



Eucalyptus Pulp Fibers with In-Situ Precipitated Calcium Carbonate – A 12-Inch Laboratory Paper Machine Study

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Paper manufacturing on a global scale is a highly competitive market which requires to constantly improve the manufacturing process to be competitive. To decrease production cost paper manufactures, add filler material prior to sheet forming to replace costly wood fiber based raw material.

This research project investigates the use of in-situ precipitated calcium carbonate produced in the presence of eucalyptus fiber material at a 41.0% filler level prior to beating. The in-situ filler containing eucalyptus fiber suspension was used on a 12' (304mm) wide Laboratory Fourdrinier Paper Machine together with non-filler containing eucalyptus fiber material, and a commercial precipitated calcium carbonate filler material.

The manufactured in-situ fiber suspension resulted in a higher ash retention compared to the addition of the powdered commercial PCC filler material. In addition to commercial filler material retention is improved at higher filler addition above 30%.

The increased ash retention is linked to the increased micro fibrillation fiber material of the in-situ filler-fiber suspension forming neckless like particles on the fibers microfibrils.

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Mechanical paper properties showed an improvement for in-situ precipitated filler material compared to commercial filler material addition. Optical properties could be improved in comparison to the eucalyptus fiber without filler addition for in-situ precipitated filler material and a combination of in-situ and commercial filler material.

Keywords: Calcium carbonate; eucalyptus; filler; in-situ precipitation; hybrid filler; paper; precipitated calcium carbonate; refining; paper manufacturing.

1. INTRODUCTION

Paper manufacturing in today's global market is dependent on the manufacturing site, availability of raw materials, utility factors, increasing environmental regulations, and a high competitiveness in a worldwide trade market.

Paper and cardboard production reached nearly 72 million metric tons in the US [1] and 420 million metric tons worldwide in 2018, with an estimated market value of over 81 billion dollars in the US [2]. Beside printing and writing paper grades, packaging and board paper grades have become a significant portion of the U.S. paper industry, representing approximately over 69% of the paper production in the United States today [1].

Paper and board producers experience declining profit margins by increased operational costs. This requires them to research new production methods and revisit past and present existing production process to decrease production costs [3,4,5,6].

To decrease production cost paper manufacturers, add at present time Precipitated Calcium Carbonate (PCC), Kaolin, and Ground Calcium Carbonate (GCC) [7,8]. GCC and PCC is added for example in the blend chest in wet-end section of the paper mill and at the fan pump shortly before the fiber suspension is entering the paper machine headbox after which the sheet forming process occurs [7].

Today, printing and writing paper grades incorporate usually up to 20% filler content [8]. Paper board products, contain based on own observations, up to around 6% in North America, and utilize only filler material that is contained in recovered fiber sources used to produce the specific board products.

Incorporating filler material in the printing and writing paper product segment has advantages such as higher optical properties, improved printability [4,5,6], and energy and pulp savings

during the paper manufacturing process that can be up to \$4.0 for each 1% increase in filler content [9].

Therefore, the last decade's paper industry research has attempted to find the upper bound of filler content in a sheet of paper which is a paper product specific task. However, increasing the filler level may also result in disadvantages for printing and processing paper, such as less mechanical integrity of the paper sheet, loss of bulk, and problems in the paper manufacturing process. As of today, for the board and packaging paper segment, the addition of filler materials is not implemented in the manufacturing process [7,8].

Filler materials today are manufactured in separate manufacturing plants and are transported to the paper manufacturing location where they are incorporated as additives into the paper manufacturing process. In past decades, a variety of research on new filler materials has been done at the laboratory level, but no commercial applications have been implemented, to our knowledge.

Implementing new technologies in paper production represents a tremendous challenge due to 24-hour, 7 days operation year-round only interrupted by short maintenance and repair shut-downs, and the many complicated manufacturing, chemical process, and quality related issues for each paper grade produced. Modern paper machine operations cost, depending on the product, can reach over \$50,000 per hour and, for instance, one change in the process sequence or applied chemical additives, can jeopardize the quality of the produced product, resulting in losses that can jeopardize a mill's operation. For these reasons it is necessary to prove a concept first on a laboratory scale, then on a small pilot scale, followed by upscaling to a semi-commercial pilot scale to prove the concept and gain interest of the manufacturing sector and to mitigate associated technical risks.

The following research project has the objectives to investigate the performance of a fiber suspension containing in-situ precipitated calcium carbonate filler material to produce a copy-type paper product. Tests were performed using a 12-inch (304 mm) wide laboratory paper machine for evaluating mechanical and optical properties of the produced paper product.

