

Mechanical pulp fines: Effect of particle size and shape

KARI LUUKKO AND HANNU PAULAPURO

THE MECHANICAL DEFIBRATION process produces a large amount of fines material, consisting of a wide range of different types of particles. The fines play a significant role in determining the properties of mechanical pulps, because the weight percentage of the fines fraction may account for up to 40% of the mechanical pulp in current high-quality printing papers. The effect of the fines content on the properties of pulp and paper has been studied extensively, but the fines quality has attracted little attention. The factors determining the properties of fines have been studied even less.

The work of Brecht and Klemm (1) is a fundamental study, characterizing the fines of mechanical pulp. The authors named two types of fines: flour stuff and slime stuff. The flour stuff consists of granular fiber pieces, fiber fragments, and ray cells, whereas the slime stuff contains mostly fine fibrils. The authors showed that the flour stuff and the slime stuff had different effects on sheet properties. Many subsequent studies have shown that the slime stuff, i.e., fibril-rich fines, is good bond-forming material, whereas stiff and compact flake-like particles from the fiber wall and middle lamella, i.e., flour stuff, have poor bonding ability (2–4).

The division of mechanical pulp fines into flour stuff and slime stuff is descriptive and well illustrates the general properties of such types of fines. Obviously, the fines consist of many types of particles with different

shapes and sizes, and with no clear borderline between flour stuff and slime stuff. However, it could be hypothesized that the characteristics of fines can be described by the relative proportion of fibrillar and flake-like particles in the fines. This view is in agreement with the original idea put forward by Brecht and Klemm (1).

Despite the many studies carried out to date, the effect of flake-like and fibrillar particles with varying size on the fines properties has not been fully proven. One reason for this is the difficulty in separating and preparing fines subfractions. Furthermore, suitable methods for direct measurement of fines particles have not been available. In this study, we investigated the effect of particle shape and size on the properties of mechanical pulp fines. Two different particle types, fibrils and flakes, were examined. The fibrils and flakes represent extremes in particle shape, with high and low bonding potential, respectively. The initial division of the particles into fibrils and flakes is based on a novel image analysis method, which has been described in an earlier publication (5).

EXPERIMENTAL

Sample preparation

Several fines samples containing various amounts of fibrillar material with different particle sizes were prepared. Thermomechanical pulps (TMPs) produced from Norway spruce (*Picea abies*) at a Finnish paper mill (with a target of 50 mL CSF) were used for preparing the samples. Fibril-rich fines fractions

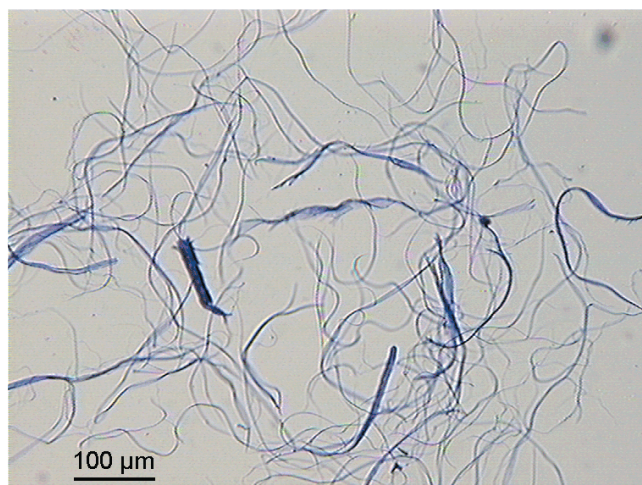
ABSTRACT

The effect of different types of particles on the properties of the whole-fines fraction and on the paper properties was studied. The purpose of the investigation was to classify the fines particles into two different categories: fibrils and flakes. The fibril fraction consists of fibrillar material, i.e., ribbons, fibrils, and thin lamellae particles. The flake fraction consists of flake-like material, i.e., fiber wall fragments, thick lamellae, and ray cells. An advanced image analysis method was used to characterize the properties of fibrils and flakes. The results demonstrate that the fibril and flake fractions have distinctly different characteristics and effects on sheet properties. The fibrils are strongly responsible for the strength properties, while the flakes improve light scattering. Generally, the smaller the particle size, the higher the sheet density and strength. It is proposed that the amount of fibrillar material is an important basic property of mechanical pulp fines.

