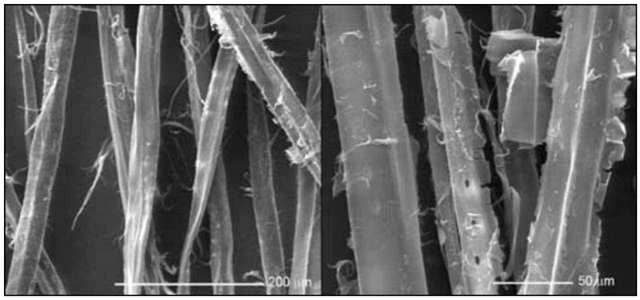
**Figures 2** and **3** show the main effects [16] of the disrupting parameter on pulp freeness and fiber length. Grinding stone No. 46 with a grit diameter of 149-210 µm was found to



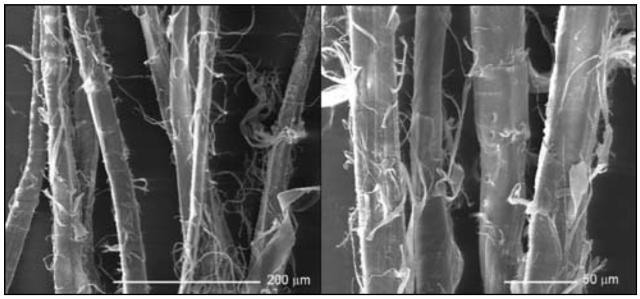

*2. Average main effects (disrupting intensity, rotational speed, and grit size of grinding stone) on pulp freeness.*



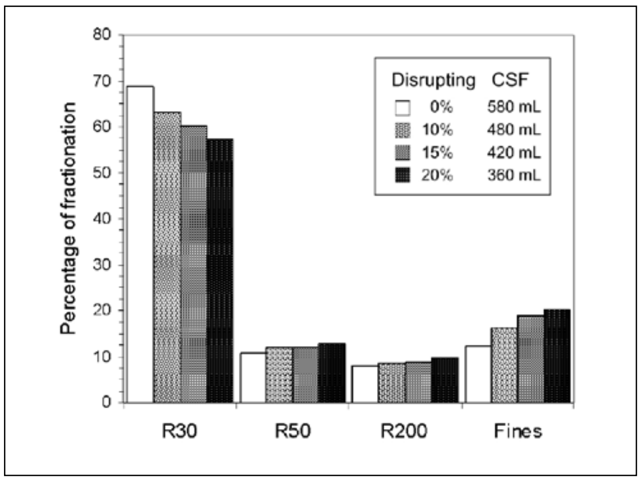

*3. Average main effects (disrupting intensity, rotational speed, and grit size of a grinding stone) on fiber length.*




*4. First-stage TMP pulp fibers having CSF of 580 mL (R30).*




*5. First-stage TMP pulp fibers disrupted using a grit material to CSF of 360 mL (R30).*




*6. Fractionation of first-stage TMP pulp fibers at different degrees of disruption.*

produce fast development of pulp freeness, while maintaining fiber length. A low peripheral speed of 1200 rpm and grinding position of 30 µm below the contact point of the stones (high intensity of treatment) resulted in faster development of pulp freeness, but caused more cutting of fibers.

To achieve efficient disruption of pulp fibers and to minimize their shortening, it was suggested that the disruption of the first-stage TMP pulp should be performed using a grinding stone with a grit diameter of 297-420 µm. The grinder should be operated at a high rotational speed of 1500 rpm and a grinding position of 5 µm below a contact point of the grinding stones (a low intensity of disruption).

**Figure 4** shows the surface morphology of the long-fiber fraction (R30) of the first-stage TMP pulp, observed with a scanning electron microscope. The pulp fibers were somewhat fibrillated, and the outer surface clearly consisted of the middle lamella, the primary wall, and the secondary S1 layer, related to the separation zone of TMP fibers in the wood matrix [1, 2, 20, 21]. When the grit material was applied to the pulp fibers, varying the specific energy consumption from 10 to 20% of total refining energy consumption, the cell wall structure of fibers was modified with less degradation of fiber properties.