2. MATERIALS AND METHODS

2.1 Materials

For this research project producing In-Situ Precipitate Calcium Carbonate (ISPCC) in the following called Hybrid Pulp (HP). Hardwood pulp in the form of Bleached Eucalyptus Kraft Pulp (BEKP) from CMPC Celulosa was used for this study. Calcium hydroxide ($\text{Ca}(\text{OH})_2$) powder was obtained from Lhoist North America.

Commercial PCC in dried powder form was used a filler material with a particle size spectrum of 1.0 μm to 4.0 μm to increase the filler content during the machine run.

Industrial grade carbon dioxide (CO_2) gas was used for precipitation of the ISPCC with a 99% purity, supplied in a pressurized container containing 50 lbs. (22.68 kg) of gas.

2.2 Manufacture of Hybrid Pulp

The manufacturing of the in-situ precipitated calcium carbonate (ISPCC) filler in the presence of EC pulp fibers for this beating and paper properties study was done according to the procedure described by Doelle & Bajrami [1,2,3]. The ISPCC pulp suspension produced had a filler content of 41.0% based on Oven Dry (OD) fiber content. It is referred to as HP Filler in the following results discussion.

2.3 Testing Methods

For this research project the following testing methods of the Technical Association of the Pulp and Paper Industry (TAPPI) and International Organization for Standardization (ISO) were used:

The ash was measured after T 211 om-02, "Ash in wood, pulp, paper and paperboard: combustion at 525°C [10]. Physical testing of handsheets was performed in accordance to T 220 sp-06, "Physical testing of pulp handsheets" [11]. Freeness of pulp was measured as

Canadian Standard Freeness (CSF) according to T 227 om-09 "Freeness of pulp (Canadian standard method)" [12].

Consistency of a pulp suspension was measured with TAPPI T240 om-07 "Consistency (concentration) of pulp suspensions" [13].

Conditioning of the paper samples was done according to T402 sp-08, "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products" [14]. Burst Index was measured in accordance with T 403 om-02 "Bursting strength of paper" [15]. Basis weight was measured with T 410 om-08. "Grammage of Paper and Paperboard (weight per unit area)" [16]. Thickness of the paper was measured according to TAPPI T411 Om-05, "Thickness (caliper) of paper, paperboard and combined board" [17]. Tear resistance was measured according to TAPPI T414 om-04, "Internal tearing resistance of paper (Elmendorf-type method)" [18].

Color was measured according to TAPPI T527 om-07, "Color of paper and paperboard (d/0, C/2)" [19].

Opacity was measured according to ISO 2471 "Determination of opacity (paper backing) – Diffuse reflectance method" [20].

Brightness was measured according to ISO 2469 "Paper, board and pulps - Measurement of diffuse radiance factor (diffuse reflectance factor)" [21].

Tensile strength was performed following T494 om-06, "Tensile properties of paper and paperboard (using constant rate of elongation apparatus)" [22].

For measuring temperature and pH of the pulp suspension an Accumet AP85 instrument was used.

2.4 Scanning Electron Microscopy

JEOL JSM-5800 LV low vacuum scanning electron microscope was used to prepare surface image of the paper containing HP.

2.5 Manufacture of Hybrid Pulp Containing Paper

A 12 inch (304 mm) wide Laboratory Fourdrinier Paper Machine (LFPM) shown in Fig. 3. was used to produce the HP containing paper. The

pulp was prepared in stock preparation system shown in Fig. 1. of the LFPM. The wet end system of the LFPM shown in Fig. 2., prepared the pulp for papermaking on the LFPM.

2.5.1 Stock preparation

The stock preparation of the LFPM consists of a 5 hp (3.73 kW), 35-gal (132.5 l) low consistency pulper, a 3 hp (2.24 kW) transfer pump, a 10 hp (7.46 kW) low consistency conical Jordan refiner, and two storage chests with a usable volume of 240 gal. (908.5 l) each, and a propeller agitator with 1.5 hp (1.12 kW). The chests can be operated separate or together. Additives for papermaking can be added either in the pulper or the storage chests.

2.5.2 Wet end

The wet end of the LFPM, shown in Fig. 2. consists of the two storage chests with a usable

volume of 240 gal. (908.5 l) each, and a propeller agitator with 1.5 hp (1.12 kW). The 2 storage chests serve as the LFPM machine chest. Additives might be added at the machine chest as needed. The chests can be operated separate or together. An impeller transfer pump with 1.5 hp (1.12 kW) supplies the prepared fiber suspension to the stuff box stuff box. Additives might be added at the stuff box as needed. From the stuff box the fiber suspension is metered into the 10 gal. (37.4 l) mix chest, where additives might be added as needed. Part of the fiber suspension from the stuff box is recirculated to the machine chest. In the mix chest the fiber suspension is diluted with the white water from the LFPM white water trough. A possible overflow is transferred to the sewer. An impeller pump with 1 hp (0.75 kW) transfers the final prepared fiber suspension to the LFPM for papermaking.