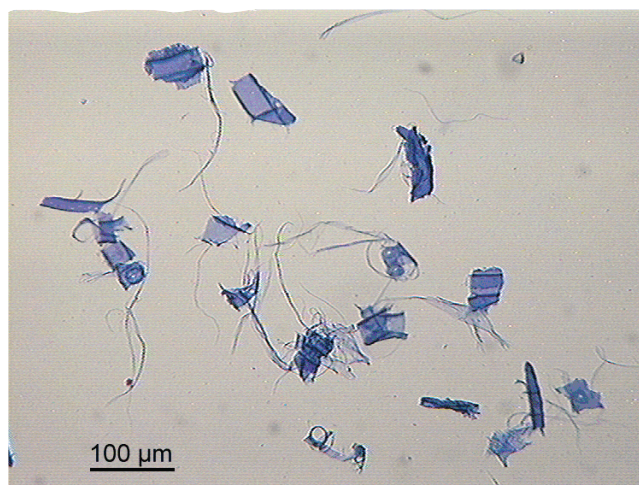
Application:

This study demonstrates how the papermaking properties of mechanical pulp fines are determined. The results can be used to control fines quality and ultimately pulp and paper quality.

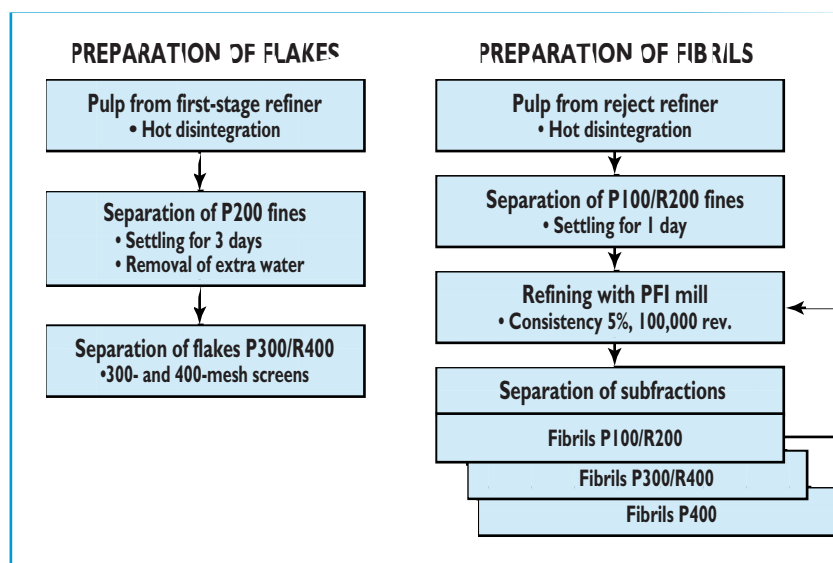
were prepared from the pulp taken from the blow line of the reject refiner. The fraction that passed the 100-mesh and was retained on the 200-mesh screen was obtained with a Bauer-McNett apparatus. The mass proportion of this fraction (P100/R200), which consisted mostly of long fibrillar ribbons (Fig. 1), was about 11% of the reject refined pulp. This material was then thickened to a solids content of 5%, refined in a PFI mill (at 100,000 revolutions), and fraction-



1. Fibrils P100/R200



2. Flakes P300/R400



3. Procedure for sampling and preparing fibrils and flakes

ated into subfractions P300/R400 and P400. The fractions contained only a small amount of flakes. The fibril fractions were named “Fibrils P100/R200,” “Fibrils P300/R400,” and “Fibrils P400.”

Flake-rich fines were prepared by taking the pulp after the first-stage refiner and isolating the fraction P300/R400 that consisted mostly of flake-like particles (Fig. 2). The flakes were named “Flakes P300/R400.” The mass proportion of the Flakes P300/R400 was about 2.7% of the first-stage refiner pulp. **Figure 3**

shows the procedure for preparing the fibril and flake fractions.

Furthermore, fractions P200 and P400 of the unbleached accepted pulp were studied. The “TMP P200” fines were used as a reference, representing typically accepted pulp fines in a TMP process. A fraction P400, separated from the TMP P200 fines, was used to represent fines consisting of the smallest fibrils and flakes. This fraction was named “Fibrils+flakes P400.” The proportion of the P400 fines in the TMP P200 fines was 72.4%.