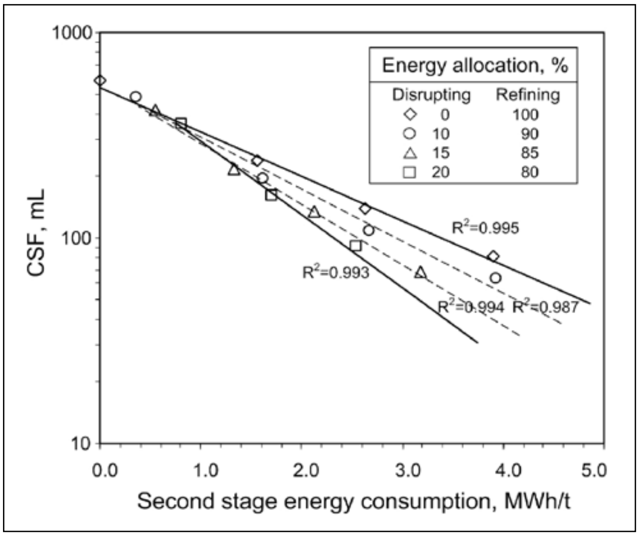
**Figures 5** and **6** and **Table I** show the effects of the grit treatment on the properties of fibers. Pulp freeness was reduced from 580 mL to 360 mL. External fibrillation, splitting of fibers and the pore volume of the fiber cell wall were found to increase. The average length of the whole pulp fibers did not change. Based on the fractionation analysis, however, the long-fiber fraction (R30) decreased by about 10%. The strength properties of the long-fiber fraction were not severely degraded.

According to these results, disruption and opening of the fiber cell wall, with minimized shortening and weakening of the pulp fibers before fibrillation, can be achieved with an abrasive stone with a grit diameter of 297-420 µm, operated at low intensity (approximately a contact point of the stones), and high rotational speed of 1500 rpm. The disruption can be performed from pulp freeness of 580 to 360 mL.

| | | Percentage of disrupting energy | | | |
|---|---|---|---|---|---|
| | | 0 % | 10 % | 15% | 20% |
| Freeness | (mL) | 580 | 480 | 420 | 360 |
| Fiber length | (mm) | 1.96 | 1.96 | 2.03 | 2.02 |
| Pore volume* | (mL/g) | 0.65 | 0.65 | 0.66 | 0.68 |
| Fibrillated fibers* | (%) | 34 | 43 | 42 | 49 |
| Fiber splitting* | (%) | 17 | 15 | 14 | 21 |
| Fiber coarseness* | (mg/m) | 0.635 | 0.356 | 0.390 | 0.408 |
| Fiber strength* | (mN) | 279 | 161 | 160 | 193 |

* Fractionated pulp, R30

***I. Effects of surface mechanical treatment on fiber properties.***



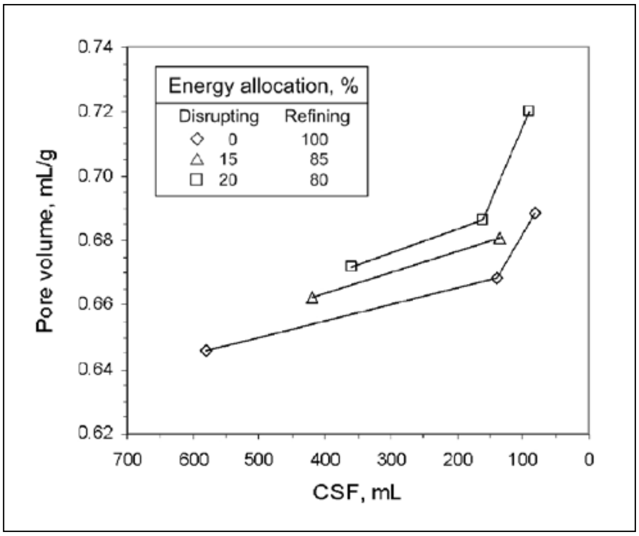

***7. Freeness development as a function of specific energy consumption in second-stage treatment including disruption and refining.***

### *Second-stage refining*

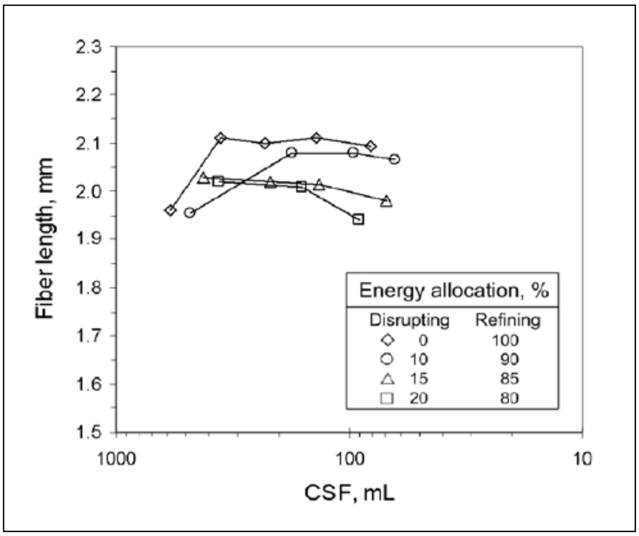
At the beginning of pulp development, from a pulp freeness of 580 to 360 mL, disruption and refining consumed the same amount of energy, as shown in **Fig. 7**. When the pulps were further refined, the freeness trend of the disrupted pulps began to slope more steeply than those of non-disrupted pulp. This indicates that the target freeness will be achieved faster, while consuming less energy.

