Differences on fibre level between GW and TMP for magazine grades.

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ABSTRACT
In paper making, surface properties are of major importance for the printability of the final paper. It is therefore essential to identify the fundamental fibre properties causing surface problems in order to be able to improve the final paper. It is well known that the amount of intact fibres is higher in TMP than in GW. It is also believed that thick-walled intact fibres, especially large-diameter fibres, are negative for surface properties. When TMP and GW for magazine grades are analyzed with respect to fibre dimensions by scanning electron microscopy (SEM) images of fibre cross-sections, far more thick-walled fibres are found in TMP than in GW. It is therefore probably more important in quality control to focus on thick-walled fibres for TMP than for GW. On the other hand the amount of shives is considerably higher for GW than for TMP and such material is also negative for the surface properties.

Both shives and fibre dimensions have been analyzed using cross sectional SEM images of Bauer McNett >50 fractions in a study including screening, cleaning and reject refining of a GW pulp for magazine paper. The same analysis was also conducted for a number of different final GW pulps and one TMP used for magazine paper.

Slotted screens are commonly used today for successfully separating large shives, but are not capable of removing smaller shives. It is obvious that most of the shives measured in a Somerville laboratory screen (0.15mm slots) will be separated in the slotted screens. However, measuring shives in cross sections shows that only a small amount of the shives is separated in the screens. Even if the pulp has been treated in both screens and cleaners, approximately one third of the shives still remain. This indicates how difficult it is to get rid of shives in the screen room, and therefore it is critical to minimize the amount of shives in the grinding process.

Despite the fact that Somerville shive measurements indicated no significant difference between different commercial mechanical pulps for magazine paper (GW and TMP), major differences in shives measured in cross sections of the fibres were found. The amount of shives was higher compared to the amount of large thick-walled fibres for most GW pulps, but for TMP it was the opposite in this comparison. It is therefore probably important to focus on reduction of shives in GW pulping and on reduction of thick-walled fibres for TMP. In mechanical pulping it is important to manufacture a pulp with as low an amount of shives as possible, especially if the screen room only has screens.

INTRODUCTION
When comparing GW and TMP, there are basic differences in the pulp due to the dissimilar process conditions in the defibration stage [1, 2]. It is, for example, clear that the amount of intact fibres in a TMP is much higher than in a GW pulp [3-5]. Thick-walled intact fibres with a large diameter are often considered to be a main cause of poor surface properties [6-8]. However, shives have also been identified as negative for surface properties. [9, 10]. Bonding of the long fibre is also important for surface properties [8], but our main focus in this study was fibre dimensions and shives. For future evaluations of the effect of bonding on surface properties, it would be preferable to have a more informative method for measuring the fibre bonding. For shives and fibre dimensions, it is possible to get a distribution, but for bonding only methods giving average values are available. However, promising work is currently in progress to develop a method for bonding distribution of fibres [11].

As shives and thick-walled fibres are thought to have a negative influence on surface properties, an evaluation of the separation of these fractions in different process stages was carried out. A GW pulp taken from different process stages was evaluated both for standard pulp properties and fibre dimensions. In the study it was important to measure shives accurately. However, existing methods for shive measurements cannot reliably measure all shives, especially small ones which are difficult to separate from fibres. The mechanical separation of shives in various devices does not include small shives [3] and in some of these methods, very well fibrillated fibres are also separated together with the shives, resulting in inaccurate measurements. A different way of measuring shives is to use optical fibre analyzers. Experience so far shows, however, that these measurements are not accurate enough. As
it is probably difficult to distinguish small shives from fibres, it was considered necessary to try an alternative method capable of accounting even for the small shives.

In another study a commercially manufactured TMP was compared to a number of different commercially manufactured GW pulps for magazine grades both at a fibre level and for standard pulp properties. The differences between GW pulps and TMP with respect to fibre dimensions and shives are discussed and compared further to standard pulp testing, especially surface roughness for laboratory sheets.

**EXPERIMENTAL**

The pulps in this study were analyzed using both standard pulp properties on laboratory sheets as well as cross-sectional analysis of the fibres on SEM micrographs.

