Wet-Web Strength and Pressability of Highly-Filled Sheets

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ABSTRACT

Increasing filler content in paper could be an attractive strategy to improve paper quality and reduce fibre consumption and drying energy. However, filler addition reduces fibre-fibre bonding and hence tensile strength of paper and wet-web. Low wet-web strength leads to frequent sheet breaks and thus poor machine runnability. In this work, we have determined the impact of increasing filler content on the strength and pressability of wet web. The results indicate that addition of precipitated calcium carbonate (PCC) filler into sheets substantially reduced their wet web strength. At a PCC content of 50%, wet tensile energy absorption index decreased by about fivefold at a web solids content of 50%. Although the web was drier under constant drainage and press conditions, increasing PCC content actually reduced web pressability, and the fibre portion in the web became wetter in the presence of PCC. We have also found that wet-web strength is dependent on the filler type used. For instance, the PCC and GCC (ground calcium carbonate) reduced wet-web strength more than clay fillers. Therefore, manufacturing of highly filled paper requires developing strategies for improving wet-web strength to ensure adequate machine runnability.

INTRODUCTION

Mineral fillers are commonly used in the manufacture of printing papers and other grades. The filler improves the optical properties and appearance of the sheet, as well as its print quality. In general, fillers have a lower cost than fibres. Savings can be substantial when low cost fillers, such as kaolin clay, precipitated calcium carbonate (PCC), ground calcium carbonate (GCC), chalk, or precipitated calcium sulphate (PCS), are used to replace expensive pulp fibres. In addition, filled paper is easier to dry than paper without filler, resulting lower machine steam consumption. Thus, a paper machine can run faster with filler when it has limited drying capacity.

However, there are limits to the amount of filler that can be added to the paper for a given sheet grammage. Paper machine runnability and the strength of paper are usually the most important factors limiting the filler content in paper. Because filler does not have bonding capacity, inclusion of filler in paper impedes fibre-fibre bonding. As a result, wet paper containing a high amount of filler can break more easily at the open draws of a paper machine, whereas in the dry state, breaks may be more frequent during printing, conversion and end uses.

Unlike dry strength, wet-web strength at low solids is largely governed by water surface tension and capillary forces. Interfibre bonding comes into effect only at high solids, typically over 35-50% [1]. Interfibre friction also plays an important role in the development of wet-web strength. Thus, the effect of filler on wet-web strength does not necessarily echo its effect on dry strength. Although filler is known to reduce wet-web strength, published information on wet-web strength of filled paper is scarce.

Laleg *et al* [2-6] conducted a series of studies on the effect of strengthening agents on wet-web strength of unfilled sheets made from chemical and mechanical pulp furnishes. Chitosan and aldehyde starch were found to be the two best strengthening agents. Using a new laboratory wet-web strength tester, Kouko *et al* [7] showed wet-web tensile strength dropped as filler content increased from 10% to 30%. The effect of filler was strongly dependent on the web solids content obtainable under a given set of press conditions. However, comparison of web solids contents under the same press conditions was difficult because a standard laboratory press does not simulate well the fast roll press in a commercial paper machine. Isabell and Cobbett [8] also reported that the wet-web strength of filled handsheets was complicated by the effect of filler on moisture content under given press conditions. Because filler does not hold as much water as fibre does, so one would expect that filled paper is drier after pressing than unfilled paper. On the other hand, filler could change web pressability, thus its pressed web solids content. There is no information available in the public domain regarding the influence of filler on web pressability. The purpose of the present work was to give a more comprehensive view regarding the effect of filler on wet-web strength at any given web solids in a broad filler range. Another objective was to understand how filler affects web pressability, that is, the web solids after pressing.

EXPERIMENTAL

Materials

A single fine paper furnish was used in this work. It was composed of 75% bleached maple kraft pulp and 25% bleached softwood kraft (a mixture of spruce and jack pine). The two pulps were refined individually with a low consistency refiner (Beloit Jones DD4000) to a combined freeness of 230 ml (CSF). The filler used was a commercial precipitated calcium carbonate (PCC), Albacar 5970 obtained from Specialty Minerals Inc. A cationic polyacrylamide, Percol 292, from CIBA Specialty Chemicals Corp. was used as a retention aid.

