Surface application of cellulose nanofibrils to fine paper using different base sheet freeness levels

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Abstract

Cellulose nanofibrils (CNF) have been shown to increase paper strength when added internally to paper. CNF can also be added to the surface of the sheet at the wet end with a slot coater, curtain coater, or secondary headbox. Surface application of CNF can greatly enhance surface and barrier properties of paper for fine papers and brown grades.

This work describes the surface application of CNF to a fine paper grade, using a slot coater. Different base paper freeness levels were used, adding CNF processed to various fines levels. At a given freeness level, adding CNF to the surface will increase surface properties such as porosity, but some machine runnability characteristics will be adversely affected. The data shows that targeted surface properties can be reached by adding surface CNF to base papers at different freeness levels. Using a base sheet with a higher freeness level can result in improvement in certain machine runnability characteristics, including higher press solids, lower shrinkage, and lower vacuum demand.

Cellulose nanofibrils (CNF) can be added to a papermaking furnish, as well as added to the surface of the paper, to influence internal and surface paper properties.

Some of these effects were previously illustrated in a pilot paper machine study at The University of Maine’s Process Development Center, producing a filled fine paper grade. In that study, paper was made on the pilot machine at a basis weight of 80 gsm, with varying levels of ash.

CNF was added both internally to the sheet and on the surface of the sheet, and Figure 1 holds select paper properties graphed against ash content of the paper. Adding the CNF internally increased the tensile and bond values, both increasing as the amount of internal CNF added increases. The surface application of the CNF also increased the tensile strength, but perhaps less than the internal application. The bond was not improved with surface application.

The porosity values show the much greater effect of surface application of CNF as compared to the internal application. While the internal application did result in an increase of porosity values, increasing with CNF loading, the surface application showed a much larger effect. The highest level of internal CNF gave considerably lower porosity values than the lower level of
surface application. The roughness values showed much the same effect – internal CNF having a relatively small impact on surface roughness, in contrast to surface applied CNF which showed greatly improved sheet smoothness.

Benefits to strength and surface properties with CNF added internally and on the surface of the sheet came with decreasing drainage on the paper machine, resulting in decreasing press solids and increasing sheet shrinkage.

![Graphs showing effects of CNF addition on tensile index, internal bond, porosity, and roughness](image)

**Figure 1.** Internal and surface application of CNF to filled fine paper at various ash contents. Surface application via secondary headbox. 90% fines CNF for both surface and internal applications. Tensile index, internal bond, porosity, and roughness.

Previous work has also explored the effects of base sheet freeness on CNF addition in handsheets [Johnson, DA. 2015. The addition of CNF to papermaking furnish – Part 2. 2015 Tappi Nanotechnology Conference]. This work again showed improvements in properties with the internal addition of CNF to the handsheet, for both physical properties and surface properties. Adding CNF to furnish at any freeness level increased tensile and bond values, increased porosity, and decreased roughness (Figure 2). A desired property could often be reached with a lower base sheet refining level by adding more CNF to the sheet. Adding CNF did decrease the freeness of the furnish mix.
These studies showed internal and surface property improvements to paper with the addition of CNF internally or to the surface of the sheet. However, adding CNF does come at the cost of certain machine runnability characteristics. The handsheet work indicated that a base sheet at a higher freeness could achieve the same properties as a more refined base sheet, if a higher CNF loading was used. The present pilot study looks at reduced base sheet refining effects on paper properties and machine runnability factors.

A recent pilot trial at the Process Development Center looked at the effects of surface application of CNF, on base paper of different freeness levels. The base sheet was a 75:25 hardwood:softwood blend; the softwood was refined to 400 CSF, and the hardwood was refined to 500, 350, and 200 CSF, giving blended stock freeness of 475, 360, and 250 CSF. All paper was run to a basis weight of 80 gsm. To limit the number of variables being examined, no retention aid was added to the furnish, and vacuum settings and dryer settings were held constant throughout the trial.

