

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

## 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% hardwood and 20% softwood mix. The filler content varied between 10, 15 and 20%. The study showed that the hybrid filler material achieved a retention of up to 92.68% as well as a higher caliper of up to 208  $\mu\text{m}$  compared to commercial ground and precipitated calcium carbonate of 120.4  $\mu\text{m}$  and 145.6  $\mu\text{m}$  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].

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

35 of the chemical impurities by flotation, the final particle size distribution is achieved by  
36 micronization. Solid contents of the commercial slurries of GCC are about 78% [3].  
37 PCC, on the other hand, belongs to the group of synthetic carbonates, which are obtained  
38 through a three-stage process. First, quicklime is produced by thermal removal of CO<sub>2</sub>.  
39 Subsequently, the quicklime is converted with H<sub>2</sub>O to calcium hydroxide. The reintroduction  
40 of CO<sub>2</sub> causes the precipitation of PCC at a solids content of 20-35%, a level much  
41 lower than comparable GCC slurries [3].

42 Since the beginning of the twentieth century, wood flour has been used as an  
43 extender for glue and absorbents of explosives. As a filler in the production of plastic parts,  
44 wood flour was first processed in 1916. [6] The term “wood flour,” for which no clear-cut  
45 definition has been adopted, is applied somewhat loosely to wood reduced to finely divided  
46 particles approximating those of cereal flours in size, appearance, and texture. A specific  
47 method of production is not involved in the name “wood flour.” [7] Practically speaking, wood  
48 flour usually refers to wood particles that are small enough to pass through a screen with  
49 850-micron openings (20 US standard mesh) [7]. Earlier studies have shown that the use of  
50 wood flour can be an alternative cellulosic based wood additive [8]. A deterioration in  
51 brightness and smoothness could be compensated for by the combined use with calcium  
52 carbonate [9]. This handsheet study investigates if a hybrid filler material, a combination of  
53 WF and precipitated calcium carbonate, can have a positive impact on mechanical and  
54 optical paper properties.

## 55 56 2. MATERIAL AND METHODS

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

### 62 63 2.1 TAPPI Methods

64 Pulp refining was done according to T 200 sp-06 “Laboratory beating of pulp (Valley beater  
65 method) [10], Handsheets for physical testing were prepared in accordance with T 205 sp-06  
66 [11], Ash in wood pulp was tested with T 211 0m-02, “Ash in wood pulp, paper and  
67 paperboard: combustion at 525°C” [12]. Physical testing of pulp handsheets was performed  
68 in accordance to T 220 sp-06, “Physical testing of pulp handsheets” [13], the freeness of  
69 pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09  
70 “Freeness of pulp (Canadian standard method)” [14]. Conditioning of the paper samples was  
71 done according to T 402 sp-08, “Standard conditioning and testing atmospheres for paper,  
72 board, pulp handsheets, and related products” [15]. Tensile strength was measured in  
73 accordance with T404 cm-92, {Tensile breaking strength and elongation of paper and  
74 paperboard} [16]. Basis weight was measured with T 410 om-08, {Grammage of Paper and  
75 Paperboard (weight per unit area)} [17]. The paper thickness was measured by T 411 om-10  
76 {Thickness (caliper) of paper, paperboard, and combined board} [18]. The moisture content  
77 of pulp was determined by T412 om-06 {Moisture in pulp, paper and paperboard} [19]. The  
78 tear strength was done by following the T 414 om-12, {Internal tearing resistance of paper  
79 (Elmendorf-type method)} [20]. The opacity of paper handsheets was performed according  
80 to T 425 om-06, {Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance backing  
81 and paper backing)} [21]. Brightness of pulp was measured according to T 452 om-08,  
82 {Brightness of pulp, paper and paperboard (directional reflectance at 457 nm)} [22]. Stiffness  
83 of the paper was measured according to T 489 om-08, {Bending resistance (stiffness) of  
84 paper and paperboard (Taber-type tester in basic configuration)} [23]. The paper color was  
85 measured by T 524 {Color of paper and paperboard} [24].

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88 **2.2 Materials**

89 For the handsheet study the fiber materials used was a blend of 80% Sappi Saiccor  
90 Eucalyptus Hardwood and 20% AV Terrace Bay Northern Bleached Softwood Kraft (NBSK).  
91 The furnish was beaten to a 320 ml TAPPI CSF freeness in a valley beater following TAPPI  
92 T 200 sp-06 method [9].

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

98 The first PCC (PCC1) used was a PCC powder with a mean particle size of 1.0 μm to 2.0  
99 μm. A 20% slurry using deionized water was produced for the application in the handsheets.  
100 The second PCC (PCC2) applied to the handsheets was PCC slurry produced on-site at a  
101 paper mill site in the U.S. with 19.58% solids content and a mean particle size of 1.66 μm.

