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New mechanical treatment for chemical pulp

T Kang* and **H Paulapuro**
Department of Forest Products Technology, Helsinki University of Technology, Espoo, Finland

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Abstract: This study presents a new method to modify chemical pulp mechanically using an ultra-fine friction grinder, which works in a different way compared with conventional refiners. It consists of two grinding stones: a lower rotating one and an upper stationary one. The pulp passing through the gap between the stone plates is subjected to compressive and shear forces.

The results showed that the gap clearance of the grinder plays an important role in controlling the fibrillation of fibres and the specific energy. External fibrillation became a dominant effect at a larger gap, whereas internal fibrillation developed faster at a smaller gap. Fibres were modified mostly into fibrils at a much smaller gap. Scott bond strength of pulps treated in the grinder was better than that of Valley-beaten pulps. Pulp properties can be varied by adjusting the pulp consistency, rotating speed, grit size, the dullness of the plate surface, and the number of pulp recirculations.

Keywords: mechanical treatment, chemical pulp, ultra-fine friction grinder, control of fibrillation, internal fibrillation, external fibrillation

1 INTRODUCTION

Mechanical treatment or refining is an essential step in developing pulp fibres to their desired quality level in the papermaking process. Numerous effects of refining on the fibre structure have been well documented, with the main effects including 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 control the fibrillation of fibres. Using shear refiners [**3**, **4**] and compressive refiners [**3**, **5**, **6**], several attempts have been made to prevent the refining effects from occurring simultaneously and to produce a homogeneous effect, for instance, dominant external fibrillation caused by shear forces and dominant internal fibrillation caused by compressive forces. Although these refiners are used for laboratory-scale refining, these experiments have provided new knowledge on how to utilize the full potential of fibrous material.

Conventional industrial refiners and laboratory-scale refiners fail to exploit the full potential of pulp fibres because of the limited number of variables available to control pulp quality. Therefore, a new technique is required to control the fibrillation of fibres better and to exploit the full potential of pulp fibres. An ultra-fine friction grinder works in a different way and might, therefore, also treat the fibres in a different way compared with conventional refiners. In this study, an ultra-fine friction grinder was used to modify pulp fibres mechanically under various conditions, and the results of the treatment were compared with those obtained with a Valley beater.

2 EXPERIMENTAL

2.1 Pulps

Once-dried bleached kraft softwood pulp, consisting of a mixture of Scots pine (*Pinus sylvestris*, 56 per cent) and Norway spruce (*Picea abies*, 44 per cent), was obtained from a Finnish pulp mill and used for the experiment.

Corresponding author: Laboratory of Paper Technology, Department of Forest Products Technology, Helsinki University of Technology, PO Box 6300, Espoo 02015, Finland. email: tkang@cc.hut.fi

2.2 Mechanical treatment

The pulp was disintegrated for 10 min and then beaten for 10, 30, and 60 min in a Valley beater (SCAN-C 25:76). 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 1.

2.3 Description of the ultra-fine friction grinder

The ultra-fine friction grinder shown in Fig. 1(a) consists of two grinding stones with 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 that moves the rotating stone vertically in 20 μm increments. The pulp passing through the gap between the stone plates is subjected to compressive and shear forces. The gap between the plates 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 ~3000 r/min with a frequency converter.

The grinder has a nominal motor power of 11 kW. The no-load power of the grinder measured with water only in the fully backed-off position was 0.6 kW at 1500 r/min and 0.3 kW at 900 r/min. The specific energy (kW h/t) was calculated by dividing the net power (kW) by the throughput of pulp per hour (t/h) in each pass.

Figure 1(b) shows the surface of the grinding stone. The surface image was scanned using a Form Talysurf Series 2 (Taylor Hobson Ltd, UK). It may be useful to compare the scanned images for evaluating the changes in the degree of wear of the stone surface.