The method for measuring fibre dimensions using cross-section SEM images has been developed by PFI [12]. The fibres are aligned and formed into fibre bundles before they are freeze-dried and impregnated with epoxy. The preparates are then cut perpendicular to the fibre direction and cross section images are taken using a SEM. The images are analyzed to retrieve information about the fibre dimensions. The idea was to utilize this technique and extend the method so that the shive content in pulps would also be measured. The analysis is based only on the Bauer McNett > 50 fraction of the pulp. The reason for selecting this fraction is that it is believed to include basically all fibres in the pulp sample. In this investigation the fibre fraction >50 was separated by Bauer McNett at Falun Research Centre and sent to PFI for measurement of both fibre cross-sectional dimensions and shive content.

Standard laboratory sheets were made at Falun Research Centre according to following standards. The pulps were hot disintegrated (85°C) using standard water (20°C± 5°C). After disintegration, the stocks were diluted to 0.3% consistency and CSF was measured according to ISO 5267-2. The pulp samples were fractionated in Bauer McNett fractionators, according to SCAN M6:05 and the fibre length measured in a Kajaani FS-200. Shive measurements were done using a Somerville screen (0.15 mm slot). Laboratory sheets of 60 g/m2 were made using recycled whitewater (conductivity 100mS/m) and pressed at an effective pressure of 400kPa for 5 minutes. Paper characteristics such as tensile index, tear index, z-strength and more were assessed from 60 g/m2 laboratory sheets. Surface roughness was measured on the glossy plate side. Laboratory sheets of the 16-30 Bauer McNett fraction was made without recycled whitewater using the same procedure as for the standard laboratory sheets.

**RESULTS AND DISCUSSION**

In this study, a method for more accurate measurement of the shive content, especially small shives has been used. To evaluate the method, the shive content for reject-refined GW pulps was compared to refining energy. Furthermore, a number of pulps were analyzed with respect to fibre characteristics and pulp properties, the aim being to elucidate the differences between TMP and GW pulps on a fibre level and also to investigate the effect of shive, fibre and pulp properties on surface properties.

**Analyses of shives for a GW pulp in some process stages**

The method of measuring fibre dimensions using cross-section SEM images at PFI gives valuable information about the character of the fibres in the pulp. To gain information on the shive content, it was decided also to measure the shives in the cross sections at the same time as fibre dimensions. An example of a cross sectional SEM image with coloured shives can be seen in Figure 1.
When calculating the shive content in the cross-sectional analysis, the number of images was increased to get statistically accurate data. The image analysis offers information regarding total number of shives, number of fibres in each shive and also the total shive area.

To get a comparable measure of the shive content between different pulps it was decided to use the relationship between total shive area divided by total fibre and shive area, called shive index:

\[
 \text{Shive Index} = \frac{\text{Shive area}}{\text{Total fibre area}} \quad (\text{Calculated for the Bauer McNett > 50 fraction of the pulp})
\]

This way of calculating the shive content is independent of the amount of fibre material in each image.

In this measurement of shives it is also possible to get the number of fibres in each individual shive. A comparison of the amount of shives with different number of fibres for an unscreened and screened GW pulp is shown in Figure 2. The result is presented as number of shives in all analyzed SEM images. The results are also recalculated to compensate for the different amount of fibre material in the analyzed images for the two pulps.

In this report, shives consisting of less than two intact fibres but at least three split/fragmented fibres are denominated as “<2*” in the figure. Further more, the rest of the shives are denominated by the number of intact fibres.

It is quite obvious that a large number of shives only have 2-4 fibres and that these shives are too small to be separated in slotted screens with for example 0.15 mm slots. The figure also shows an increase of the small shives in the accept compared to the screening inject.
One common way to measure shives is using a Somerville screen, which uses slots of 0.15 mm for mechanically separating the shives. This method only measures large shives and when evaluating the shive removal efficiency in screens with this method, results in this study show that the screens reduce the Somerville shive content by 95% as seen in Figure 3. However, if shives are measured using shive index, the reductions of shives in the screening is considerably lower, as seen in Figure 3. In the figure, the total shive content is also presented, which is the calculated shive content of the whole pulp, not just the Bauer McNett > 50 fraction.

\[
\text{Total shive content} = \text{Shive Index} \times \frac{\text{amount of Bauer McNett > 50}}{\text{total amount}}
\]

In this calculation, it is assumed that the fibre wall is homogenous and has the same density. Then the area % of the cross sections is considered to be equal to the weight % of the fraction. It is also assumed that there are no shives in the Bauer McNett < 50 fraction.

Figure 3. Somerville and shive index measurements, before and after screening.

Considering that the main amount of shives consists of only 2-4 fibres, see Figure 2, it is logical that the screening only separates 15% of all shives according to total shive content calculated by using shive index, see Figure 3.

