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# Hybrid Precipitated Calcium Carbonate Containing Wood Flour for Paper Applications – A Comparative Handsheet Study

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author KD supervised and managed the study, wrote the final draft and approved the final manuscript.*

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## ABSTRACT

The main objective of this paper handsheet study is to investigate if a hybrid filler material containing wood flour and precipitated calcium carbonate can replace and/or supplement commercially available ground calcium carbonate and precipitated calcium carbonate mineral filler material for papermaking. The handsheet study contains 25 different furnish mixtures. Four different types of wood flour were used to manufacture the hybrid filler material, including two wood flour blends with a strengthening agent. All handsheet were manufactured with an 80% harwood and 20% softwood mix. The filler content varied between 10, 15 and 20%. The study showed that the hybrid filler

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material achieved a retention of up to 92.68% as well as a higher caliper of up to 208 µm compared to commercial ground and precipitated calcium carbonate of 120.4 µm and 145.6 µm respectively. Tensile and tear strength did not show an improvement. Elongation and tensile energy absorption did improve of up to 30% with the strength additive containing hybrid filler material. Opacity was improved of up to 10% with the hybrid filler material. Brightness and color values were lower due to the natural brow color of the wood flower material.

*Keywords: Wood flour; filler; PCC; GCC; additive; strength; retention; papermaking; paper properties.*

## 1. INTRODUCTION

In the last decade, worldwide efforts in technology and society have been made to find ways to replace ephemeral plastic products with environmentally friendly materials. A promising product with a wide range of uses is paper. In order to further increase its ability to compete with established plastic products, the paper-making process must also be viewed critically with regard to the use of energy and raw material usage [1]. The following work focuses on the replacement of mineral fillers with Wood Flour (WF). The filler to be replaced in this study is calcium carbonate in the form of Ground Calcium Carbonate (GCC) and Precipitated Calcium Carbonate (PCC), the most commonly used filler material in papermaking [2]. The share of mineral filler in the total raw material input of the paper industry is currently 8%. However, the trend of recent years shows a clear skew towards the production of papers containing higher filler [3,4].

The application of GCC and PCC mineral filler material in the paper manufacturing process lowers production cost due to the lower cost of filler to raw fiber material [2,3]. The application of filler materials increase optical properties such as whiteness, brightness, and opacity and can have a positive impact on formation [5]. On the other hand, the addition of mineral fillers lowers the mechanical properties of the paper product [2].

GCC occurs by the degradation of calcium carbonate. This is a naturally occurring material whose raw stone is extracted from chalk, lime and marble deposits. A great difference to other fillers is its rhombohedral calcite crystals. After several comminution steps and removal of the chemical impurities by flotation, the final particle size distribution is achieved by micronization. Solid contents of the commercial slurries of GCC are about 78% [3].

PCC, on the other hand, belongs to the group of synthetic carbonates, which are obtained through a three-stage process. First, quicklime is produced by thermal removal of $CO_2$. Subsequently, the quicklime is converted with $H_2O$ to calcium hydroxide. The reintroduction of $CO_2$ causes the precipitation of PCC at a solids content of 20-35%, a level much lower than comparable GCC slurries [3].

Since the beginning of the twentieth century, wood flour (WF) has been used as an extender for glue and absorbents of explosives. As a filler in the production of plastic parts, wood flour was first processed in 1916. [6] The term “wood flour,” for which no clear-cut definition has been adopted, is applied somewhat loosely to wood reduced to finely divided particles approximating those of cereal flours in size, appearance, and texture. A specific method of production is not involved in the name “wood flour.” [7] Practically speaking, wood flour usually refers to wood particles that are small enough to pass through a screen with 850-micron openings (20 US standard mesh) [7]. Earlier studies have shown that the use of wood flour can be an alternative cellulosic based wood additive [8]. A deterioration in brightness and smoothness could be compensated for by the combined use with calcium carbonate [9]. This handsheet study investigates if a hybrid filler material, a combination of WF and precipitated calcium carbonate, can have a positive impact on mechanical and optical paper properties.

## 2. MATERIALS AND METHODS

This section describes the materials, standardized test methods and procedures of the Technical Association of the Pulp and Paper Industry (TAPPI), used for this study. Repeatability of the results stayed in between the allowable margins of the TAPPI testing standards.