Handsheet Preparation

Handsheets (80g/m^2) were made and couched using the standard PAPTAC procedure (C4). For measurement of wet-web strength, a special sheet mold was applied over the forming wire to obtain 3 strips, each with a dimension of 2.5 × 12 cm. Couched handsheets were separated into five groups. One group was maintained at the couch solids by placing the strips between polyethylene sheets in a sealed bag. The other four groups were pressed for five minutes between blotters in a Carver press under one of four preset pressure settings as shown in Table I (the values in the table are relative pressure settings, not actual ones). Under these couch and press conditions, the resulting solids content of the sheets ranged between 24% and 65% [9]. Additional blotters and pressings were applied to obtain web solids greater than 65%.

TABLE I.
Laboratory press conditions to obtain different solids contents.

Condition No.	*Pressure setting (arbitrary units)*	*Pressing Time (Min.)*
1	*couch*	*couch*
2	*20*	*5*
3	*275*	*5*
4	*925*	*5*
5	*1235*	*5*

Wet-Web Strength Measurement

Standard PAPTAC method (D23P) was used to measure the strength properties of the wet webs prepared as described above, except that a strain rate of 50 mm/min was employed instead of 100 mm/min.

Pressability Test

To study the effect of filler on pressability, handsheets filled with various levels of PCC were pressed on a single-felted two-roll pilot press. The top roll was made of steel and the bottom felted roll had a grooved rubber cover. Both rolls had a diameter of 0.75 meters. We used a commercial felt with three layers of batt designed for fine paper machines. Other details of the press have been described in previous reports by Pikulik *et al*. [10] and McDonald *et al*. [11]. The press was running at a speed of 70 m/min under one of three nip loads: 25, 60, and 115 kN/m, which led to press impulses of 21, 51, and 99 kPa·s, respectively. Under these press conditions, the range of outgoing wet solids contents covered the typical values obtained from commercial fine paper machines, which are about 45% with three-nip press [12], and up to 52% with extended nip press. A range of ingoing web solids contents was achieved by varying the speed and weight of the couch roll. After pressing, the sheet was peeled from the top steel roll and weighed immediately. Finally, each sheet was oven-dried to determine its dry weight, which was used to calculate web solids content before and after pressing.

RESULTS AND DISCUSSION

Effect of Filler on Wet-Web Strength

Figure 1a shows breaking length of the handsheets made from the softwood and hardwood kraft pulp blend as a function of web solids content. Breaking length increases exponentially as web solids content increases. When the solids content is lower than 50%, breaking length is only 1-3% of that of dry sheet. A similar relationship was observed when tensile energy absorption (TEA) index was plotted against web solids (see Figure 1b). Figure 2 shows that as PCC was incorporated into the sheets, wet web strength was further reduced. As depicted in Figures 3a and 3b, the impact of filler on wet-web strength can be demonstrated more clearly when breaking length and tensile energy absorption are plotted against filler content at a constant web solids of 50%. The breaking length dropped from 0.27 km at zero filler level to less than 0.1 km at 50% PCC. The corresponding TEA index was reduced from about 100 mJ/g to only about 20 mJ/g. Such low web strength would reduce significantly paper machine runnability when producing paper containing a high filler level.

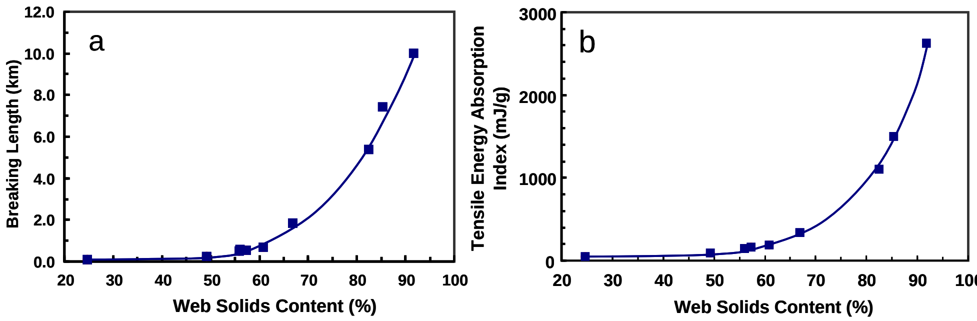

Figure 1. Wet web tensile strength as a function of solids content in the absence of filler, a: breaking length, b: tensile energy absorption index (TEA).