The GW pulp in this study was both screened, cleaned and LC refined in the main line and yet approximately half of the initial amount of shives according to shive index still remained in the pulp. In this case shive index decreased from 12 to 5.5 over all process stages. When the total shive content was calculated by also accounting for the decreased amount of Bauer McNett > 50 fraction, the total shive content was reduced from 4.6 to 1.5. These results shows the importance of producing GW pulps with as low a shive content as possible in the grinders.

Reject from the same GW pulp has been investigated in pilot scale in two different refiners. The reject refining in both cases reduces shive index very well with energy consumption, as seen in Figure 4.

Figure 4. Shive index versus SEC for two different refining operations.
The samples shown in Figure 4 have also been tested for shives in an optical measuring device but these results were much less logical versus energy than the shive index. For example, refined reject could have a higher amount of shives than the unrefined reject in the optical measurements. It is probably very difficult in an optical measuring device to separate the small shives from the wide and fibrillated fibres, and, as can be seen in Figure 2, there are large amounts of shives with only a few fibres.

**Differences on fibre level between GW pulps and TMP for magazine grades.**

There are fundamental differences between GW and TMP pulps due to the dissimilar process conditions. TMP has more intact and thick-walled fibres whereas GW has more shives [13, 14]. Both these properties are believed to be negative for surface properties [8-10]. To evaluate the differences on the fibre level between GW and TMP pulps, six commercial pulps for magazine grades were selected and analyzed with respect to fibre and shive dimensions at PFI. The pulps in this study are five GW pulps and one TMP pulp, all used for magazine grades. The fibre fraction used for the cross sectional analyses of the fibres are Bauer McNett > 50. The amount of the analyzed fraction for each pulp is presented in Figure 5.

![Figure 5. The amount of >50 for each pulp.](image)

The selected fraction is believed to include roughly all of the fibre material [12]. There is a considerable difference between the amounts of >50 for the pulps, which must be taken into account when analyzing the results. The shive index for the six pulps is shown in Figure 6.

![Figure 6. Shive index calculated on the >50 fraction.](image)

![Figure 7. The total shive content, based on the entire pulp.](image)

There is a major difference in shive index between the GW pulps, but they are all considerably higher than the TMP pulp, with a shive index of 0.18. The definition of shive index is the calculated amount of shives in the > 50 fraction. To be able to give a more correct measure of the total shive content, shive index is recalculated with respect to the whole pulp. It is assumed that the area percentage of the measured shive content corresponds to the weight percentage. This requires that the wall area of the fibres is homogenous, which is a reasonable assumption in this case. By doing this, it is possible to calculate the actual shive content in the entire pulp, see Figure 7.
This gives a more accurate description of the shive content for each pulp independent of the amount of > 50 fraction. Even though Somerville measurements indicated no significant difference between the pulps, major differences in shive index were found.

In addition to shive index, the cross-sectional analysis also gives information about the fibre dimensions and the amount of split fibres in the samples. To give a more detailed description of the fibre material, the >50 fraction has then been further characterized in intact fibres, split fibres and shives. The intact fibres were divided into four groups (small thin-walled, small thick-walled, large thin-walled and large thick-walled) and the area percentage calculated for each group. The limits used for this separation are found in Table 1.

Table 1. Limits for the separation of different types of fibres.

<table>
<thead>
<tr>
<th>Description</th>
<th>Perimeter (µm)</th>
<th>Cell wall thickness (µM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large thick-walled</td>
<td>&gt; 80</td>
<td>&gt; 4</td>
</tr>
<tr>
<td>Large thin-walled</td>
<td>&gt; 80</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>Small thick-walled</td>
<td>&lt; 80</td>
<td>&gt; 4</td>
</tr>
<tr>
<td>Small thin-walled</td>
<td>&lt; 80</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>Split fibres</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By using area percentage as an estimate for weight percentage, the area fractions could then be used to describe the actual amount of each fraction in the total pulp. It is generally believed that intact thick-walled fibres, especially large-diameter ones, are negative for surface properties. To compare the amount of thick-walled fibres with shive content, the calculated fractions for each pulp are compiled in Figure 8.

Figure 8. The sum of large and small thick walled fibres and shives in the pulps.

The amount of shives compared to thick-walled fibres is in some cases higher for GW pulps. Especially large thick-walled fibres are thought to be negative for fibre-roughening, but this part of the fibre material was smaller than the amount of shives for most GW-pulps. The situation is the opposite for the TMP pulp, where the shive content is very small compared to the amount of thick-walled fibres.