Fines of commercial bleached kraft pine pulp (BK) were compared with the mechanical pulp fines. The pulp was beaten 120 min in a Valley laboratory beater (final SR number: 86 mL), and the fines passing through the 200-mesh screen of a Bauer-McNett classifier were collected. The mass proportion of the fines was about 9.1% of the pulp. This fraction is referred to as “BK P200.”

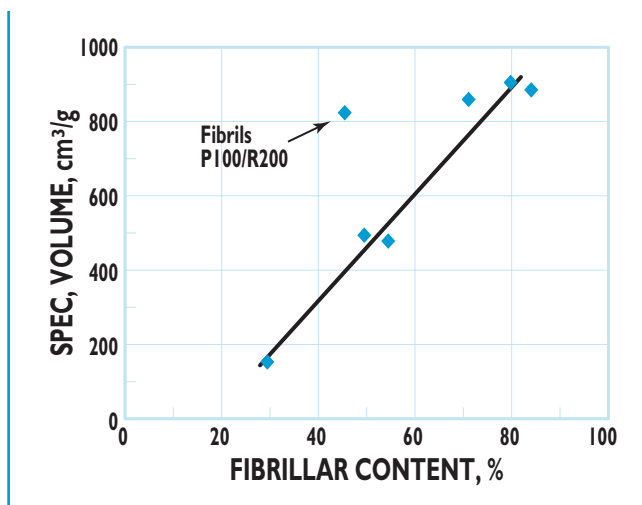
Methods

An image analysis method, the hydrodynamic specific volume of the fines, and testing of fines-containing handsheets were used to investigate the fines properties.

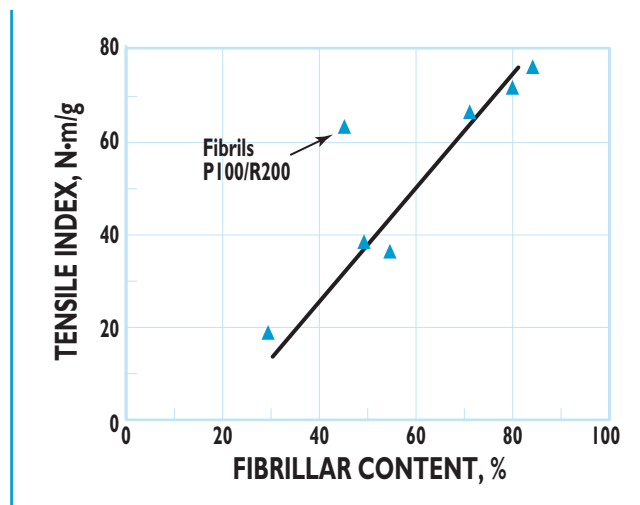
The image analysis method used is presented in the literature (5). In the analysis, fines particles are classified into two categories: (a) fibrillar material that contains fibrils and thin lamellae as well as fibrils that are attached, for example, to a fiber wall fragment and (b) nonfibrillar material (i.e., flakes), which contains fiber wall fragments, thick lamellae, and ray cells. It is assumed that the fibrils attached to flakes have a similar ability to form bonds as separated fibrils, despite their limited mobility. The image analysis cannot see whether a fibril is physically attached to a flake. Thus, it is reasonable to classify all fibrils as fibrillar material.

Property	Flakes P300/R400	Fibrils P100/R200	Fibrils+ flakes P400	TMP P200	Fibrils P300/R400	Fibrils P400	BK P200
Fibrillar content, %	29.2	45.3	49.4	54.5	71.1	79.8	84.1
Effective fibril length, μm	77.0	85.7	44.2	41.4	65.0	46.8	41.2
Flake area, pixels	386	361	179	200	247	182	175
Specific volume, cm^3/g	155	831	498	484	862	910	890
<u>100% fines sheet</u>							
Density, kg/m^3	356	734	492	454	847	1010	1040
Tensile index, $\text{N}\cdot\text{m}/\text{g}$	18.9	63.2	38.6	36.4	66.5	70.6	76.0
Light-scattering coeff., m^2/kg	81.2	34.1	94.8	97.5	28.0	18.6	8.5