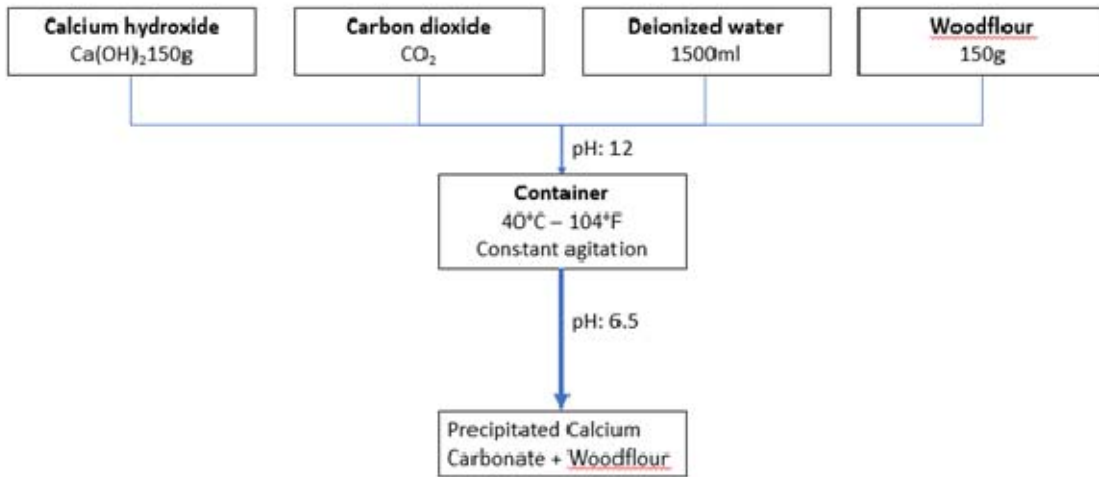
102 For the second trial four different precipitated calcium carbonates (PCC) + Wood Flour (WF)  
103 were produced and integrated into the handsheets.

104 To produce the laboratory hybrid WF-PCC, a calcium hydroxide (Ca(OH)<sub>2</sub>) type was used  
105 suitable for PCC production in combination with two WF types with and without Strength  
106 Additive (SA) that is activated on contact drying. WF1 had a particle size distribution of 20μm  
107 to 50μm and WF2 had a particle size distribution of 40μm to 70μm.

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

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111 **2.3 PCC + Wood flour material preparation**

112 The preparation of the PCCWF product followed the process sequence laid out in Figure 1  
113 which shows the flow of the production process with all components and important data. A  
114 Fischer Scientific Isothemp Lab Stirring Hotplate was used for stirring and heating the  
115 suspension in a 2000 ml beaker. Industrial grade CO<sub>2</sub> from a 150 lbs. gas bottle with  
116 pressure regulator was used as the precipitation reactant. The CO<sub>2</sub> was dispersed in the  
117 beaker with an air stone.



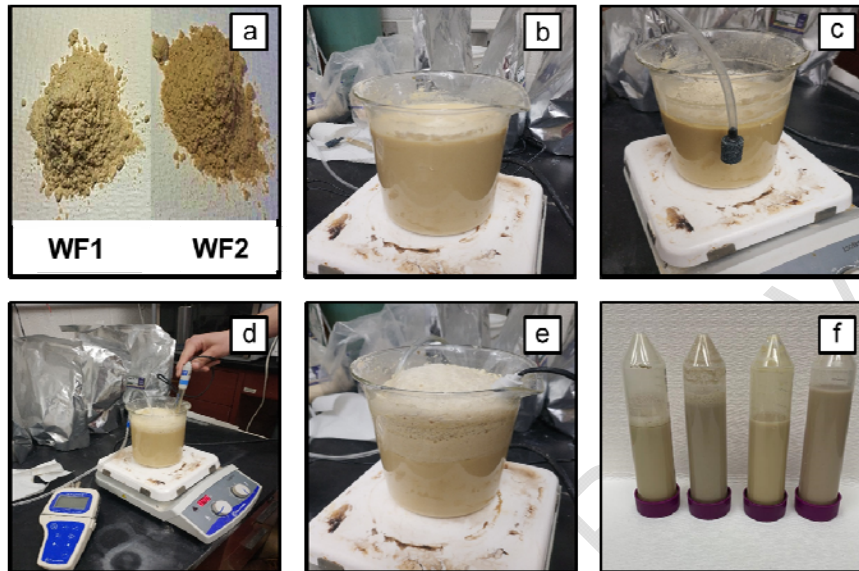
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120 **Fig. 1. PCC+ WF process sequence**

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122 The preparation of the material started with the weighing of 1500 ml of deionized water 150g  
123 Calcium di-hydroxide Ca(OH)<sub>2</sub> and 150g of the respective wood flour (Figure 2a). The next  
124 process step was heating water to 40°C. Subsequently, first GCC and the respective wood  
125 flour was added one after the other. In order to avoid clumping and to ensure good mixing,

126 slow addition of the powders and constant agitation was necessary (Figure 2b). After that the  
127 addition of CO<sub>2</sub> could be started (Figure 2c). The amount of added CO<sub>2</sub> was determined  
128 visually, because the wood flour foamed strongly when too much was added. (Figure 2e).  
129 Once the amount was set, it was left. Throughout the process, the temperature and pH were  
130 measured with a pH meter (Figure 2d). The initial pH value was 12.0. The measurement of  
131 pH was important because it was the indicator for the precipitation of PCC, the target value  
132 of the pH after precipitation was set to a pH of 6.5.  
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135 **Fig. 2. PCC Production with WF a) WF types, b) WF-CA(OH)<sub>2</sub> slurry, c) CO<sub>2</sub> injection**  
136 **system d) pH and temperature measurement, e) foam built up f) final PCCWF from left:**  
137 **WFPCC1, WFPCC1SA, WFPCC2, WFPCC2SA**  
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139 Figure 3 shows that all four blends start with the same initial values (pH 12.0, 40°C) and  
140 follow the same pattern throughout the process. During the first phase of the reaction the pH  
141 stays constant while the temperature increases quickly until a maximum is reached. Striking  
142 here is the difference of the length of this phase. The precipitation of WFPCC1 and  
143 WFPCC1SA reached a temperature of 56°C after 33 minutes, and 54°C after 36 minutes  
144 respectively. For WFPCC2 and WFPCC2SA precipitation, a maximum temperature of 55°C  
145 after 37 minutes and 52°C were reached respectively. As soon as the maximum temperature  
146 was reached, the pH level dropped in less than three minutes to the target value of pH 6.5  
147 and the CO<sub>2</sub> influx was turned off. After continuing stirring for 2 minutes without adding more  
148 CO<sub>2</sub>, the pH levels stabilized around 6.8. The finished slurries were bottled and stored in a  
149 cold room at 5°C.