Table 1 Conditions for mechanical treatment in an ultra-fine friction grinder

Variables	Condition
Gap (μm)	60–230
Rotating speed (r/min)	900 and 1500
Initial pulp consistency (%)	3 and 6
Grit class	46 (grit size 297–420 μm) and 80 (grit size 149–210 μm)

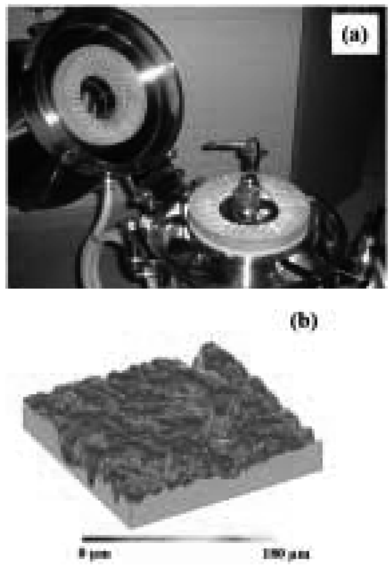

Fig. 1 An ultra-fine friction grinder (a) and surface of stone plate of grit class of 46, scan size 2 mm × 2 mm (b)

2.4 Fibre and sheet characterization

The freeness value (Schopper Riegler, SR, SCAN C19:65), fibre (>30 mesh), and fines content (<200 mesh) of the whole pulp were measured using a Bauer–McNett classifier, according to SCAN M 6:69. The degree of internal fibrillation was measured in terms of the fibre saturation point (FSP) with the solute exclusion method [**7**] using a 2×10^6 Dalton dextran polymer (Amersham Biosciences AB, Uppsala, Sweden). Only the longer fraction (R100) collected using a Bauer–McNett classifier was used for FSP measurement. The Simons stain technique [**8**, **9**] was used to evaluate the degree of fibrillation qualitatively. Light microscopic observation of the Simons stained fibres was carried out using DMLAM (Leica, Germany).

Standard 60 g/m^2 laboratory sheets (SCAN-C 26:76) were prepared from the whole pulps, and the paper properties were evaluated according to the SCAN and TAPPI methods.

3 RESULTS AND DISCUSSION

3.1 Influence of gap clearance

Only the gap clearance was changed to evaluate the effect of gap clearance on the specific energy and the properties of fibres, whereas the other variables were kept constant. The specific energy varies with the gap clearance, as shown in Fig. 2. As the gap decreases, the specific energy increases faster than that of a larger gap, as a function of the pulp passage.

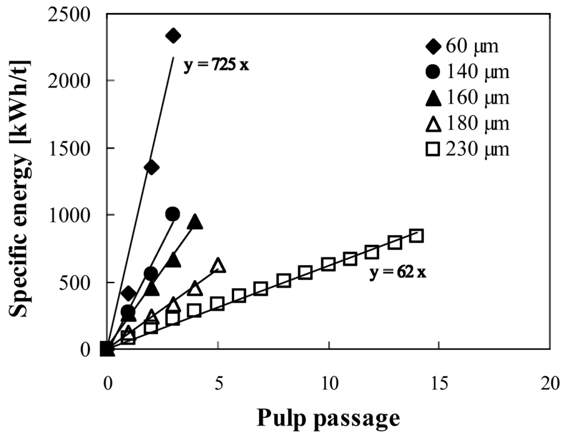

Fig. 2 Effect of gap clearance on specific energy. Pulp passage is defined as the number of pulp recirculations through the gap. Pulp with 6 per cent consistency treated at a rotating speed of 1500 r/min

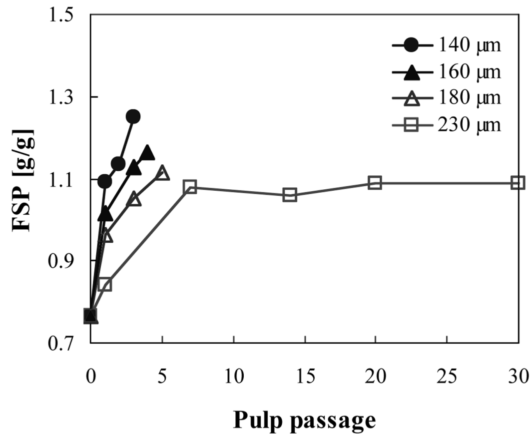

Fig. 4 Effect of gap on fibre swelling (R100 fraction). FSP of the reference pulp: 1.03 g/g for 10 min, 1.23 g/g for 30 min, and 1.42 g/g for 60 min beaten in a Valley beater. Pulp with 6 per cent consistency treated at a rotating speed of 1500 r/min

Figure 3 shows the effect of gap clearance on fines formation. As the gap is increased, less fines are produced. A smaller gap seems to provide a harsh treatment with a higher specific energy.

The gap of the grinder was found to be an important variable in controlling the fibrillation of fibres. As the gap was increased, the internal fibrillation measured as the FSP with solute exclusion developed slowly, as shown in Fig. 4. With a gap of 230 μm, no changes in FSP were observed between 7 and 30 passages, although fines were still generated (Fig. 3) as a result of the increased external fibrillation [**10**]. Shearing force is believed to become a dominant factor in mechanical treatment as the gap increases.