1. Properties of fines



4. Relationship between fibrillar content and hydrodynamic specific volume of the fines



5. Effect of fibrillar content of the fines on the tensile index of a sheet prepared from 100% fines

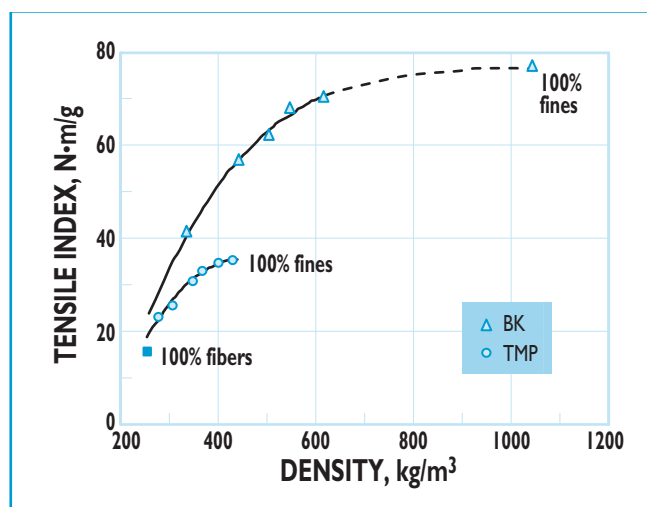
Of the image analysis parameters, the fibrillar content, effective fibril length, and area of the flakes were used to characterize the properties of fines. The fibrillar content is the percentage of fibrillar particles in all particles. In calculating the fibrillar content, the thickness of the particles, not only the area, is taken into account (5). The unit of the flake area and fibril length is 1 pixel (in the imaging system, the size of the pixel is $1.0 \times 1.4 \mu\text{m}^2$). The effective fibril length is equal to the number of pixels of the fibril. An automatic

imaging device was used to take 1000 images of each fines sample (6). The mean value of the effective fibril length and flake area is presented in the results.

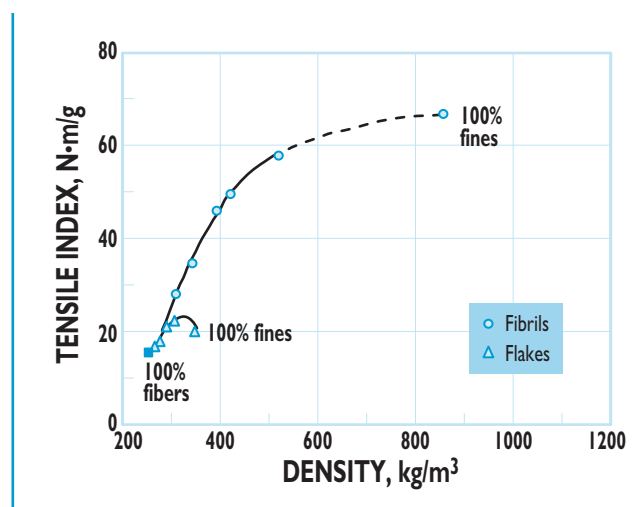
The hydrodynamic specific volume of the fines was measured by using a method described by Marton and Robie (7). The fines (1.0 g/L) were allowed to settle in a 0.5 mg/L MgSO_4 aqueous solution for 24 hours in a meter glass at constant conditions (20°C). Additional air from the fines suspension was removed by vacuum before settling. After the set-

tling time, the sediment volume was read, and the fines were filtered and weighted.

Laboratory handsheets, consisting solely of fines and a mixture of fibers and fines, were prepared and tested to examine the properties of the fines. A Bauer-McNett R100 fraction of the unbleached accepted TMP (50 mL CSF) was used as the fiber fraction in the mixture sheets. The fiber fraction is referred to as "100% fibers." The fines content in the mixture sheets varied from 10 to 50%. The fines/fiber mixture sheets were



6. Effect of adding TMP fines and bleached kraft pulp fines (BK) (P200) on the tensile index and density of the fines/fiber mixture sheet. The fines content increases from zero (100% fibers) to 50%. The point for the 100% fines sheet is also included. 100% fibers are TMP fibers only.



7. Effect of adding fibrillar fines and flake-like fines (P300/R400 fractions) on the tensile index and density of the fines/fiber mixture sheet

prepared according to SCAN-C 26:76 with white water circulation. The procedure for preparing 100% fines sheets is described in a previous paper (5). All the sheets were wet pressed (490 kPa, 4 min), dried on drums between blotters for 2 hours, and tested according to SCAN standards. The tensile index of the sheets was tested with a clamp distance of 50 mm.