150 Figure 2f shows the color differences of the produced WFPCC slurries from left to right:  
151 WFPCC1 with 14.35 % solids content, WFPCC2 with 14.28% solids content, WFPCC1 with  
152 16.99% solids content, and WFPCC2SA with a 16.53% solids content. Noticeable is the  
153 lighter color of the WF1PCC after precipitation.  
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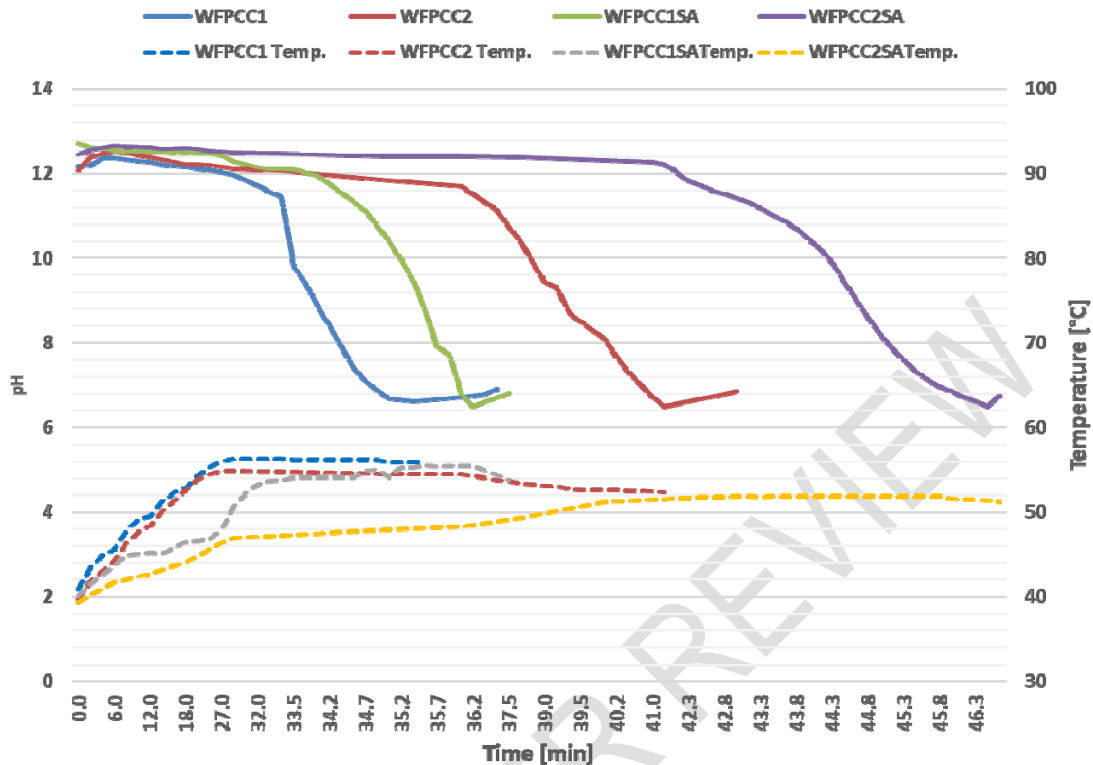


Fig. 3. Process temperature and pH during laboratory PCC production

#### 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/m<sup>2</sup>. The amount and type of filler was changed in every furnish. 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  $1.57 \pm 0.04\%$  and a temperature of  $23 \pm 2^\circ\text{C}$ . 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 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.

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### 3.1 Retention

Figure 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 WFPCC1 product.

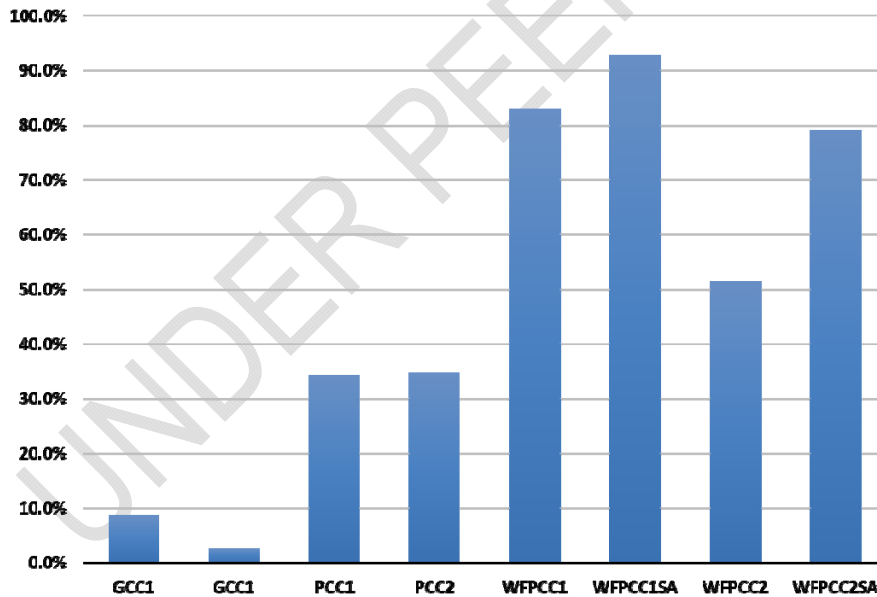


Fig. 4. Filler retention

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### 3.2 Caliper, Basis weight, Stiffness Index