### 2.1 TAPPI Methods

Pulp refining was done according to T 200 sp-06 “Laboratory beating of pulp (Valley beater method) [10], Handsheets for physical testing were prepared in accordance with T 205 sp-06 [11], Ash in wood pulp was tested with T 211 0m-02, "Ash in wood pulp, paper and paperboard: combustion at 525°C" [12]. Physical testing of pulp handsheets was performed in accordance to T 220 sp-06, "Physical testing of pulp handsheets" [13], the freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 "Freeness of pulp (Canadian standard method)" [14]. Conditioning of the paper samples was done according to T 402 sp-08, "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products" [15]. Tensile strength was measured in accordance with T404 cm-92, (Tensile breaking strength and elongation of paper and paperboard) [16]. Basis weight was measured with T 410 om-08. {Grammage of Paper and Paperboard (weight per unit area)} [17]. The paper thickness was measured by T 411 om-10 (Thickness (caliper) of paper, paperboard, and combined board) [18]. The moisture content of pulp was determined by T412 om-06 (Moisture in pulp, paper and paperboard) [19]. The tear strength was done by following the T 414 om-12, {Internal tearing resistance of paper (Elmendorf-type method)} [20]. The opacity of paper handsheets was performed according to T 425 om-06, {Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance backing and paper backing)} [21]. Brightness of pulp was measured according to T 452 om-08, {Brightness of pulp, paper and paperboard (directional reflectance at 457 nm)} [22]. Stiffness of the paper was measured according to T 489 om-08, {Bending resistance (stiffness) of paper and paperboard (Taber-type tester in basic configuration)} [23]. The paper color was measured by T 524 (Color of paper and paperboard) [24].

## 2.2 Materials

For the handsheet study the fiber materials used was a blend of 80% Sappi Saiccor Eucalyptus Hardwood and 20% AV Terrace Bay Northern Bleached Softwood Kraft (NBSK). For this study the fiber material was beaten together in a Valley Beater to a 320 ml CSF freeness, suitable for papermaking, following TAPPI T 200 sp-06 method [9].

For the study, two different commercially available GCC and PCC types were used. The first GCC (GCC1) used was a GCC powder with a mean particle size of 0.7 µm. A 20% slurry using deionized water was produced for the application in the handsheets. The second GCC (GCC2) applied to the handsheets was a commercially available GCC slurry with 76.72% solids content with a mean particle size of 0.73µm.

The first PCC (PCC1) used was a PCC powder with a mean particle size of 1.0 µm to 2.0 µm. A 20% slurry using deionized water was produced for the application in the handsheets. The second PCC (PCC2) applied to the handsheets was PCC slurry produced on-site at a paper mill site in the U.S. with 19.58% solids content and a mean particle size of 1.66 µm. For the second trial four different precipitated calcium carbonates (PCC) + Wood Flour (WF) were produced and integrated into the handsheets.

To produce the laboratory hybrid WF-PCC, a calcium hydroxide ($Ca(OH)_2$) type was used suitable for PCC production in combination with two WF types with and without Strength Additive (SA) that is activated on contact drying. WF1 had a particle size distribution of 20µm to 50µm and WF2 had a particle size distribution of 40µm to 70µm.

The produced hybrid WFPCC1 had a solids content of 14.35%, WFPCC1SA of 16.99%, WFPCC2 of 13.28%, and WFPCC2SA of 16/35%.

## 2.3 PCC + Wood Flour Material Preparation

The preparation of the PCCWF product followed the process sequence laid out in Fig. 1 which shows the flow of the production process with all components and important data. A Fischer Scientific Isothemp Lab Stirring Hotplate was used for stirring and heating the suspension in a 2000 ml beaker. Industrial grade $CO_2$ from a 150 lbs. gas bottle with pressure regulator was used as the precipitation reactant. The $CO_2$ was dispersed in the beaker with an air stone.

The preparation of the material started with the weighing of 1500 ml of deionized water 150g Calcium di-hydroxide $Ca(OH)_2$ and 150g of the respective wood flour (Fig 2a). The next process step was heating water to 40°C. Subsequently, first GCC and the respective wood flour was

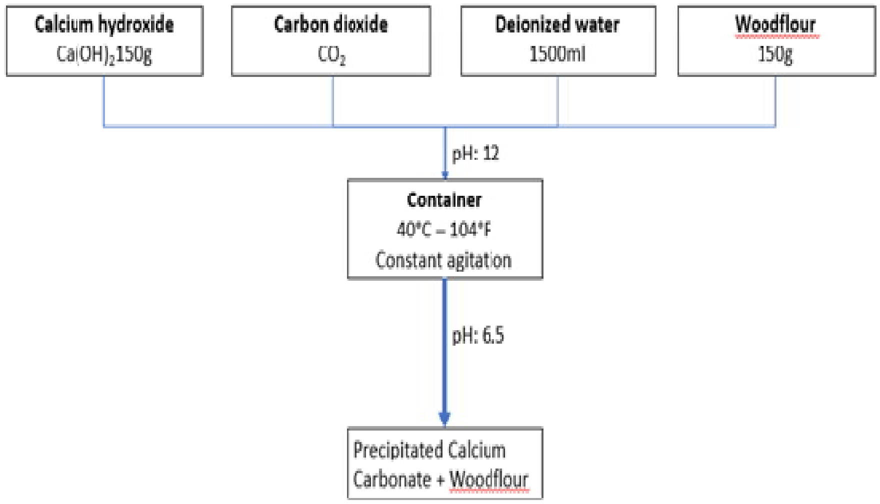



**Fig. 1. PCC+ WF process sequence**

added one after the other. In order to avoid clumping and to ensure good mixing, slow addition of the powders and constant agitation was necessary (Fig. 2b). After that the addition of $CO_2$ could be started (Fig. 2c). The amount of added $CO_2$ was determined visually, because the wood flour foamed strongly when too much was added. (Fig. 2e). Once the amount was set, it was left. Throughout the process, the temperature and pH were measured with a pH meter (Fig. 2d). The initial pH value was 12.0. The measurement of pH was important because it was the indicator for the precipitation of PCC, the target value of the pH after precipitation was set to a pH of 6.5.