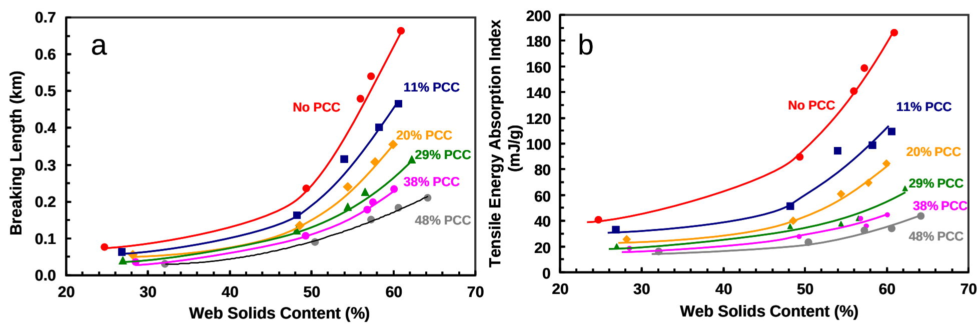

Figure 2. Tensile strength of wet-web containing various levels of PCC as functions of solids content, a: breaking length, b: tensile energy absorption index.

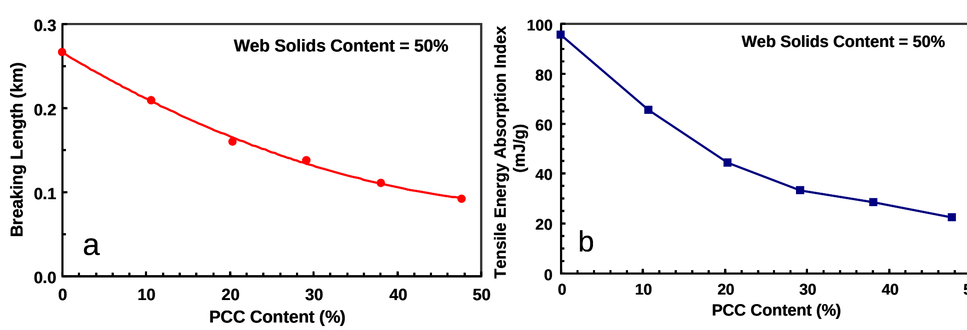

Figure 3. Tensile strength of wet-web as a function of PCC content at a constant web solids content of 50%, a: breaking length; b: tensile energy absorption index.

Effect of PCC on Web Pressability

In the previous section, web strength properties were compared at a given web solids content. Because filler does not hold as much water as wood fibres, it is reasonable to expect that a filled sheet should be easier to dewater, and hence reach a higher solids content after both forming and press sections. Thus, to establish a fair and realistic comparison scheme, wet web strength should be determined under equal drainage and press conditions. To investigate the effect of filler on web solids under constant press conditions, handsheets filled with PCC were couched to various solids contents, then pressed with a pilot press. Press data with an impulse of 51 kPa·s are shown in Figure 4. The web solids after pressing increased linearly with initial solids content before pressing. Under the press conditions used, the initial web solids content had a minor effect. When the initial web solids increased from 18% to 37%, the pressed web solids only increased by about 2%. Similar results were obtained under two other press conditions. Thus, paper solids content is largely determined by press conditions if dewatering is adequate at the machine forming zone, in agreement with the findings of McDonald and Pikulik [13].

Using the data in Figure 4, web solids at any given initial solids were calculated from linear regression equations. Figure 5 shows the pressed web solids with an initial solids of 23% under three press impulses. As expected, raising press impulse increased web solids. This increase approached a plateau at a high nip impulse. On the other hand, increasing filler content increased web solids under all press conditions. The influence of filler can be readily observed by a plot of pressed-web solids against PCC content as illustrated in Figure 6. The web solids content increased linearly with filler content, from 45.5% with no filler present, to 49.8% with 50% PCC.