In Figure 9, the whole pulps are divided into small-fibre material (BMcNett <50), split fibres, and amount of fibres in the four groups as well as shives content.
This gives a good overview of the fibre materials in the pulps. The amount of split fibres in the Bauer McNett >50 fraction is very similar for the TMP and GW pulps. However, the Bauer McNett <50 fraction, which contains shorter splitted material, is much higher for GW pulps compared to the TMP. This type of material is also beneficial for surface properties.

**Fibre properties and shive content versus surface roughness for laboratory sheets.**

Roughness Bendtsen measured on laboratory sheets could be seen as an indication for the tendency of the pulps to influence roughness. The surface roughness is influenced by both fibre length distribution, quality of the fibres and shives [8]. Surface roughness has a very low correlation to the amount of BauerMcNett fraction >16 for the samples taken from the different process stages for the GW pulp as seen in Figure 10.

The amount of fines for these samples seems to correlate to roughness, especially for the pulps with a lower amount of fines than 25 %, as seen in Figure 11. The bonding of the long fibre (measured as tensile index for the BauerMcNett 16-30 fraction) also seems to correlate to roughness, as seen in Figure 12.
The total shive content also correlates with roughness, as seen in Figure 13. As both the amount of fines and the bonding for the long fibre correlated very well with roughness, three samples with the same amount of fines and long fibre quality are marked in Figure 13. One explanation of the different surface roughnesses of these three samples may well then be the shive content. Surface roughness versus the sum of shives and large thick-walled fibres is shown in Figure 14, both probably being negative for the surface. There are, however, different surface roughnesses for the samples with the same amount of shives and large thick-walled fibres, but both amounts of long fibre bonding and amounts of fines have a positive influence on surface roughness. Comparing Sample 5 with Sample 4, the long-fibre bonding and amount of fines are higher for Sample 4, which could explain the lower surface roughness. Sample 2 has the same amount of fines, but a higher long-fibre bonding than Sample 3 which could explain the lower roughness for Sample 2. In addition, Sample 1 has the same long-fibre bonding, but a higher amount of fines than Sample 2, which might explain the lower roughness for sample 1. A conclusion could be that it is a combined effect of the amount of fines, long-fibre bonding, shives and wide thick-walled fibres that influences surface roughness. However, the amount of long fibre (Bauer McNett >16), on the other hand seems not to have a good correlation to surface roughness.
Roughness versus amount of BauerMcNett fraction >16 is also shown in Figure 15 for the commercial pulps for magazine grades.

For these pulps there was a negative correlation for surface roughness versus Bauer McNett fraction >16, but the explanation of this is probably a higher amount of energy for the pulps with a higher amount of Bauer McNett >16. A higher energy input in the pulp results in higher long-fibre bonding. These pulps show a much better correlation to fibre bonding than to the amount of Bauer McNett >16 fraction, see Figure 16.

It is believed that wide thick-walled fibres and shives are negative for surface roughness and for these pulps there is in fact a very good correlation between the amount of them and roughness as seen in Figure 17.

**CONCLUSIONS**

In order to characterize differences between GW and TMP, cross sectional analysis of fibre dimensions and shives has been carried out. The main results from this study were the following:

- Measuring shives in cross-section SEM images is an excellent method to measure all the shives in the pulp.
- Even though shive measurements using Somerville screens indicated no significant difference between the commercially manufactured pulps, major differences in shive index were found.
- Slotted screens with a slot width of 0.15 mm are effective in separating large shives, but are not capable of removing smaller shives. Results show that the majority of shives consist of only 2-4 fibres. These small shives, not separated in screens, are probably negative for surface properties.
- The amount of shives is considerably higher for the investigated GW pulps than for the TMP in this study. On the other hand the TMP has much more thick-walled intact fibres than the GW pulps.
- Low amount of shives and thick-walled fibres have a relatively good correlation with low surface roughness for the laboratory sheets. High long-fibre bonding and amounts of fines also seem beneficial for
surface roughness. However, judging from this study a low amount of >16 fraction would not appear to be positive for surface roughness.

GW has a higher amount of shives compared to TMP and this study has indicated that shives are negative for surface roughness. Despite screening and cleaning stages in the process, approximately one third of the initial shive content still remains in the pulp. It is therefore important to produce a GW pulp with as low shive content as possible in the grinders to improve surface properties.

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