The potential for reducing the energy consumption can be simply assessed from the differences in the slope of the freeness trend lines [15]. Disrupting the pulp using 10%, 15%, and 20 % of the total energy reduced the energy consumption in the second stage of refining by up to 13%, 26%, and 37%, respectively, calculated across a freeness range spanning 580 mL to 70 mL.

Based on the results of the mechanical treatment using grit material and the subsequent refining of disrupted pulp, we believe that increasing disruption and opening of the fiber wall structure is promising for promoting further development of the fractured fibers. This may reduce the work needed for breaking down the fiber wall structure and generating




***8. Micropore volume of fiber cell walls (R30) in second-stage refining.***



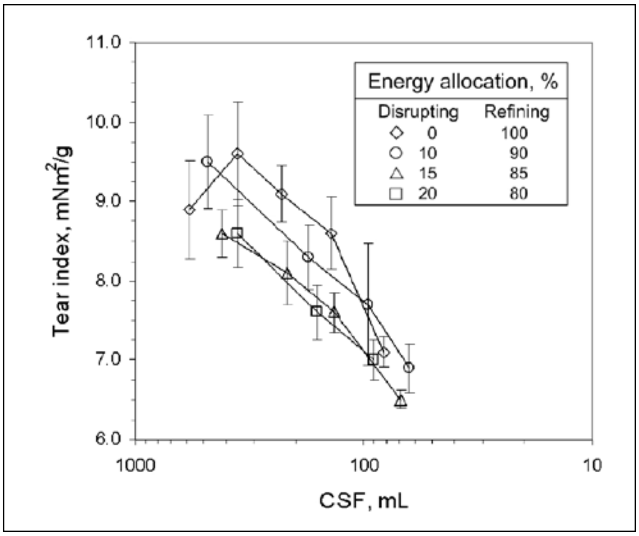

***9. Fiber length (whole pulp) as a function of pulp freeness in second-stage refining.***

internal and external fibrillation in the second stage of refining. Consequently, less energy would be required to develop the pulp fibers to the desired quality for papermaking.

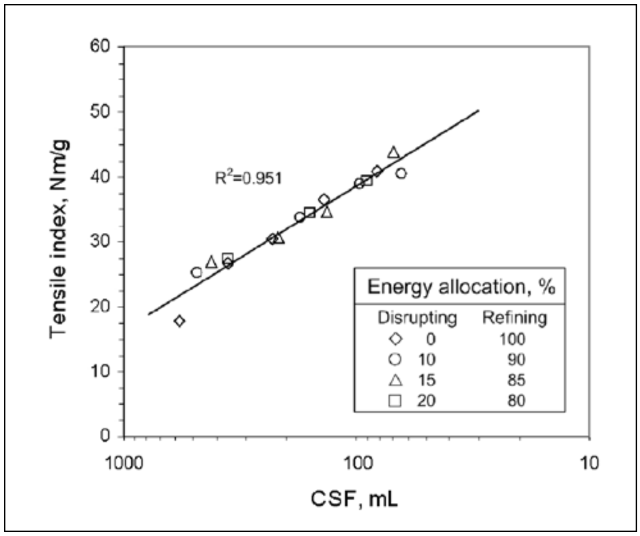
### *Pulp and paper properties*

**Figure 8** shows the pore volume of the cell wall of fractionated fibers at different levels of grit treatment and further refining. At a given pulp freeness, the treated pulps show a higher pore volume, indicating more disruption of the fiber wall structure. The results imply that disruption and opening of the outer layers of fibers will result in a greater disintegration of the fiber wall structure in further refining.

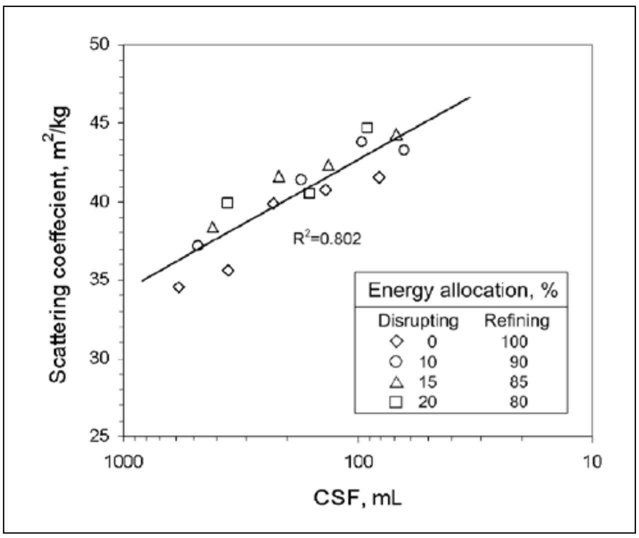
**Figure 9** shows the fiber length of disrupted and reference pulps as a function of freeness for the second-stage refined pulps. The disrupted fibers are not severely shortened in proportion to the degree of refining. This suggests that dis-