The cellulose nanofibrils (CNF) used in this study was produced at internally from bleached softwood kraft pulp by low consistency disk refining, to a fines content of 80%, 90%, and greater than 100% (100+%). The surface application of CNF was achieved via a pilot scale curtain/slot
coater – a hydrosizer manufactured by GL&V. Surface applications ranged from 0 to 4.5 gsm CNF. Levels of CNF applied to surface were somewhat limited by the flow rates/water usage/pump capabilities of our pilot machine and the hydrosizer, and by the constant vacuum settings. Higher levels of surface application have been achieved with our secondary headbox.

Figure 3 shows the tensile index of paper made from base sheet furnish at three different refining levels, with surface application of 0 to 5 gsm. Surface application of CNF did not greatly change the internal strength properties of the sheet, whereas internal application has been seen to significantly enhance strength properties (as seen in Figure 1). There appeared to be some increase in tensile values with the lower freeness furnishes at higher surface applications, as compared to very little effect at the 500 CSF furnish. Fines level of the CNF did not seem to have a strong influence on results at the chosen CNF fines levels.

Internal bond, a property that has been shown to increase with internal application (Figure 1), increased with surface application of CNF at the lower freeness base sheet, but decreased somewhat with the higher freeness base sheet.

Figure 3. Surface application of CNF at various fines levels, on base sheets at different refining levels – tensile index.
While internal strength properties were only somewhat affected by the surface application of CNF, surface properties, including porosity and roughness, were greatly enhanced. This had also been seen in the work presented in Figure 1. For the current study, Figure 3 shows the increase in porosity with surface addition of CNF, with increasing level of surface CNF giving increasing porosity values. Adding surface CNF to the lowest refined base sheet, 500 CSF, seemed to give a proportionally greater effect on porosity values than to the more refined base sheets. Roughness, seen in Figure 6, showed similar effects, with increasing surface application of CNF giving increasing sheet smoothness, and the higher freeness sheet getting more of an effect from the surface addition than the lower freeness sheets.

For porosity values, the level of fines in the CNF did influence the results, with higher levels of CNF fines giving higher porosity values. Roughness showed somewhat less dependence on fines levels, although there was still a trend for higher fines CNF to give a smoother sheet.
Figure 5. CNF surface application on base sheets at different refining levels – porosity.

Figure 6. CNF surface application on base sheets at different refining levels – roughness, felt side measurement.
As Figure 7 shows, press solids tended to decrease with the addition of CNF to the surface of the sheet for the lower freeness base sheets. The 500 CSF base sheet shows some increase in press solids with moderate surface addition of 80% and 90% fines CNF, although the 100+% fines CNF did not show the same increase. Sheet shrinkage increased with increasing CNF surface addition for all base sheet freeness levels (Figure 8). Total table vacuum also increased with increasing CNF surface application (Figure 9).

As freeness of the base sheet increases, the press solids greatly increase, the shrinkage decreases, and the table vacuum decreases. So, if desired surface properties could be achieved using higher freeness base sheet, this may translate into significant paper machine efficiency and productivity benefits.

*Figure 7. CNF surface application on base sheets at different refining levels – press solids.*
Figure 8. CNF surface application on base sheets at different refining levels – shrinkage.

Figure 9. CNF surface application on base sheets at different refining levels – vacuum.
Similar porosity values can be achieved from the different base sheet refining levels by varying the amount of surface CNF applied. Figure 10 shows both roughness and porosity graphed against gsm CNF surface application, for the 80% fines level CNF. At 2.4 gsm CNF surface application on the 350 CSF base sheet, the porosity value is 66 Gurley seconds, while a similar porosity is achieved for the 500 CSF base sheet with 3.7 gsm surface CNF. The 200 CSF base sheet achieves 79 seconds porosity with no CNF on the surface.

At these CNF surface addition rates, the 350 CSF base sheet has a roughness of 163 Sheffield units, the less refined 500 CSF base sheet a roughness of 120, and the more refined 200 CSF base sheet a roughness of 211.