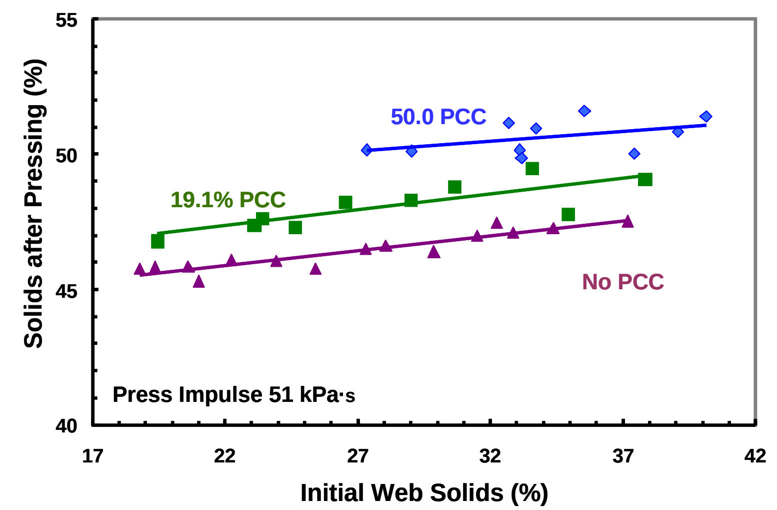

Figure 4. Web solids content after pressing at a nip impulse of 51 kPa·s as a function of couch solids.

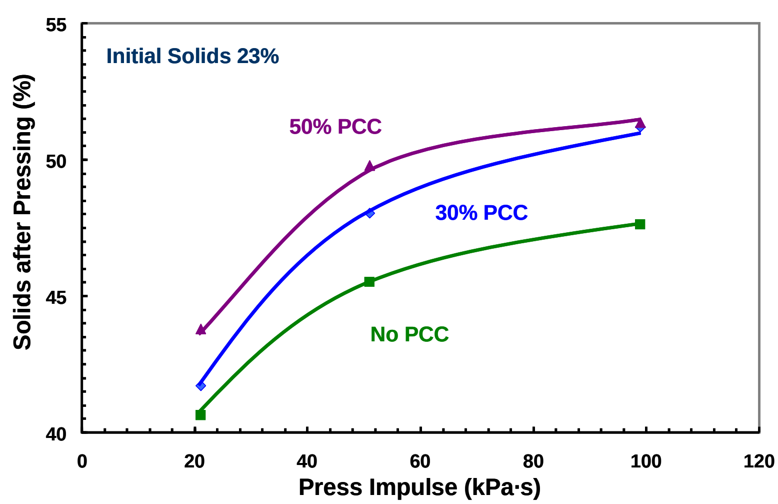

Figure 5. Web solids content after press as a function of nip impulse. The initial web solids content was 23%.

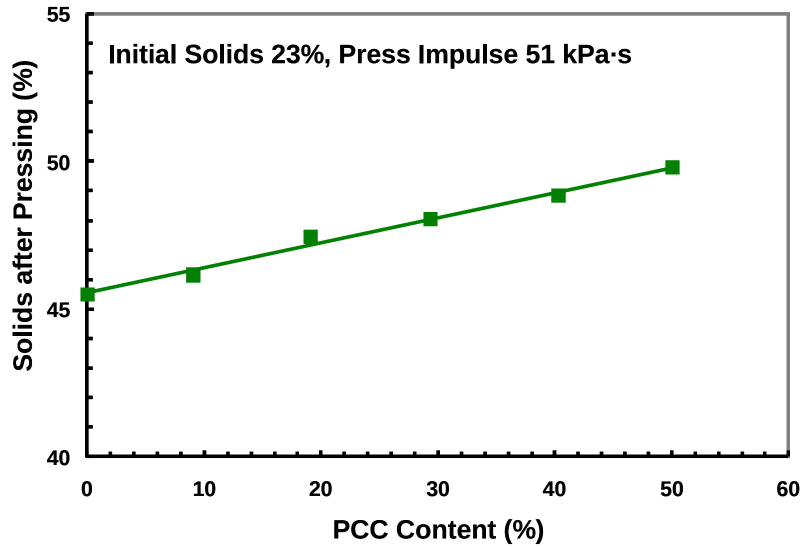

Figure 6. Web solids content after press as a function of PCC content. The initial web solids content was 23%, and press impulse was 51 kPa•s.