Fig. 3 shows that all four blends start with the same initial values (pH 12.0, 40°C) and follow the same pattern throughout the process. During the first phase of the reaction the pH stays constant while the temperature increases quickly until a maximum is reached. Striking here is the difference of the length of this phase. The precipitation of WFPCC1 and WFPCC1SA reached a temperature of 56°C after 33 minutes, and 54°C after 36 minutes respectively. For WFPCC2 and WFPCC2SA precipitation, a maximum temperature of 55°C after 37 minutes and 52°C were reached respectively. As soon as the maximum temperature was reached, the pH level dropped in less than three minutes to the target value of pH 6.5 and the $CO_2$ influx was turned off. After continuing stirring for 2 minutes without adding more $CO_2$, the pH levels stabilized around 6.8. The finished slurries were bottled and stored in a cold room at 5°C.

Fig. 2f shows the color differences of the produced WFPCC slurries from left to right: WFPCC1 with 14.35% solids content, WFPCC2 with 14.28% solids content, WFPCC1 with 16.99% solids content, and WFPCC2SA with a 16.53% solids content. Noticeable is the lighter color of the WF1PCC after precipitation.

## 2.4 Handsheet Study

All handsheets contained the same amount of fiber (80% SW and 20% HW) for the base line and the eight filler varieties described above. The target for the basis of the handsheets was 85 g/m². The amount and type of filler was changed in everyfurnish. The handsheets consisted of a filler variation from 0%, 10%, 15% and 20% for every filler type that was used. From each variety five handsheets were formed.

The beating of the SW/HW pulp was done in accordance with TAPPI T 200 with a consistency of 1.57 ± 0.04% and a temperature of 23 ± 2°C. The pulp was loaded into the Valley Beater, the Valley Beater was operated with no load for 3 min. After that, the initial sample was taken, and the beating was initiated by applying a weight of 5500g to the grinding plate lever. The pulp was refined to CSF value of 320. After the pulp is refined, handsheets are made to the composition mentioned above and tested according to TAPPI standards. When weighing the fillers, it was

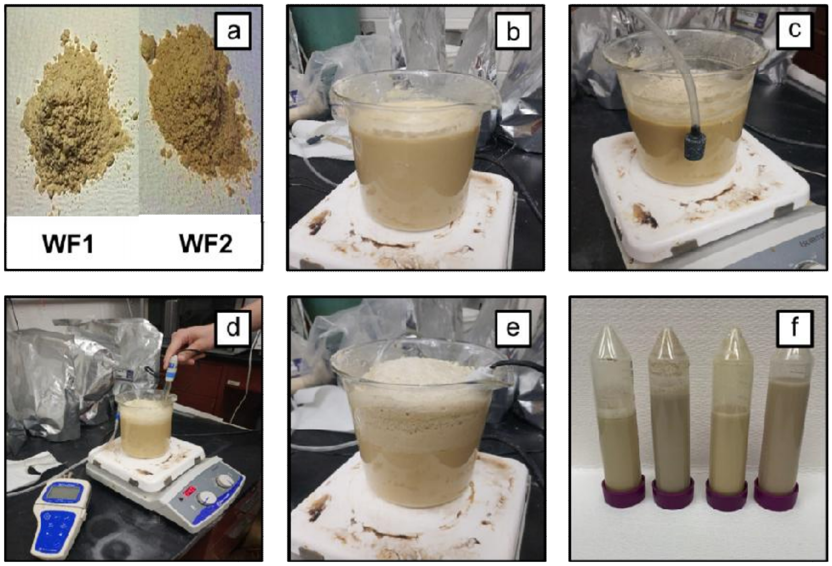



**Fig. 2. PCC Production with WF a) WF types, b) WF-CA(OH)$_2$ slurry, c) $CO_2$ injection system d) pH and temperature measurement, e) foam built up f) final PCCWF from left: WFPPC1, WFPCC1SA, WFPCC2, WFPCC2SA**

important to note that the slurries in the bottles were well mixed and all deposits on the bottom were dispelled. Then the weighed fillers were added to the fiber suspension and stirred for about a minute. Subsequently, the handsheets were formed, pressed and conditioned in the laboratory. The sheets which contained strengthener were contact dried after pressing at 120°C for 5 minutes on both sides.

## 3. RESULTS AND DISCUSSION

All handsheets were tested for basis weight, caliper, stiffness, tear, tensile, elongation, Tensile Energy Absorption (TEA), opacity, brightness and L-/a-/b-values according to the TAPPI testing standards mentioned above and compared to a basis sheet consisting only our fiber blend without the addition of any filler.