The mechanism of fines formation in the grinder seems to be different in a Valley beater. This is shown in Fig. 5. The peeling-off of the outer surface of the fibre caused by the grinding action might promote fines generation in the grinder, resulting in greater fines generation with a given longer fibre fraction.

Table 2 shows the increase in fibre straightening as grinding and Valley beating proceed. Fibres are straightened faster with a smaller gap in the grinder. Beating in a Valley beater seems to be more efficient for straightening fibres when compared with the grinder. This is probably because the cyclic compression forces generated in a Valley beater contribute to the straightening of fibres.

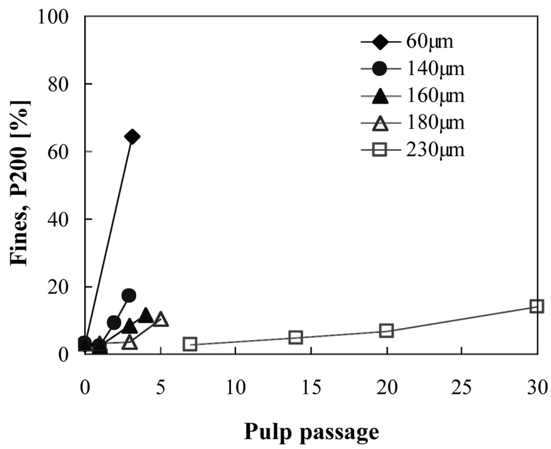

Fig. 3 Effect of gap clearance on fines formation. Pulp with 6 per cent consistency treated at a rotating speed of 1500 r/min

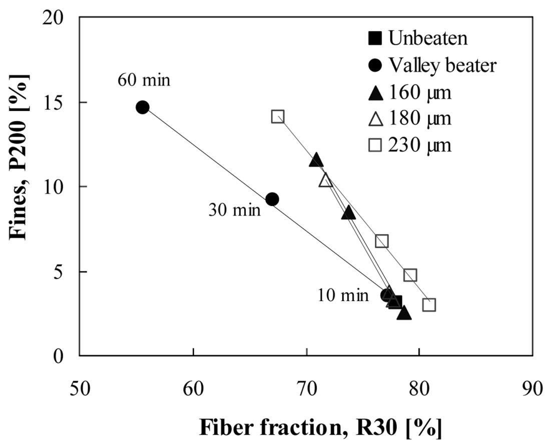

Fig. 5 Fines generation in a Valley beater and grinder. Pulp with 6 per cent consistency treated at rotating speed of 1500 r/min

Table 2 Curl index of a long fraction (R100)

Pulp passage (160 μm)	Curl (%)	Pulp passage (180 μm)	Six curl (%)	Pulp passage (230 μm)	Curl (%)	Valley beating (min)	Curl (%)
0	22.4	0	22.4	0	22.4	0	22.4
1	22.2	1	23.2	1	22.1	10	18.4
2	–	2	21.5	7	21.0	30	17.5
3	19.8	3	–	14	21.1	60	16
4	19.6	4	20.6	20	20.9		
5	–	5	20.6	30	19.7		

Six per cent pulp consistency treated in the rotating speed of 1500 r/min.

Structural characteristics of the fibres treated in a Valley beater and the grinder are shown in Figs 6(a) and (b). According to the Simons stain technique [**8**, **9**], an intact fibre is shown in blue, whereas fibres shown in orange become dominant as mechanical treatment proceeds. As the beating increases in the Valley beater, the proportion of orange colour increases. Fibres treated in the grinder show a variety of structural characteristics. No fibre-like shape is found in the pulp treated at 60 and 100 μm gaps with the pulp recirculated five times. Instead, fibril-like particles separated from fibres are dominant. With a smaller gap, the grinding action results in a completely different effect when compared with the conventional refiners. Fibres shown in orange are dominant at 160 μm, and fibres in blue are dominant in pulp treated at 230 μm with the pulp recirculated 30 times. The images of fibres treated at 160 and 230 μm seem to agree well with the FSP results shown in Fig. 4.

Figures 7 and 8 show the strength development as a function of sheet density. At a given density, the tensile strength of pulps beaten in the grinder was lower than that of Valley-beaten pulps. This was also observed in Waterhouse's work [**4**] using a shear refiner. However, Scott bond strength values were better than those of the Valley-beaten pulps. Regardless of the differences in gap clearance, all points of tensile and Scott bond strengths are placed almost on the same straight line as a function of density.