At first sight, Figure 6 suggests that filler improved pressability of sheets, because mineral filler holds much less moisture than wood fibres. Figure 7 shows the solids content of the filler itself after wet filler was pressed, without fibres, against a filter paper under various nip impulses. The couch solids of PCC was already quite high, over 58% before pressing, and levelled off to 66% beyond an impulse of 51 kPa. This data showed that filler does hold some moisture, probably due to surface adsorption and capillary forces in the interstices of filler particles. This moisture cannot be removed 100% by pressing only. Assuming the same amount of moisture was associated with filler in the wet fibre network, the moisture content of the fibre portion in the wet-web can be calculated. The results in Figure 8 show that fibre solids content decreased as filler content increased, and this effect was greater at a higher PCC content. Hence filler actually impedes the dewatering of fibres during pressing. As shown by Kerekes and McDonald [14], web pressability is determined by its permeability and compressibility. Obviously, filler reduces the pressability of sheets because filler is much less compressible than cellulosic fibres.

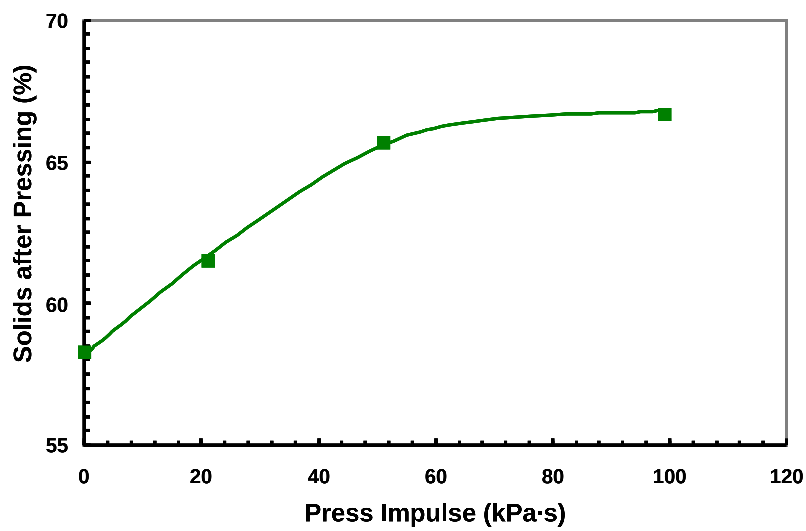

Figure 7. Solids content of a PCC layer after pressed under various nip impulses.

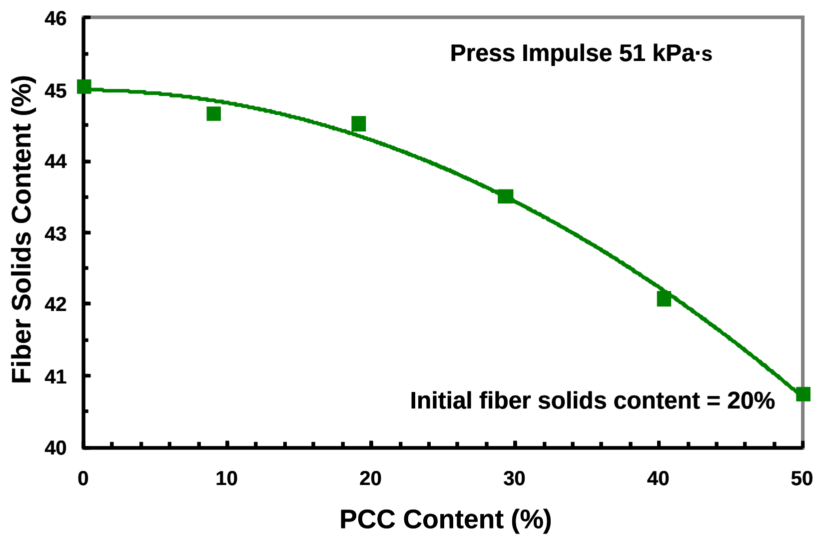

Figure 8. Solids content of fibre-portion in pressed-web containing various amounts of PCC. The initial solids content of the fibre-portion was 20% (fibre moisture ratio = 4.0), and nip impulse was 51 kPa·s.