### 3.1 Retention

Fig. 4 displays the differences, regarding retention, between the eight filler types. For determining the level of retention, we averaged the amount of ash of all three handsheets (10%, 15%, 20% target filler value) which were produced using the same filler. One of the most important parameters of our handsheets was the exact loading of certain quantities of filler. Only by achieving constant amounts of filler, the physical properties of the handsheets can be compared with each other. Based on experience on filler retention in handsheet moulds and the knowledge about the much poorer retention, handsheets were first produced with eight times as much filler as to determine the actual retention and to adjust the dosage factor.

Comparing the GCC powder and the GCC slurry, the powder had a three times higher retention rate than the slurry (8.66% versus 2.58%). In contrast, the PCC powder and the PCC slurry show a nearly identical behavior (34.32% and 34.77%). In addition, PCC shows better retention than GCC. The reason for this is probably the larger surface, the larger particle size and more branched structure of the PCC.

The PCC slurries produced together with the WF have a significantly higher retention than the pure PCC. The integration of wood flour into the filler offers the possibility of hydrogen bonds between the filler particles and the fibers of the paper.

This does not exist with pure inorganic filler. It is noticeable that the type WFPCC1 has a retention of 82.98% much higher than the type WFPCC2 with 51.51%. The reason for this could again be the larger particle sizes of the WF product.

The best retention of 92.68% was achieved by using WFPCC1SA. THE WFPCC2SA also showed an increased retention of 79.13% compared to the commercially available filler materials, but lower retention compared to the WFPCC1product.

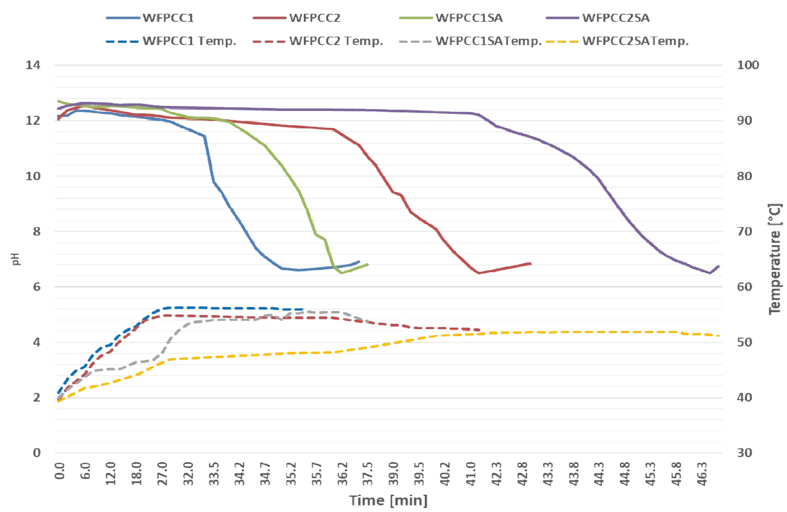



**Fig. 3. Process temperature and pH during laboratory PCC production**

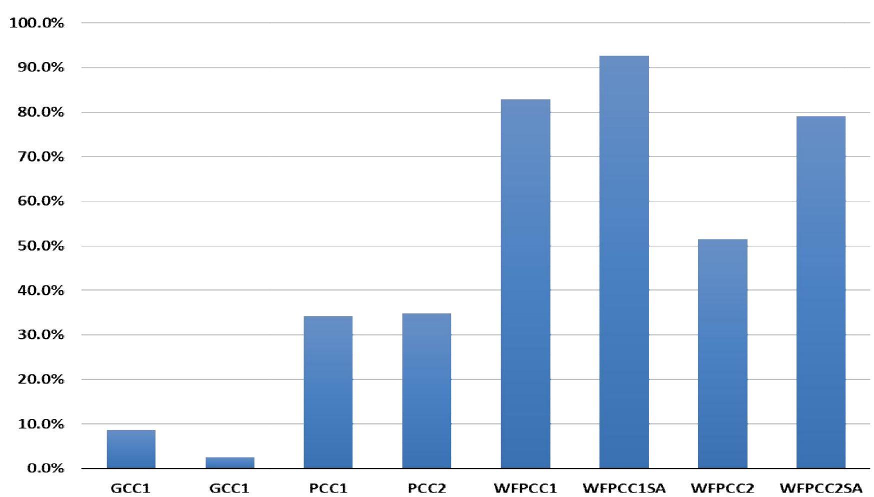



**Fig. 4. Filler retention**

### 3.2 Caliper, Basis weight, Stiffness Index

For comparison of the basis weight, the base sheet had 87.54 g/m². The PCC1 handsheet had a basis weight of 87.18 g/m² comparable to the GCC1 basis weight of 85.65 g/m². GCC2 hansheets had a basis weight of 80.94 g/m² while PCC2 had a basis weight of 92.22 g/m². For handsheets manufactured with wood flour the basis weight had a range of 107.31 g/m² WFPCC1 to 117.03 g/m² WFPCC2.