Using a higher freeness base sheet can also improve paper machine efficiency and productivity. With a higher freeness base sheet, the same porosity can be achieved (using more CNF) at a higher press solids. Figure 11 shows both press solids and porosity graphed against surface application, for the 80% fines level CNF. Looking again at the 0 gsm, 2.4 gsm, and 3.7 gsm CNF surface addition rates for the 200 CSF, 350 CSF, and 500 CSF base sheets, with similar porosity values - the 350 CSF base sheet gives a press solids of 42%, while the less refined 500 CSF base sheet gives a 3% higher press solids of 45%, and the more refined 200 CSF base sheet, gives a press solids of 40%.

The 500 CSF base sheet press solids seem more stable over the range of surface application, whereas both the 350 and the 200 CSF base sheet press solids decrease with increasing CNF surface application.
Figure 11. Press solids and porosity over CNF surface application rate for base sheets at different refining levels. Circles denote data points of similar porosity levels, triangles denote press solids at those porosity values.

Decreasing the amount of refining of the base sheet decreases the shrinkage of the sheet (Figure 12). At the similar porosity values for the three base sheets, the shrinkage goes from 6.8% for the 350 CSF base sheet, to 4.9% for the less refined 500 CSF base sheet, and to 7.8% for the more refined 200 CSF base sheet. This could be significant for paper grades that are sensitive to dimensional stability, such as release liner.

Table vacuum settings were held constant throughout the runs, so differences in the total vacuum draw were due to the furnish differences. Base sheets of lower refining levels resulted in less total table vacuum. Using the CNF loading with similar porosity values as previously, the 350 CSF base sheet had a vacuum of 76, and the 500 CSF base sheet a vacuum of 67, and the 200 CSF base sheet a vacuum of 73.
Figure 12. Shrinkage and porosity over CNF surface application rate for base sheets at different refining levels. Circles denote data points of similar porosity levels, triangles denote shrinkage at those porosity values.

Figure 13. Vacuum and porosity over CNF surface application rate for base sheets at different refining levels. Circles denote data points of similar porosity levels, triangles denote vacuum at those porosity values.
Table 1 summarizes some of the data in the previous graphs. At similar porosity values, the decreasing refining of the base sheet increases smoothness, increases press solids, and decreases sheet shrinkage. Surface properties can be preserved or enhanced, while also improving machine runnability characteristics. Lower base sheet refining does decrease the physical properties of the paper, especially the highest freeness base sheet.

<table>
<thead>
<tr>
<th>Base sheet freeness - CSF</th>
<th>200</th>
<th>350</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>gsm surface CNF</td>
<td>0</td>
<td>2.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Porosity – Gurley sec</td>
<td>79</td>
<td>66</td>
<td>78</td>
</tr>
<tr>
<td>Roughness – Sheffield units</td>
<td>211</td>
<td>163</td>
<td>186</td>
</tr>
<tr>
<td>Press solids - %</td>
<td>40</td>
<td>42</td>
<td>45</td>
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<tr>
<td>Shrinkage - %</td>
<td>7.8</td>
<td>6.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Vacuum</td>
<td>73</td>
<td>76</td>
<td>44</td>
</tr>
<tr>
<td>Tensile – N.m/g</td>
<td>81</td>
<td>79</td>
<td>55</td>
</tr>
<tr>
<td>Bond – ft.lb * 1000</td>
<td>236</td>
<td>115</td>
<td>66</td>
</tr>
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</table>

This study has demonstrated that similar surface properties can be achieved with base sheets of different refining levels. A less-refined base sheet with a surface application of CNF can achieve the surface properties of a more refined base sheet by adjusting the surface CNF loading level. These surface properties could not be achieved by additional base sheet refining alone.

By using a higher freeness base sheet, machine runnability can be improved at the same time as surface properties are improved.

Lower refining does sacrifice some internal strength properties. Work is in progress to combine surface CNF with internal CNF to optimize the balance of internal strength properties and surface characteristics.