For comparison of the basis weight, the base sheet had 87.54 g/m<sup>2</sup>. The PCC1 handsheet had a basis weight of 87.18 g/m<sup>2</sup> comparable to the GCC1 basis weight of 85.65 g/m<sup>2</sup>. GCC2 handsheets had a basis weight of 80.94 g/m<sup>2</sup> while PCC2 had a basis weight of 92.22

219 g/m<sup>2</sup>. For handsheets manufactured with wood flour the basis weight had a range of 107.31  
 220 g/m<sup>2</sup> WFPCC1 to 117.03 g/m<sup>2</sup> WFPCC2.  
 221 The caliper of the basis sheet and the sheets with GCC filler had comparable properties of  
 222 128.8 μm and 120.4 μm GCC1 and 119.2 μm GCC2 μm respectively. The handsheets with  
 223 the PCC as filler had slightly higher caliper in the tests. The PCC1 had a caliper of 145.6 μm  
 224 comparable to the PCC2 with 142.8 μm.  
 225 The produced handsheets with wood flour showed different caliper depending on the used  
 226 WF. It was noticeable that PCCWF2 with distance showed the highest caliper with 268 μm.  
 227 WFPCC2SA + WFPCC1SA had comparable values of 198 μm and 208 μm. The lowest  
 228 caliper was achieved had WFPCC1 with 185 μm, which is still higher than that of the purely  
 229 inorganic fillers and the basis sheet.  
 230 The resulting stiffness index of 0.123 was higher for the basis sheet and lower for all other  
 231 filler except WFPCC2 of stiffness index of 0.127. In general, the stiffness of each filler



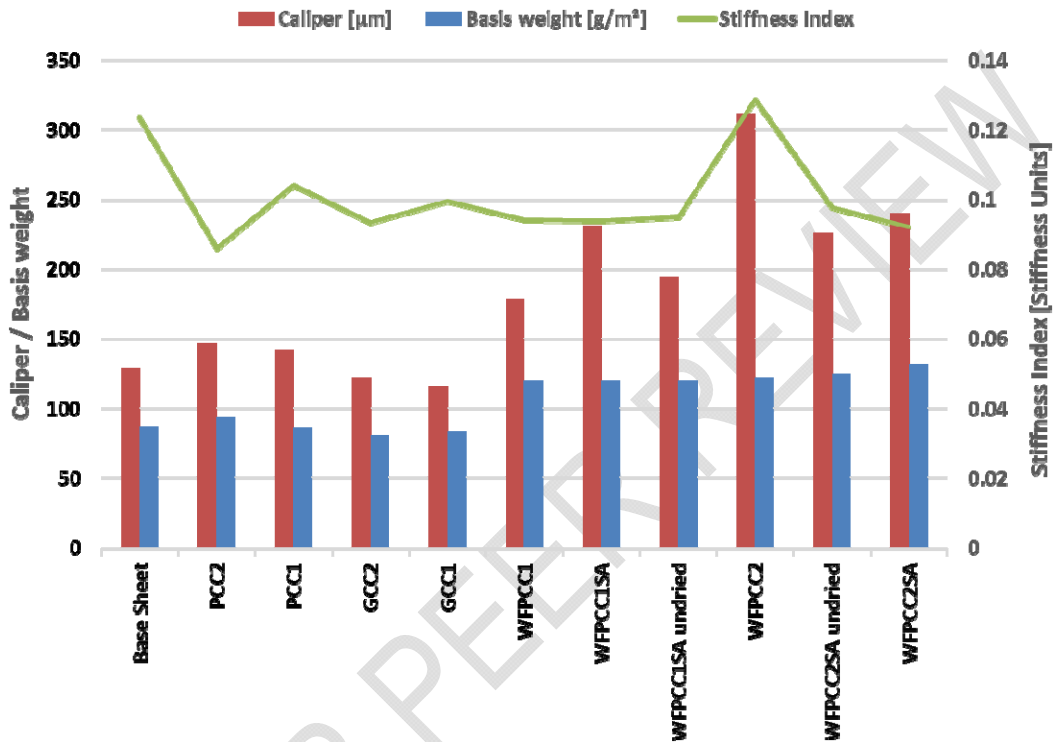
232 remained about the same. The range was between 0.096 and 0.107 after calculating the  
 233 index.

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

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 236 The high retention of the wood flour + PCC filler resulted in a final ash content of 15% for the  
 237 10% handsheet series. Accordingly, all other test series were well above their targeted ash  
 238 content. In order to ensure a comparability, only sheets with the same amount of filler were  
 239 compared with each other. Since the proportion of fibers was not adjusted to the  
 240 unexpectedly higher retention, higher basis weights resulted accordingly.

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

248 All tests were repeated with 20% filler sheets in Figure 6 to reproduce the previous results  
 249 that are shown in Figure 6. By a higher proportion of wood flour, any influences are to be  
 250 displayed more clearly. Additionally, two sets of handsheets were made containing both WF  
 251 with and without SA, which required contact drying. These handsheets were examined by all  
 252 the above test methods to find the differences that contact drying makes.  
 253 Both basis weight and caliper have increased as expected due to the higher filler load. The  
 254 stiffness has not changed compared to 15%. The activation process of the SA shows no  
 255 influence on caliper and stiffness.