RESULTS

Properties of the fines

Table I shows the properties of the fines according to the image analysis. As expected, the Flakes P300/R400 portion had the lowest and the kraft fines (BK P200) segment had the highest fibrillar content. The latter fines are assumed to mainly consist of fibrillar material and ray cells.

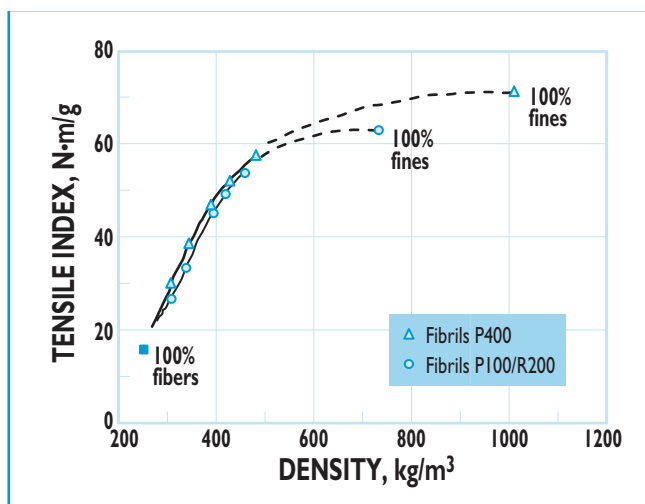
The fibrillar content of the fibrillar-rich fines decreased with an increase in the particle size of the fraction, which was mainly caused by a change in the flake size: The fibrillar content decreases rapidly if there are large and thick flakes in the fines.

This is a specific feature of the image analysis; it measures the actual mass percentages of fibrillar and flake-like material in the fines, taking into account the thickness of the particles, i.e., that the fibrillar content is the mass-weighted percentage of fibrillar material in the fines. This is essential for predicting the papermaking potential of fines, because compact and thick flakes are assumed to take more space in the fiber network in relation to their bonding ability than thin and flexible fibrils (3).

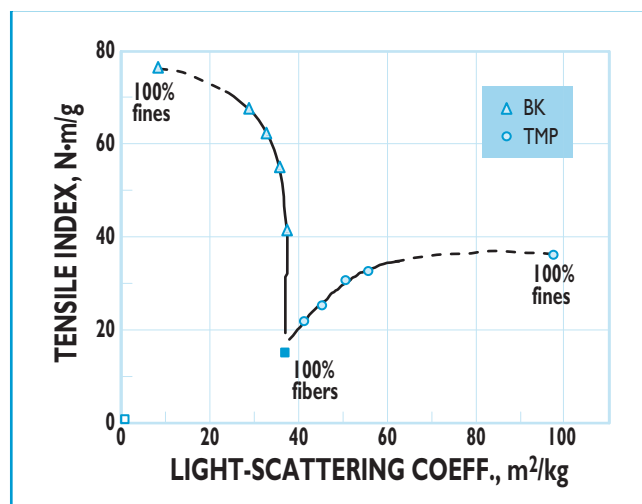
The functionality of the image analysis is demonstrated in Fig. 4, which shows that the fibrillar content correlates well with the hydrodynamic specific volume. The fibrillar content also correlated well with the tensile index of the sheet (Fig. 5). Fibrils P100/R200 deviated from the regression line because of the large flakes that reduced the fibrillar content in the image analysis. This fraction size is perhaps too large to allow it to be compared with P200 fines fractions.

Basic sheet properties, such as density, tensile strength, and light-scattering coefficient, were found to be strongly interrelated (Table I). The results show that there was a large difference in all sheet properties between the Flakes P300/R400 and Fibrils P300/R400, indicating that the particle shape plays a significant role in determining the papermaking potential of the fines. This was also supported by the difference between the Fibrils P400 and Fibrils+flakes P400 portions. The presence of small flakes in the Fibrils+flakes P400 portion decreased the density and tensile strength of the sheet, whereas it increased the light-scattering coefficient.