Wet-Web Strength under Constant Dewatering Conditions

In the first section, wet-web strength was compared at the same solids content. However, to evaluate machine runnability of filled sheets, comparison should be based on the same dewatering conditions. Results presented in the second section indicated that filled sheets have higher solids contents than unfilled sheets under the same press conditions. These results were obtained at the same starting couch solids. However, filler also affects couch solids of the web under given couch conditions. This effect should also be considered in determination of the final web solids after pressing.

Achieving constant couch conditions is not simple in the laboratory when couch solids are affected by filler content. Because couch solids without filler was 20% on average, we took this value as being representative of the fibre fraction. Using the water content in the PCC layer presented in Figure 7, we then estimated the web couch solids at increasing PCC levels. The results indicate that the presence of PCC increases couch solids (bottom line in Figure 9). These results mimic well the observation made on a commercial paper machine. For example, in a full scale machine trial, we observed that the web couch solids increased from 22 to 23.5% when PCC content increased from 17 to 20%.

Based on these estimated couch solids (Figure 9) and on the relationship between couch solids and press solids presented in Figure 4, the press solids under constant drainage and press conditions were calculated. The corresponding press solids at press impulse of 51 kPa·s are shown as the top curve in Figure 9. It can be observed that there was one percentage point increase for every 10% filler inclusion under the press conditions used in this work. Based on these web solids with varying PCC contents, the wet-web breaking length and TEA at a given PCC content were recalculated from Figure 2. The data are shown in Figures 10a and 10b. For comparison, wet-web strength data at a constant web solids (50%) are also shown. Clearly, the increase in web solids due to PCC reduced the impact of the filler on web breaking length and TEA. However, PCC has a particularly significant impact on TEA as the value decreased from 68 mJ/g without PCC to about 23 mJ/g when the sheets contained 48% PCC. This reduction in wet-web strength will affect machine runnability if no counter action is taken. In the next report, we will discuss means to improve the wet-web strength of sheets with high filler contents.

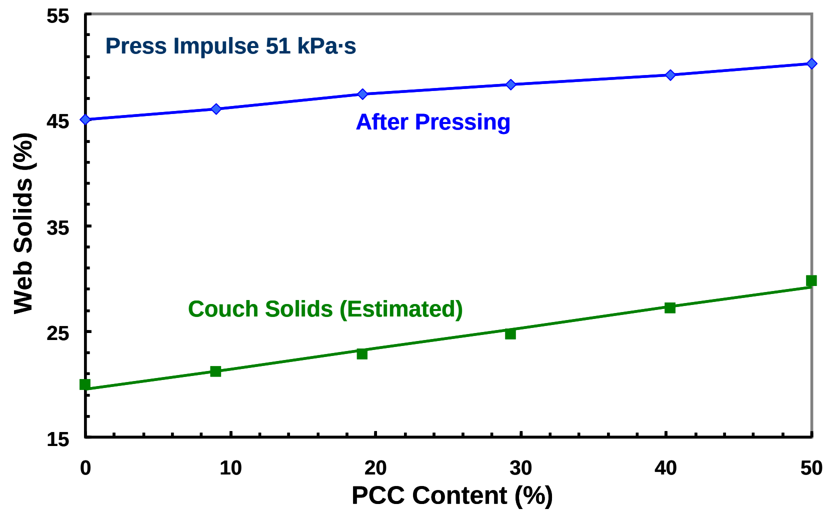

Figure 9. Couch and press solids contents of wet-web as a function of PCC content. The couch solids were estimated by assuming that PCC and fibres both had a constant solids content (moisture level) in the couched web, which were 20% and 58.3%, respectively.