The caliper of the basis sheet and the sheets with GCC filler had comparable properties of 128.8 µm and 120.4 µm GCC1 and 119.2 µm GCC2 µm respectively. The handsheets with the PCC as filler had slightly higher caliper in the tests. The PCC1 had a caliper of 145.6 µm comparable to the PCC2 with 142.8 µm.

The produced handsheets with wood flour showed different caliper depending on the used WF. It was noticeable that PCCWF2 with distance showed the highest caliper with 268 µm. WFPCC2SA + WFPCC1SA had comparable values of 198 µm and 208 µm. The lowest caliper was achieve had WFPCC1 with 185 µm, which is still higher than that of the purely inorganic fillers and the basis sheet.

The resulting stiffness index of 0.123 was higher for the basis sheet and lower for all other filler except WFPCC2 of stiffness index of 0.127. In general, the stiffness of each filler remained about the same. The range was between 0.096 and 0.107 after calculating the index.

The high retention of the wood flour + PCC filler resulted in a final ash content of 15% for the 10% handsheet series. Accordingly, all other test series were well above their targeted ash content. In order to ensure a comparability, only sheets with the same amount of filler were compared with each other. Since the proportion of fibers was not adjusted to the unexpectedly higher retention, higher basis weights resulted accordingly.

A direct result of higher fiber content and thus higher basis weight is a higher caliper. An additional factor for a higher caliper in contrast to the base sheet is the generally larger particle size of the wood flour and the possibility of swelling the wood particles. In order to compare strength properties despite different basis weights, an index was calculated. Due to the higher volume of wood flour in contrast to the PCC or GCC, the stiffness of WFPCC2 is comparable to the base sheet. Overall, the wood flour has hardly any influence on the stiffness in the finished paper.

All tests were repeated with 20% filler sheets in Fig. 6 to reproduce the previous results that are shown in Fig. 6. By a higher proportion of wood flour, any influences are to be displayed more clearly. Additionally, two sets of handsheets were made containing both WF with and without SA, which required contact drying. These handsheets were examined by all the above test methods to find the differences that contact drying makes.

Both basis weight and caliper have increased as expected due to the higher filler load. The stiffness has not changed compared to 15%. The activation process of the SA shows no influence on caliper and stiffness.

### 3.3 Tensile Index and Tear Index

The tensile and tear index in Fig. 7 shows a consistently strong correlation. The base sheet has the highest tensile and tear index values (0.69 / 6.07). Adding filler of any kind significantly reduces these strengths. Both PCC2 and PCC2 have comparable values of (0.22/4.76 and 0.22/4.94). When using GCC as the filler, slightly higher values of tensile and tear index (0.32/5.40) can be seen.

Adding wood flour to the furnish while replacing fibers, lowers the tensile and tear index significantly. Including a SA to the WFPCC shows slightly higher values in comparison with WFPCC without SA. WFPCC1 shows values of tensile and tear index 0.30/4.31 and 0.31/4.64 with SA. WFPCC2 shows values of tensile and tear index of 0.26/4.32 without SA and 0.31/4.93 with SA.

With the use of 20% filler, Fig. 8 shows identical results as Fig. 7, whereby the individual values have a lower value in comparison to the base sheet. Not to be expected in handsheets of higher strength values with strengthener without


**Fig. 5. Basis weight/ Caliper/ Stiffness 15% filler + WF**


**Fig. 6. Basis weight/ Caliper/ Stiffness 20% filler + WF**

contact drying. WFPCC1SA with contact drying had a tensile index values of 0.23 and without drying 0.30. The tear index was 3.84 with drying and of 4.23 without. WFPCC2SA with contact drying had tensile index values of 0.22 and of 0.24 without drying. The tear index was 3.22 with drying and 3.46 without.

### 3.4 Elongation and TEA

Fig. 9 shows elongation and TEA (Tensile Energy Absorption) at 15% filler. The base sheet had a maximum elongation of 1.91% and a TEA of 3.27. In comparison, PCC2 values were 1.76% and 1.57 and PCC1 values were 1.94% and 1.75 respectively. GCC2 and GCC1 results were also very close, 1.68% versus 1.72% regarding elongation and 2.10 versus 1.94 regarding TEA respectively.

WFPCC1 without strengthener has values similar to pure mineral fillers, 1.54% elongation and 1.49 TEA. Adding SA results in an elongation higher than the basis sheet (2.45%) as well as a far less reduced TEA value of 2.32. The positive influence of the strengthener with the bigger wood flour particle size of FLPCC2 is even higher; the TEA value of 3.28 is on the same level as the basis sheet (WF without SA) of 1.45. The elongation is, with 3.13% higher than 30% of the maximum elongation of the basic sheet (WF without SA) of 1.45%.