3.2 Influence of other variables

Figure 9 shows the effect of consistency and rotating speed on tensile strength. The tensile strength develops slightly better with higher consistency at a given specific energy. The SR of pulp, measured for two different consistencies, increases similarly at a gap of 180 μm, but the difference in SR becomes significant at the gap of 160 μm, with lower SR at higher consistency. Higher consistency provides milder conditions for mechanical treatment, resulting in reduced fines generation, as indicated by the lower SR. This agrees with the results obtained with a conventional refiner [**11**, **12**]. It was also found that pulps treated at a lower rotating speed develop better tensile strength at a given specific energy. A decrease in the rotating speed, causing an increase in the residence time of pulp between the plates [**13**], might result in better fibrillation of fibres with lower specific energy under the milder conditions.

Figure 10 shows the effect of plate conditions on tensile strength. Pulps beaten with larger grit size gave higher tensile strength at the same number of pulp recirculations. The tensile strength developed faster with a dull plate surface than with a sharp surface at a given number of recirculations through

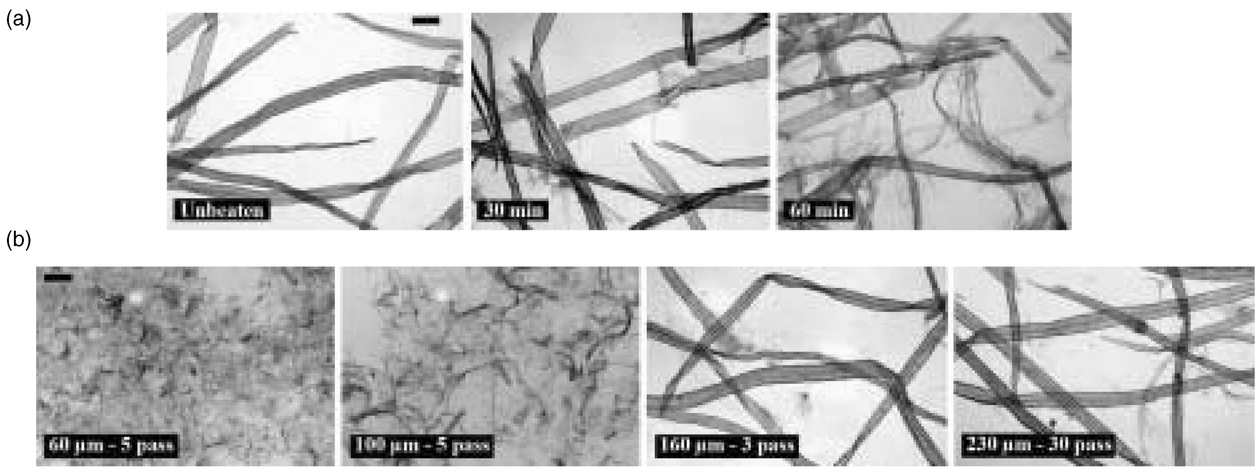

Fig. 6 (a) Light microscopic images of fibres beaten in a Valley beater. Simons stain technique used for staining fibres. Scale bar of 100 μm is shown in the left image. (b) Light microscopic images of fibres treated in the grinder. Simons stain technique used for staining fibres. Scale bar of 100 μm is shown in the left image

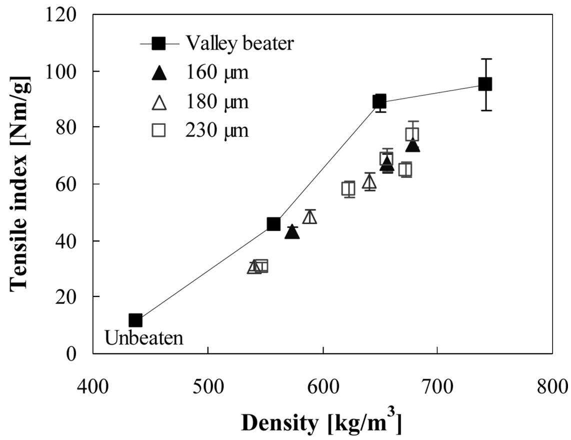

Fig. 7 Tensile index versus density. Pulp with 6 per cent consistency treated at a rotating speed of 1500 r/min. Error bars indicate 95 per cent confidence level