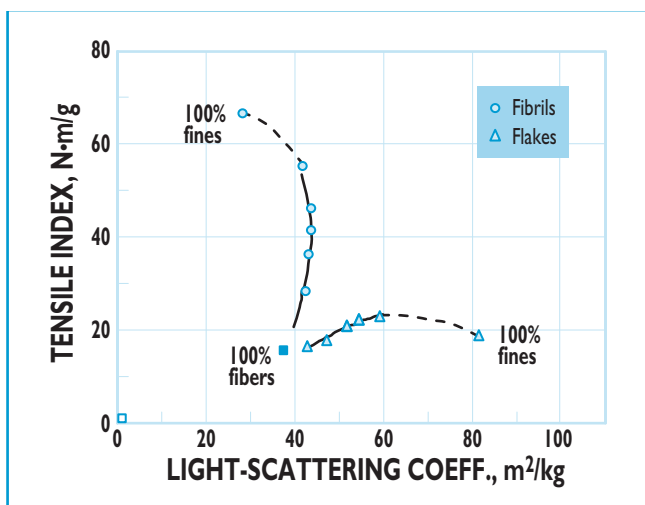
Flakes P300/R400 produced the weakest sheet with the lowest density. However, this portion did not produce the highest light-scattering coefficient, regardless of its low degree of bonding. Obviously, the fines particles are too large to scatter light effectively. The highest light-scattering coefficient was produced by the TMP P200 fines, which indicates that this fraction may have a naturally suitable particle size and shape distribution to powerfully scatter light.



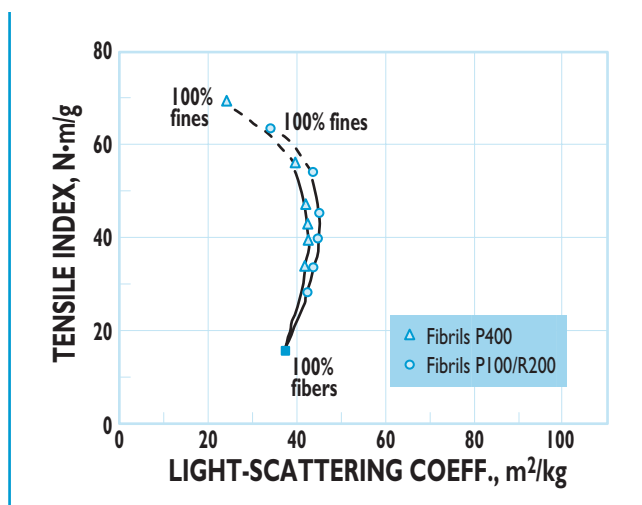
8. Effect of fibril size on the tensile index and density of the fines/fiber mixture sheet



9. Effect of TMP and kraft fines (BK) (P200) on the tensile index and light-scattering coefficient of the fines/fiber mixture sheet



10. Effect of particle type (fibrils and flakes P300/R400 fractions) on the tensile index and light-scattering coefficient of the fines/fiber mixture sheet



11. Effect of fibril size on the tensile index and light-scattering coefficient of the fines/fiber mixture sheet

The results also indicate that the smaller the particle size, the higher the density and the tensile index of the sheet. For example, larger particles in the Fibrils P100/R200 portion produced a lower sheet density and strength than small ones in the Fibrils P400 segment.

When examining the sheet properties of fibril-rich mechanical pulp fines, we surprisingly found that they were rather similar to those of the

kraft fines, which clearly produced the highest sheet density and tensile strength but the lowest light-scattering coefficient.

Fines/fiber mixture sheets

The above methods did not give information on the behavior of particles in the fiber network because sheets prepared solely from fines were tested. Therefore, sheets with an increasing fines content were prepared from a fines/fiber mixture.

Generally, the sheet density and strength increased with an increase in the fines content (Figs. 6–8). The kraft fines (BK) produced clearly higher sheet density and strength at a given fines content than the TMP fines (Fig. 6). Particle type had a strong impact on the sheet density and strength; fibrils increased these properties much more than did the flakes (Fig. 7).

Figure 8 shows that at low fines content (<50%), the fibril size had no clear effect on the density and tensile strength of the sheet. A difference can be observed only at a fines content of 100%.

The degree of bonding of the fiber network can also be observed in the light-scattering coefficient (Figs. 9–11). TMP P200 fines and the Flakes P300/R400 portion largely increased the light-scattering coefficient (Figs. 9 and 10). Fibrillar fines increased the light-scattering coefficient slightly at low fines content (<50%) but reduced it at high fines content (Figs. 10 and 11). The smaller the fibril size, the lower the light scattering because of the high degree of bonding (Fig. 11). Figures 9–11 clearly show that fibrillar fines strongly improve sheet strength, while flake-rich fines increase the light-scattering coefficient.