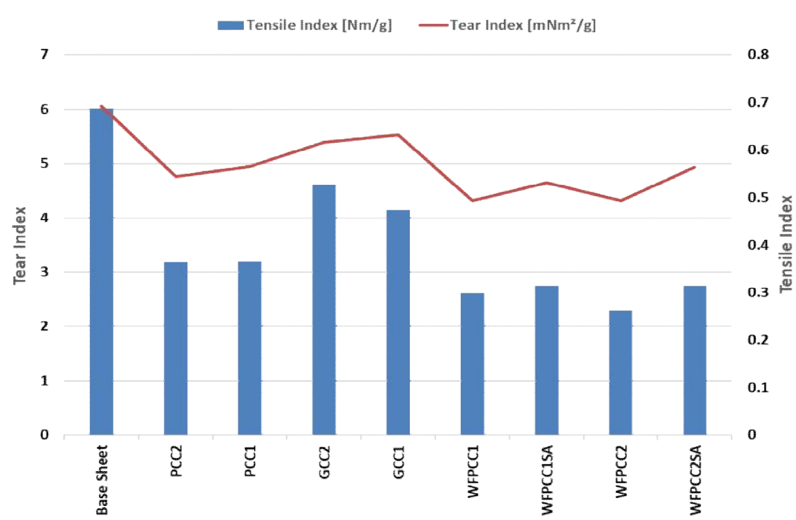



**Fig. 7. Tensile / Tear 15% filler + WF**

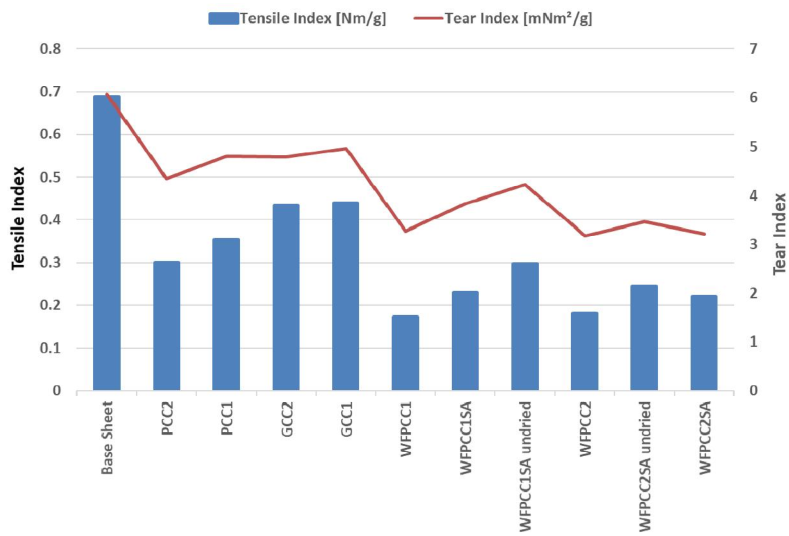



**Fig. 8. Tensile / Tear 20% filler + WF**

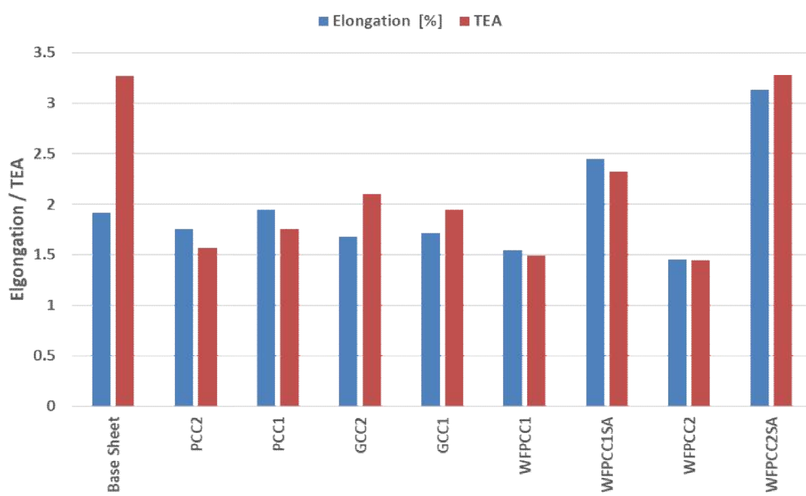



**Fig. 9. Elongation / TEA 15% filler + WF**

Fig. 10 shows that increasing the amount of filler from 15% to 20% changes the influence of the wood flour and the additional strengthener drastically. The pure mineral fillers show a loss of strength in the paper at an increased input. It is noticeable that the use of PCC (1.76%) leads to higher elongation values compared to GCC (1.61%). GCC on the other hand shows a lower TEA of 1.66 than PCC of 1.57.

The use of wood flour shows even an greater decrease in relation to elongation and TEA. It can be seen that the wood flour with strengthener exhibit both higher elongation and TEA in the paper. WFPCC1 (1.43% versus 0.88) compared to WFPCC1SA (2.55% versus 2.08). WFPCC2 (1.63% versus 1.37) has also lower values than WFPCC2SA (2.18% / 1.85%). Overall, both values are reduced compared to the use of 15% filler.

However, regarding this strength characteristic, it is interesting to note, that the activation of the sa by contact drying has a positive effect. Both the elongation and the tea show a increase after the same wood flour is contact dried than when using the same wood flour without contact drying. WFPCC1SA without drying shows elongation of 1.50% and a TEA of 1.53. WFPCC2SA without drying shows elongation of 2.07% and a TEA of 1.79.