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 257 **Fig. 6. Basis weight/ Caliper/ Stiffness 20 % filler + WF**  
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259 **3.3 Tensile Index and Tear Index**

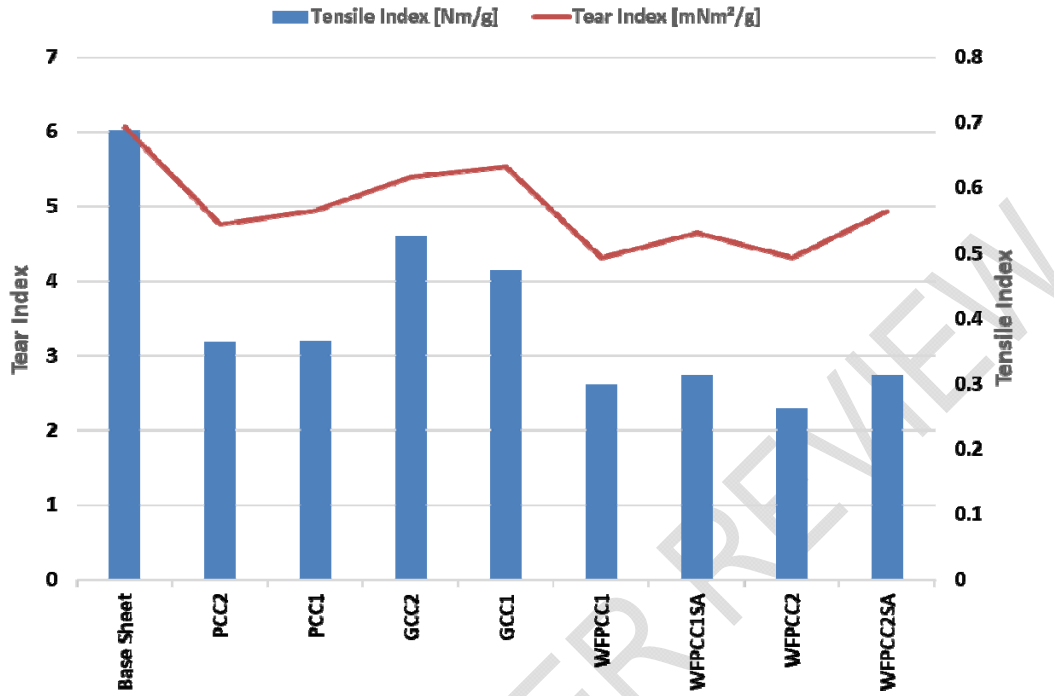
260 The tensile and tear index in Figure 7 shows a consistently strong correlation. The base  
 261 sheet has the highest tensile and tear index values (0.69 / 6.07). Adding filler of any kind  
 262 significantly reduces these strengths. Both PCC2 and PCC2 have comparable values of  
 263 (0.22/4.76 and 0.22/4.94). When using GCC as the filler, slightly higher values of tensile and  
 264 tear index (0.32/5.40) can be seen.

265 Adding wood flour to the furnish while replacing fibers, lowers the tensile and tear index  
 266 significantly. Including a SA to the WFPCC shows slightly higher values in comparison with  
 267 WFPCC without SA. WFPCC1 shows values of tensile and tear index 0.30/4.31 and  
 268 0.31/4.64 with SA. WFPCC2 shows values of tensile and tear index of 0.26/4.32 without SA  
 269 and 0.31/4.93 with SA.

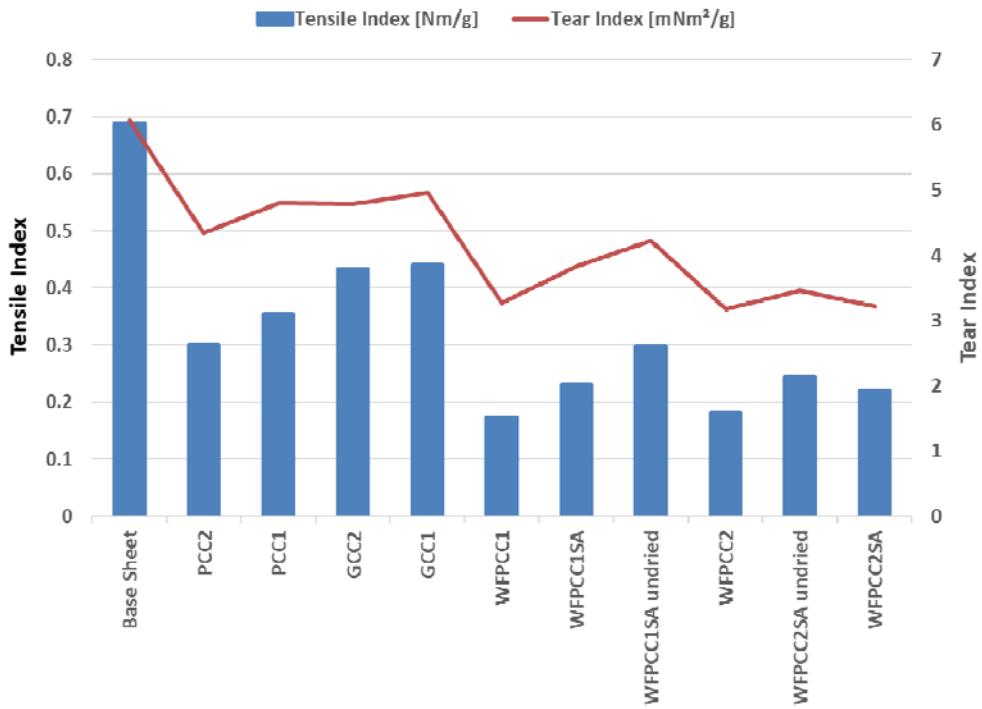
270 With the use of 20% filler, Figure 8 shows identical results as Figure 7, whereby the  
 271 individual values have a lower value in comparison to the base sheet. Not to be expected in  
 272 handsheets of higher strength values with strengthener without contact drying. WFPCC1SA  
 273 with contact drying had a tensile index values of 0.23 and without drying 0.30. The tear index