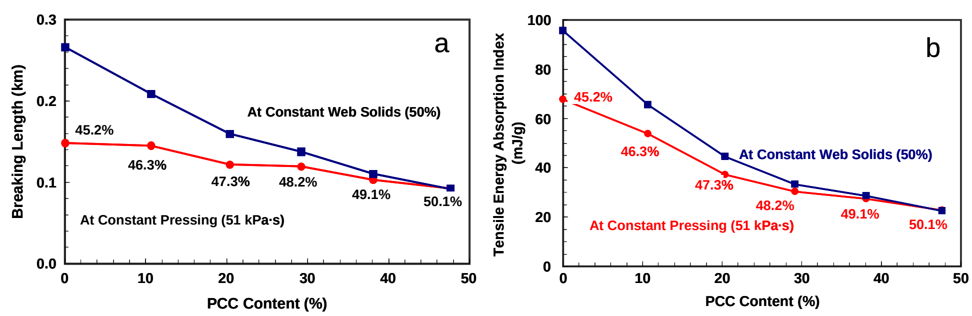

Figure 10. Wet-web tensile strength as a function of PCC content. The bottom curve represents the scenario when pressed webs had varying solids contents due to the presence of PCC. The numbers adjacent to the curve are solids contents of the web after being couched and pressed under the same conditions. The top curve was obtained at a constant web solids content of 50%. (a: breaking length; b: tensile energy absorption index).

Effect of Filler Type on Wet-Web Strength

The extent of wet-web strength reduction is also related to filler type used. Four types of fillers with high brightnesses, including a PCC, a GCC, a calcined clay, and a delaminated clay, were compared to understand their effect on wet-web strength. The typical properties of the four fillers are shown in Table II. Figures 11a and 11b show the breaking length and TEA of wet-web containing these fillers at 30% loading level. GCC and PCC filled webs had quite similar wet-web breaking length and TEA, though markedly lower than clay filled web. Wet-web strength of calcined clay filled web was stronger than that of delaminated clay. The differences among these fillers might be due to their different morphological structure.

TABLE II. The characteristics of the fillers used in this work.

Filler	*PCC*	*GCC*	*Calcined Clay*	*Delaminated Clay*
Brightness	*98*	*96*	*92.5*	*89*
< 2 μ (%)		*92*	*91*	*50*
325 mesh residue (%)	*<0.05*		*0.005*	*0.2*
pH	*~10*	*~10*	*5*	*6.8*
Surface area (m^2/g)	*7*	*11.6*		
Mean particle size (μm)	*1.9*	*0.7*	*0.6*	*2*

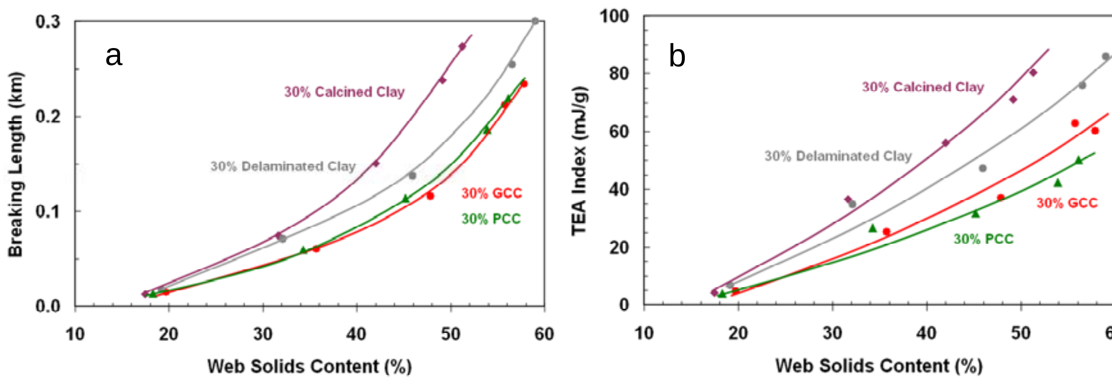

Figure 11. Tensile strength of wet-web containing various types of high-brightness filler as a function of solids content. The filler loading was 30%. a: breaking length; b: tensile energy absorption index.

CONCLUSIONS

Incorporation of filler into sheets substantially reduced their wet web strength. At a PCC content of 50%, web TEA was reduced by about five fold at a given web solids content. On the other hand, filler increased web solids content both after couching and after pressing under given drainage and press conditions. Although the web was drier with increasing PCC content, PCC actually reduced the web pressability, and the fibre portion in the web remained wetter in the presence of PCC. Overall, PCC filled sheets were significantly weaker under the same drainage and press conditions. Furthermore, wet-web strength was also dependent on filler type used. The two clay fillers used in this work reduced less the wet-web strength than did the two calcium-carbonate based fillers. To make highly filled paper, some counter action (such as chemical additives, increasing refining etc.) will be needed to have good machine runnability.

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