DISCUSSION

The basic effect of fines on the sheet structure is that they fill interstices between fibers and simultaneously densify the sheet and promote fiber bonding. It has also been proposed that the sheet fines particles may behave partly like loosely bonded filler material, creating new light-scattering surfaces and open structures (8). This appears to be valid for mechanical pulp fines, which contain both fibrillar and flake-like material, but not for chemical pulp fines. A wide range of different types of particles can be regarded as a special characteristic of mechanical pulp fines, which makes it possible to increase the strength properties and light-scattering coefficient simultaneously. For chemical pulp fines, which contain mostly fibrillar material, the bonding ability seems to be so high that these fines do not improve the light-scattering coefficient of the sheet, even at low fines content.

The function of fines particles in the fiber network has been consid-

ered in a number of recent studies (9–11). For example, de Silveira *et al.* (10) proposed four structural functions for fines particles, depending on their type:

- Fiber fragments and ray cells act as short fibers.
- Pieces of fibers fill interstices and make bridges in the fiber network.
- Smaller fragments of the primary wall or ribbon-like fragments of the secondary cell wall act as a filling and form bonds between the fibers.
- The same particles are also deposited on the outside surfaces of the fibers by “coating” them.

Görres *et al.* (11) examined the structural effect of fines on the fiber network by means of an interactive multiplanar model (IMPM). They proposed three structural functions—bridging, blocking, and filling—for mechanical pulp fines in the fiber network.

In the present study, the function of two types of particles, fibrils and flakes, was investigated. We found that the flakes increase the sheet density only slightly while fibrils do so dramatically. The flakes can be assumed to fill and bridge the fiber network. They may also block the network and thus do not substantially increase the sheet density. Obviously, the flakes cannot be compacted and cannot form bonds effectively because of the stiff structure and compact shape of the particle.

Fibrils also fill and bridge the fiber network. They are, however, so thin and flexible that they probably do not block the network, even at high fines content, so the density increases to 100% fines content. An increase in density is a consequence of flexible fibrils forming plenty of bonds, which results in a high sheet strength. Correspondingly, the light-scattering coefficient is decreased

due to the decrease in the optically active surface area of the sheet.

The results reported here are in agreement with previous results (8), supporting the conclusion that there is a profound difference in the behavior of mechanical and chemical pulp fines in the fiber network, with kraft fines making a denser sheet than TMP fines. We assume that the main reason for this is the difference in the fibrillar content of the fines. This is supported by the finding that the behavior of the fibrils of mechanical pulp fines is similar to that of the fines of bleached kraft pulp, indicating that the fibrillar material in mechanical pulp fines is largely responsible for the strength properties of the sheet. The flakes, whose bonding ability seems to be low, are largely the cause of the light-scattering ability of the sheet. The fibril length and flake area also affect the sheet density and strength, but their role seems to be minor. Thus, fibrillar material appears to be a major factor that dominates and determines the strength potential of mechanical pulp fines.

Note that the fines with a wide range of fibrillar content were artificially prepared in the laboratory and, in practice, do not appear as such in a mechanical pulp mill. However, as shown elsewhere, the fibrillar content, depending on the process stages and sequences, can be varied widely and independently from the fines content of the pulp in a mechanical pulping process (6). On the other hand, at least in a main refining line (i.e., including first- and second-stage refiners), the fibrillar content is connected to the fines content of the pulp (6).

CONCLUSIONS

In examining the effect of particle size and shape on the properties of mechanical pulp fines, we found the proportion of fibrillar material to be a significant parameter in determin-

ing most fines properties. Fibrillar material contributes largely to densifying and consolidating the sheet, while flake-like particles improve light scattering.

Particle size also contributes to the sheet properties. Generally, the smaller the particle size, the higher the sheet density and strength. An interesting finding was that the sheet properties of fibrils of mechanical pulp fines are rather similar to those of fines of bleached kraft pulp.

The effect of chemical composition, and especially the effect of surface chemical composition, on the fines properties was not analyzed in this study. However, we assume the surface content of extractives to be roughly the same in all mechanical pulp fines because of the strong washing effect in the Bauer-McNett separation of the fines. **TJ**

Luukko is a research associate at UPM-Kymmene, Jamsankoski Mill, P.O. Box 35, FIN-42301 Jamsankoski, Finland. Paulapuro is a professor at the Helsinki University of Technology, Laboratory of Paper Technology, P.O. Box 6300, FIN-02015 HUT, Finland.

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