### 3.5 Brightness and Opacity

This section describes the results of the optical examinations. Fig. 11 shows the comparison of all fillers used in terms of opacity and brightness. Fig. 11 only shows the measured values in the use of 20% filler.

As expected, when using mineral fillers, both the opacity and the brightness in the paper increase in comparison to the basis sheet. The base sheet had an opacity of 85.76 and a brightness of 86.91. When PCC was used, the opacity and the brightness increased. For PCC2 a value of 93.41 for opacity and 91.82 for brightness was achieved. When using PCC1 a value of 90.72 for opacity and 90.27 for brightness was achieved. GCC2 showed little differences in the values of 88.37 opacity and 89.65 brightness. When using GCC1 a value of 89.62 and 88.59 was achieved for opacity and brightness respectively.

When using PCC + wood flour mixtures, the brightness dropped drastically while the opacity increased significantly. The loss of brightness can clearly be traced back to the naturally darker and unbleached wood flour. The increased opacity can be explained by the increased use of fine material. When comparing the two types of wood flour it was noticeable that the opacity was not dependent on the grade but on the amount of wood flour used. The brightness was higher when using the WF1with smaller particle size than WF2 with the larger particle size.

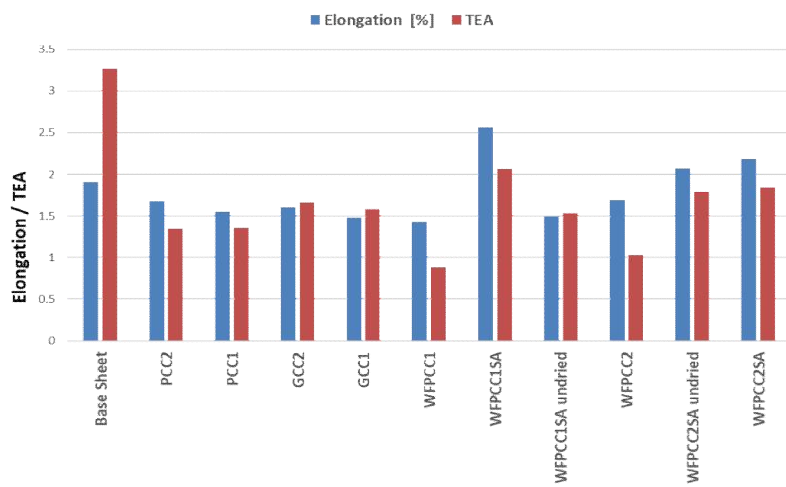



**Fig. 10. Elongation / TEA 20% filler + WF**

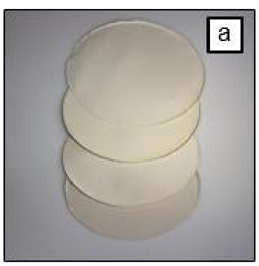

**Fig. 11. Brightness / Opacity 20% filler + WF**

There were hardly any differences in brightness and opacity within the WF grades. The values ranged between a minimum brightness of 62.91 and a maximum of 64.13. Regarding opacity the minimum value is 98.34 and the maximum 100.46.

WFPCC2 opacity values are very similar, ranging from 98.98 to 100.11. When comparing brightness, the handsheets produced without SA occurs darker (57.35) than the ones of the WFPCC2SA composition (62.08 undried and 61.82 dried) which are very similar.

Fig. 12 shows the final produced handsheets with all four wood flour PCC slurries. Picture 12a (from up to down) WFPCC1, WFPCC1SA, WFPCC2SA, and WFPCC2. Picture 12b shows the back sides of the handsheet in opposite direction.

The color differences were so significant that they were easily visible in Fig. 12.



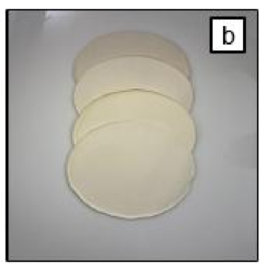




**Fig. 12. Handsheets wood flour and PCC front a) back b)**

Fig. 13 compares the L/a/b values of the handsheets with a 20% filler level to the basis sheet (L: 96.19 / a: -0.816 / b. 2.78).

The calcium based pure mineral fillers (PCC1, PCC2, GCC1, GCC2) are all in the same range. In general, the L-value of all four papers is higher than the basis sheet, all in a range of 97.7 to 96.47. Looking at the a-values, all four sheets appear less green / redder than the basis sheet, all ranging from -0.426 to -0.542. Comparing b-values, ranging from 1.77 to 2.34 with the handsheets containing filler, the basis sheet appears more yellow / less blue.Introducing wood flour to the filler blend lowers the L-, increases the a- and strongly increases the b-value in comparison to the basis sheet.