274 was 3.84 with drying and of 4.23 without. WFPCC2SA with contact drying had tensile index  
 275 values of 0.22 and of 0.24 without drying. The tear index was 3.22 with drying and 3.46  
 276 without.



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



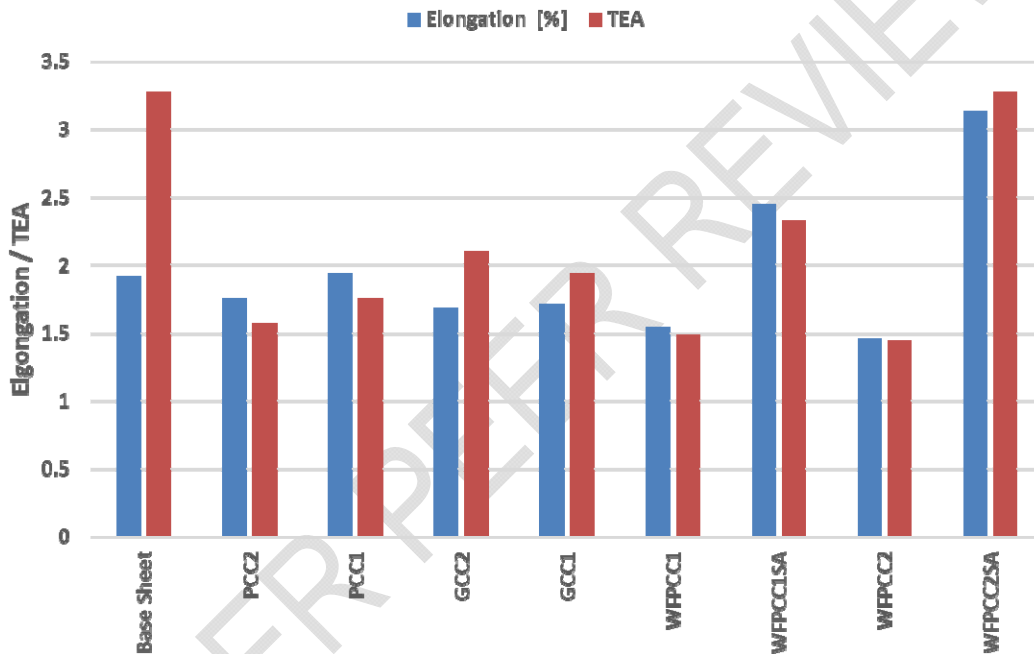
278 Fig. 8. Tensile / Tear 20% filler + WF  
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280 **3.4 Elongation and TEA**

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

287 WFPCC1 without strengthener has values similar to pure mineral fillers, 1.54% elongation  
 288 and 1.49 TEA. Adding SA results in an elongation higher than the basis sheet (2.45%) as  
 289 well as a far less reduced TEA value of 2.32. The positive influence of the strengthener with  
 290 the bigger wood flour particle size of WFPCC2 is even higher; the TEA value of 3.28 is on the  
 291 same level as the basis sheet (WF without SA) of 1.45. The elongation is, with 3.13% higher  
 292 than 30% of the maximum elongation of the basic sheet (WF without SA) of 1.45%.  
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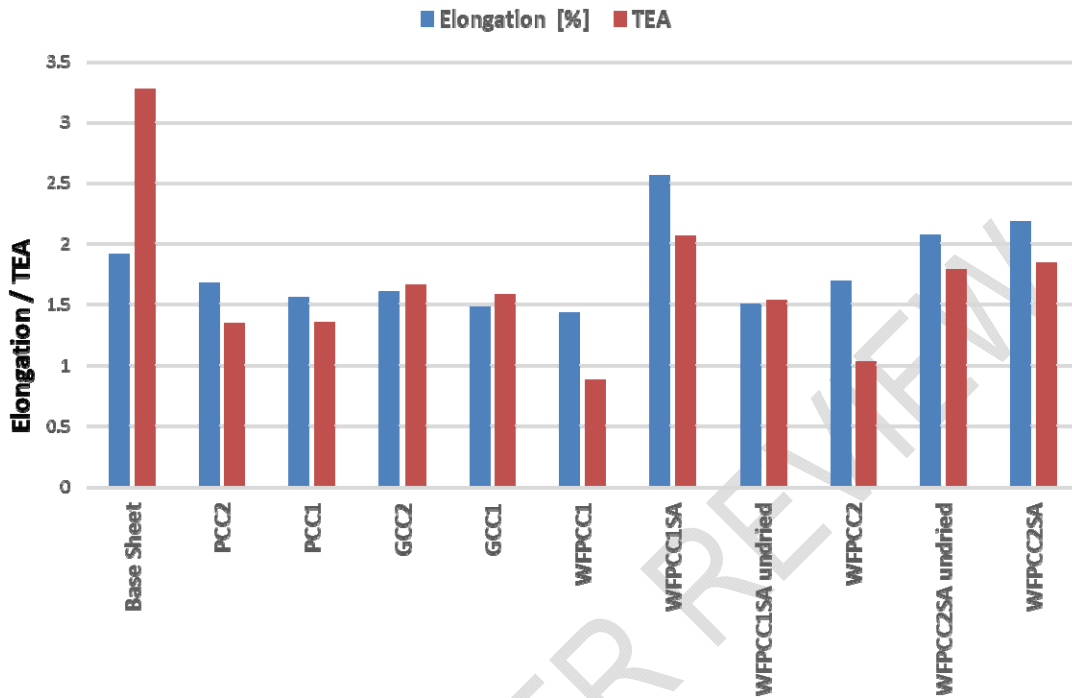
295 **Fig. 9. Elongation / TEA 15% filler + WF**