***10. Tear resistance as a function of pulp freeness in second-stage refining.***




***12. Tensile strength as a function of pulp freeness in second-stage refining.***




***11. Light scattering coefficient as a function of pulp freeness in second-stage refining.***

rupting the fibers by up to 20% of the total refining energy does not cause any harmful effects on the fibers in further refining. However, the disrupted pulps have somewhat lower fiber length than non-disrupted pulp at a given freeness.

The tear strength of disrupted pulp was somewhat lower than that of non-disrupted pulp. However, at a freeness below 100 mL, there were no significant differences in tear strength (**Fig. 10**). Light scattering coefficient and tensile strength showed no significant differences between disrupted and non-disrupted pulp at a given level of pulp freeness, as shown in **Figs. 11** and **12**.

## DISCUSSION

Acting on a previous study [15], we attempted to pretreat TMP pulp by using grit material to disrupt and open the outer layers of fibers. The pretreated pulp was refined further to the desired quality. It was found that the disrupted pulp developed faster during subsequent refining, while reducing energy consumption. However, the pretreatment with grit material caused weakening and shortening of fibers, resulting in a drop in tear strength.

Our experiment was designed to gain a better understanding of mechanical pretreatment using grit material and its application in TMP pulping. We proposed that the grit treatment could be used to disrupt coarse fibers for promoting their development in the fibrillation stage. This can be carried out practically by introducing the grit treatment between the first and the second stages of TMP refining. Our experiment was designed to use first-stage TMP pulp as a raw material. The results showed that low intensity, high rotational speed and grit size number of 46 are favorable for disrupting the pulp with minimized shortening and weakening of fibers. A degree of disruption amounting to 20% of the total refining energy could provide energy reduction up to 30% without significant losses in pulp quality.

Future research, using refiner segments with a combination of grinding and refining, will be conducted to promote breaking of the fiber cell wall. The design of grits on the segment and refining conditions will be of importance to this experiment. This approach is different from the preceding works [11-14] in which abrasive plates operated under an intensive refining condition for producing the pulp to target freeness. This causes refiner instability and severe damage to the fibers. A new segment will be proposed to operate in the first-stage refining position which functions to separate and disrupt the fibers simultaneously.

## CONCLUSIONS

In order to achieve rapid development of pulp freeness while minimizing fiber cutting, mechanical treatment of first-stage TMP pulp using grit material should be performed using a grinding stone with a grit diameter of 297-420 μm, operated at high rotational speed and low intensity. We found that this treatment developed the pulp fibers from a freeness of 580 mL to 360 mL while enhancing disruption of the fiber wall structure for further development. During the second stage of refining, we found that disrupted pulp resulted in faster development of pulp freeness while requiring 37% less energy. Laboratory sheets showed no significant differences in properties between disrupted and non-disrupted pulps at a given freeness. **TJ**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## INSIGHTS FROM THE AUTHORS

Our research project concerning the modification of refiner segments in the refining process was carried out at the Helsinki University of Technology. The project was owned by Metso Paper, which will use its results in the development of refiner segments. The focus of this research was on the application of grits on the segment surfaces to enhance the breakdown of fiber cell walls. In previous research, abrasive material was used to treat pulp intensively to reach the target freeness for making paper, but this caused severe degradation of pulp quality.

Our study and experiment were designed to gain a better understanding of mechanical pretreatment using grit material in TMP refining for the further development of refiner segments and process conditions. Our concept was to try to break down fiber cell walls using grit materials in different levels of treatment and examine the effects on subsequent refining (energy consumption and pulp and paper properties.)

Some of our interesting findings were how to disrupt fiber efficiently while maintaining fiber length, plus a high potential for energy savings. Our study could lead to the modification of refiner segments, with cooperation among pulp mills, machinery suppliers and research institutes.

***Somboon***

***Paulapuro***


*Phichit Somboon is a research scientist and Hannu Paulapuro is a professor at the Laboratory of Paper and Printing Technology, Department of Forest Products Technology, Helsinki University of Technology, Finland. A contact address is P.O. Box 6300, FIN-02150 TKK, Finland, or e-mail: phichit.somboon@tkk.fi.*