The three handsheets containing WFPCC1 all have a very similar L- (89.35 to 89.55) and a- (-0.69 to -0.76). The blend without SA has a b-value of 9.73, both sheets containing the strengthener appear more yellow (11.04 and 10.08). Contact drying to activate the strengthener does not interfere with the color.

The three handsheets containing WFPCC2 are lower in L-readings, WFPCC2 with the WF C 750 FP type being by far the darkest (84.9), the WFPCC2 types containing the SA have a L-values of 88.23 and 88.2. Comparing a- and b-readings, all three papers lay within a very narrow range (a: -0.21 to -0.03 and b: 9.58 to 9.77). The additional drying did not appear to influence the optical properties.

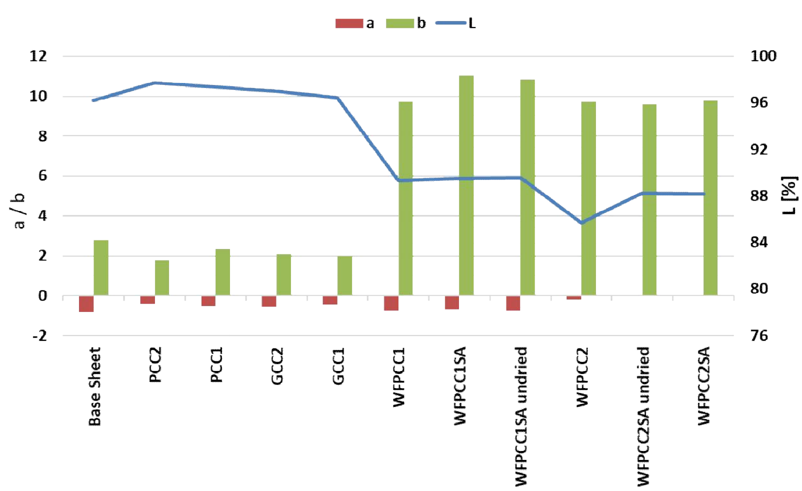



**Fig. 13. L - a - b 20% filler + WF**

### 3.6 Suggestions

During the research and the discussion of the results, several proposals are made for future research projects, which could deal more intensively with partial aspects.

To compensate for the significant losses in brightness and whiteness for printing and writing papers, the WF could be bleached prior to use as WFPCC.

To investigate the printing potential including color stability and aging of WFPCC containing paper, a suitable quantity of paper should be produced with a suitable small pilot paper machine.

Another avenue would be the comparison of low filler amounts. Smaller gradings would be advantageous to achieve an ideal ratio. This is mainly because the best results were achieved with the lowest amount of filler in this research work. One possible avenue for further research is the usage of wood flour as a retention aid, specifically, determining how as little wood flour can be added yet still produce an appreciable effect. In this scenario, sheet formation would be an area of interest; conventional retention aids (typically charged polyacrylamides) tend to damage formation by flocculating the fibers. [25, 26] It would be interesting to know if wood flour could aid retention without damaging formation.

## 4. CONCLUSION

The main objective of this study was to investigate if wood flour can replace commercial mineral fillers for papermaking with a handsheet study. The handsheet study contains 25 different furnish mixtures. For the handsheet study, the base sheet contains an 80%SW/20% HW. The filler content in the use of wood flour and mineral fillers varied between 10, 15 and 20%.

Paper handsheets containing the WFPCC did not have any different physical feel compared to the commercial filler containing handsheets.

The study showed that calcium carbonate precipitated in the presence of WF increases the retention of filler significantly of up to over 92.68%, whereas commercial PCC and GCC achieved a maximum retention of 8.66% and 34.77% respectively. The use of WFPCC resulted in a higher caliper of up to 208 µm compared to commercial GCC and PCC filler which achieved a caliper of 120.4 µm and 145.6 µm respectively.

Tensile and tear strength did not show an improvement for the WFPCC usage in comparison to the commercial GCC and PCC filler material. Usage of WFPCC with SA showed an improvement in comparison to WFPCC without SA.

Elongation and TEA did not show an improvement for the WFPCC usage in comparison to the commercial GCC and PCC filler material. The WFPCC including the SA showed a clear improvement of plus 30% for the 15% filler containing handsheets. For the 20% filler-containing hansheets the improvement is only up to 2%.

The opacity of the paper was increased with the use of WFPCC of up to 10 opacity points to 100.46 compared to commercial filler material with a maximum opacity of 93.41.

The coloring of the filler has a significantly greater influence on the final color of the paper than the conventional fillers, even in small amounts. This has resulted in lower brightness of up to 30 brightness points compared to the commercial filler material. In addition, and more yellow/cream tones of the paper could be observed.

Promising uses for this special filler type would be, for example, in corrugating medium grades, as properties such as stiffness and calipers play a major role in these grades. The optical properties, on the other hand, are rather irrelevant in the middle layer. For these reasons, these fillers could also be used as an internal layer of multi-ply, carton board and coaster board. Wood flour-containing fillers could facilitate the development of cream colored grades of paper that use little or no synthetic dye. Coloring paper in this way could also be beneficial from an environmental and marketing perspective.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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