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297 Figure 10 shows that increasing the amount of filler from 15% to 20% changes the influence  
 298 of the wood flour and the additional strengthener drastically. The pure mineral fillers show a  
 299 loss of strength in the paper at an increased input. It is noticeable that the use of PCC  
 300 (1.76%) leads to higher elongation values compared to GCC (1.61%). GCC on the other  
 301 hand shows a lower TEA of 1.66 than PCC of 1.57.

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

307 However, regarding this strength characteristic, it is interesting to note, that the activation of  
 308 the SA by contact drying has a positive effect. Both the elongation and the TEA show a



309 increase after the same wood flour is contact dried than when using the same wood flour  
 310 without contact drying. WFPCC1SA without drying shows elongation of 1.50% and a TEA of  
 311 1.53. WFPCC2SA without drying shows elongation of 2.07% and a TEA of 1.79.

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

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### 314 3.5 Brightness and Opacity

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

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

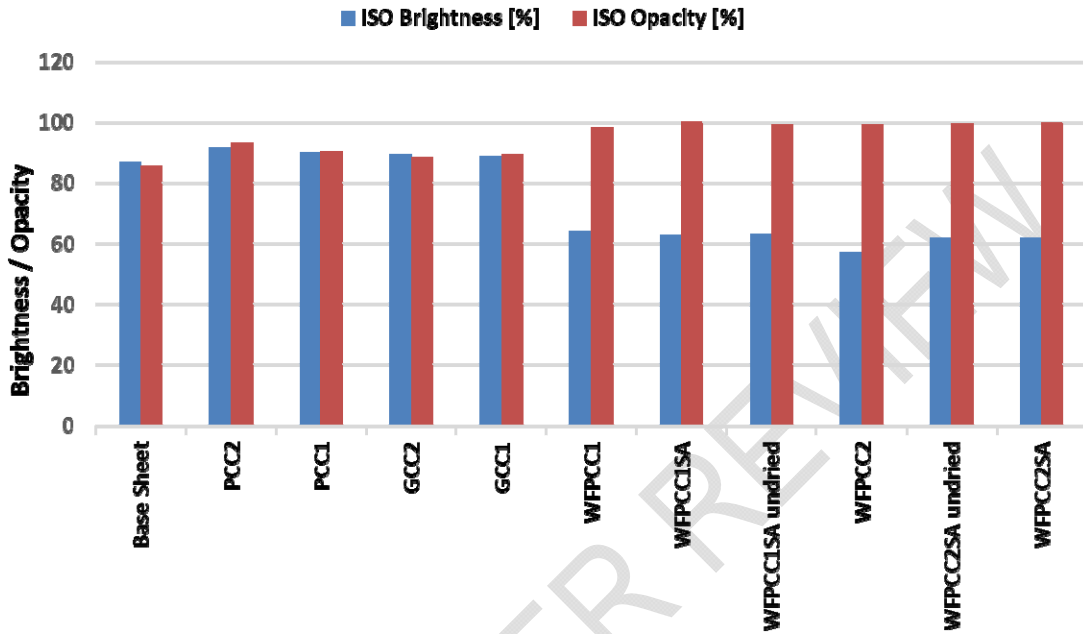
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328 When using PCC + wood flour mixtures, the brightness dropped drastically while the opacity  
 329 increased significantly. The loss of brightness can clearly be traced back to the naturally  
 330 darker and unbleached wood flour. The increased opacity can be explained by the increased  
 331 use of fine material. When comparing the two types of wood flour it was noticeable that the  
 332 opacity was not dependent on the grade but on the amount of wood flour used. The  
 333 brightness was higher when using the WF1 with smaller particle size than WF2 with the  
 334 larger particle size.

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

335 WFPCC2 opacity values are very similar, ranging from 98.98 to 100.11. When comparing  
 336 brightness, the handsheets produced without SA occurs darker (57.35) than the ones of the  
 337 WFPCC2SA composition (62.08 undried and 61.82 dried) which are very similar.  
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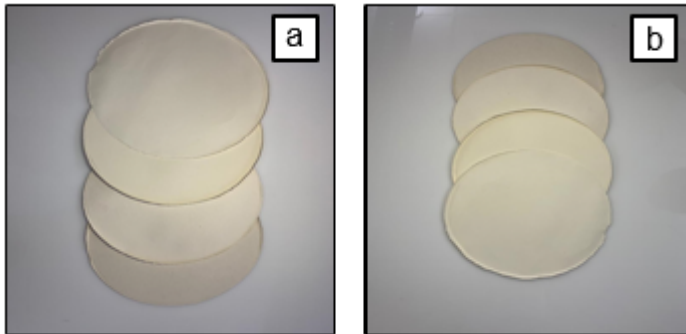
340 Fig. 11. Brightness / Opacity 20% filler + WF

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342 Figure 12 shows the final produced handsheets with all four wood flour PCC slurries. Picture  
 343 12a (from up to down) WFPCC1, WFPCC1SA, WFPCC2SA, and WFPCC2. Picture 12b  
 344 shows the back sides of the handsheet in opposite direction.