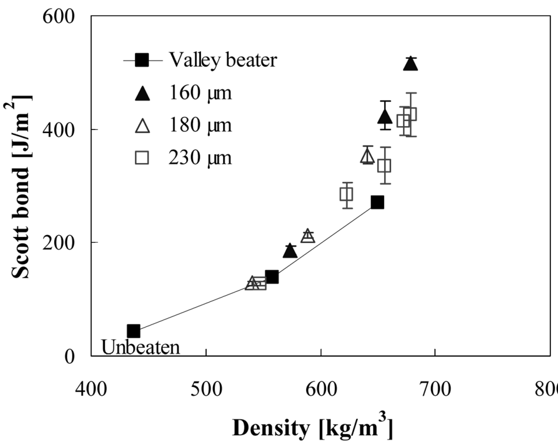

Fig. 8 Scott bond versus density. Pulp with 6 per cent consistency treated at a rotating speed of 1500 r/min. Error bars indicate 95 per cent confidence level

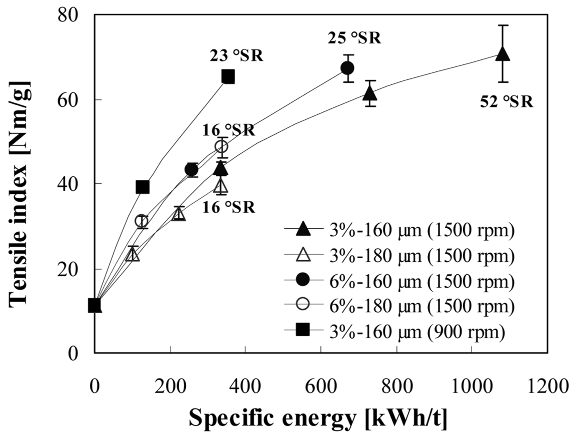

Fig. 9 Effect of rotating speed and pulp consistency on tensile strength – specific energy relationship. All pulps were recirculated three times. Error bars indicate 95 per cent confidence level

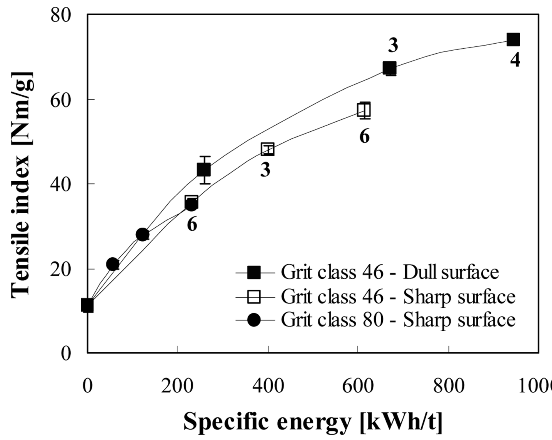

Fig. 10 Effect of plate conditions on tensile strength – specific energy relationship. Six per cent pulp consistency treated with the gap of 160 μm at a rotating speed of 1500 r/min. Numbers indicate the number of pulp recirculations. Error bars indicate 95 per cent confidence level

the gap. However, a dull plate requires a higher specific energy than a sharp plate, which is also valid for wood grinding [**14**].

The grinder allows fibres to be modified with a variety of characteristics by adjusting the gap clearance and other variables. This differs from the conventional laboratory-scale refiners, in which a limited number of variables are available to control the properties of pulp. The grinder appears to be a useful tool for expanding the knowledge on how to utilize the full potential of fibrous material.

4 CONCLUSIONS

The specific energy and pulp properties such as the fibrillation of fibres and fines formation were controlled effectively by adjusting the gap clearance of the ultra-fine friction grinder. It was found to perform in a different way when compared with the Valley beater. As the gap decreased, the specific energy increased with each recirculation and internal fibrillation developed faster. With a larger gap, external fibrillation was found to be a dominant effect.

Fibres were more straightened by the Valley beater than by the grinder. The tensile strength of pulps treated in the grinder was lower than that of Valley-beaten pulps at a given sheet density. However, Scott bond strength values were better than those of Valley-beaten pulps. Pulps treated with higher consistency and lower rotating speed gave higher tensile strength at a given specific energy and gap clearance. Pulp beaten with larger grit size gave higher tensile strength at a given number of pulp recirculations through the gap. The tensile strength developed faster with a dull plate surface than with a sharp surface at a given number of pulp recirculations through the gap.

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