345 The color differences were so significant that they were easily visible.

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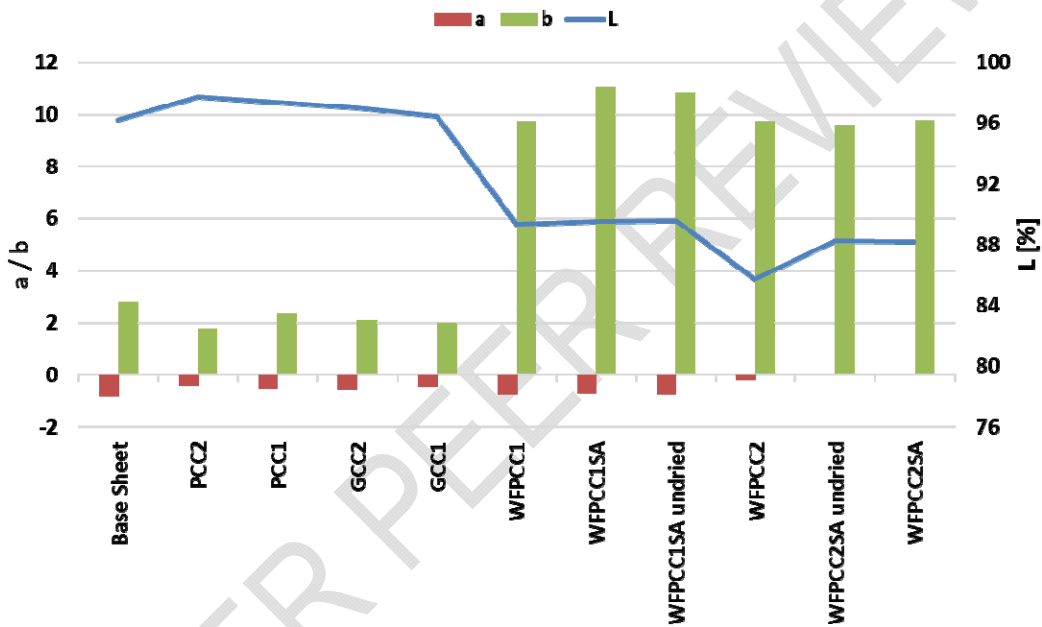
347 Fig. 12. Handsheets Wood flour and PCC front a) back b)

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

351 The calcium based pure mineral fillers (PCC1, PCC2, GCC1, GCC2) are all in the same  
 352 range. In general, the L-value of all four papers is higher than the basis sheet, all in a range  
 353 of 97.7 to 96.47. Looking at the a-values, all four sheets appear less green / redder than the

354 basis sheet, all ranging from -0.426 to -0.542. Comparing b-values, ranging from 1.77 to  
 355 2.34 with the handsheets containing filler, the basis sheet appears more yellow / less blue.  
 356 Introducing wood flour to the filler blend lowers the L-, increases the a- and strongly  
 357 increases the b-value in comparison to the basis sheet.  
 358 The three handsheets containing WFPCC1 all have a very similar L- (89.35 to 89.55) and a-  
 359 (-0.69 to -0.76). The blend without SA has a b-value of 9.73, both sheets containing the  
 360 strengthener appear more yellow (11.04 and 10.08). Contact drying to activate the  
 361 strengthener does not interfere with the color.  
 362 The three handsheets containing WFPCC2 are lower in L-readings, WFPCC2 with the WF C  
 363 750 FP type being by far the darkest (84.9), the WFPCC2 types containing the SA have a L-  
 364 values of 88.23 and 88.2. Comparing a- and b-readings, all three papers lay within a very  
 365 narrow range (a: -0.21 to -0.03 and b: 9.58 to 9.77). The additional drying did not appear to  
 366 influence the optical properties.  
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368 Fig. 13. L - a - b 20% filler + WF

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### 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, the wood flour could be bleached. Another possibility 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

385 **4. CONCLUSION**

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387 The main objective of this study **was** to investigate if wood flour can replace commercial  
388 mineral fillers for papermaking with a handsheet study. The handsheet study contains 25  
389 different furnish mixtures. For the handsheet study, the base sheet contains an 80%SW/20%  
390 HW. The filler content in the use of wood flour and mineral fillers varied between 10, 15 and  
391 20%.

392 The study showed that calcium carbonate precipitated in the presence of wood flour, the  
393 retention of filler increased significantly up to over 92.68% whereas commercial PCC and  
394 GCC achieved a maximum of 8.66% and 34.77% respectively. The use of WFPCC resulted  
395 in a higher caliper of up to 208  $\mu\text{m}$  compared to commercial GCC and PCC filler which  
396 achieved a caliper of 120.4  $\mu\text{m}$  and 145.6  $\mu\text{m}$  respectively.

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

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

404 The opacity of the paper was increased **with** the use of WFPCC of up to 10 opacity points to  
405 100.46 compared to commercial filler material with a maximum opacity of 93.41.

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

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

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