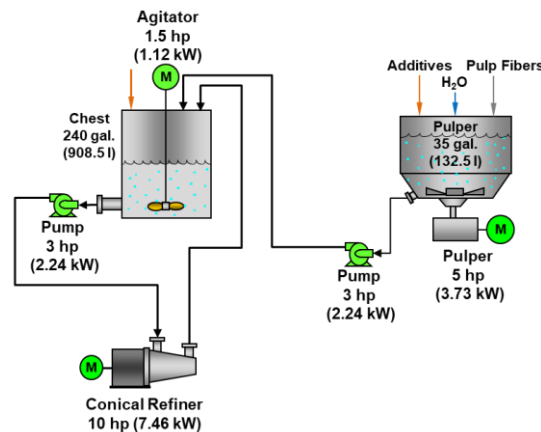


Fig. 1. Laboratory stock preparation schematic [23]

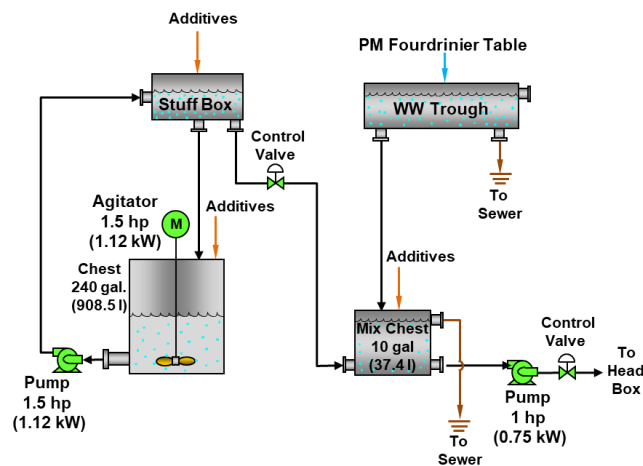


Fig. 2. Wet End 12" laboratory fourdrinier paper machine schematic [24]

2.5.3 Laboratory fourdrinier paper machine

The LFPM shown in Fig. 3. was used to upscale a former handsheet study by Doelle and Bajrami [5,6]. The LFPM features a 70 inch (1778 mm) long Fourdrinier section followed by a 2-nip press section. After the press section a dryer section containing a Yankee dryer (J1) and a 1st and 2nd dryer section with 10(D1-D10) and 8 (D12-D18) electric heated dryer drums. Each dryer drum can be heated to up to 343°C (650°F). Between the 1st and 2nd dryer section a size press is located. A 6-roll vertical calendar stack, of which on roll (C2) can be heated is located after the dryer section followed by the reel. The LFPM is driven by a 5hp (3.743 kW) electro motor and can produce a finished paper product with a basis weight between 20 g/m² and 750 g/m² at a speed of up to 2.0 m/min.

2.6 Fourdrinier Pilot Paper Machine Run

The LFPM run using EC and HP fibers was designed for a maximum of 6 hours producing a sheet at 100g/m².

First, 30 lbs (13.6 kg) OD EC pulp were pulped in three batches of 24 gal (90.8 l) each at a consistency of 5% using the 35 gal (132.5 l) low consistency laboratory pulper of the LFPM stock preparation system. After the EC pulp was disintegrated, the 5% pulp fiber slurry was transferred into the 240-gal (908.5 l) storage

chest. The 72-gal. (272.5 l) EC pulp fiber slurry was then diluted to a consistency of 2% by adding 107.7 gal. (407.5 l) water for refining. The 179.7 gal (680 l) of EC pulp slurry was then refined to a CSF value of 325 ml with a Jordan conical refiner. The CSF value was measured with TAPPI test method T 227 om-09. After refining the EC fiber slurry was diluted to a machine chest consistency of 1.5% by adding 59.8 gal (226.6 l) of water which resulted in 239.5 gal (906.5 l) of EC pulp fibers at 1.5% consistency available for paper production.

Second, 130-gal (492.1 l) of the produced HP pulp suspension with a total solids content of 2.21% containing 1.75% OD EC Fibers and 41.7 % HP filler based on OD fiber content is transferred into the second 240-gal (908.5 l) storage chest and diluted to 2% by adding 13.7 gal. (51.7 l) water for refining. The 143.7 gal (543.8 l) of EC pulp slurry was then refined to a CSF value of 340 ml with a Jordan conical refiner which represents approximately the same refining time and energy input into the fibers as for the EC fiber mixture based on findings by Doelle & Bajrami [4,5]. The CSF value was measured with TAPPI test method T 227 om-09. After refining the EC fiber slurry was diluted to a machine chest consistency of 1.5% by adding 47.9 gal (181.3 l) of water which resulted in 191.5 gal (725.0 l) of HP pulp slurry at 1.5% consistency at a pH of 7.5 available for paper production.

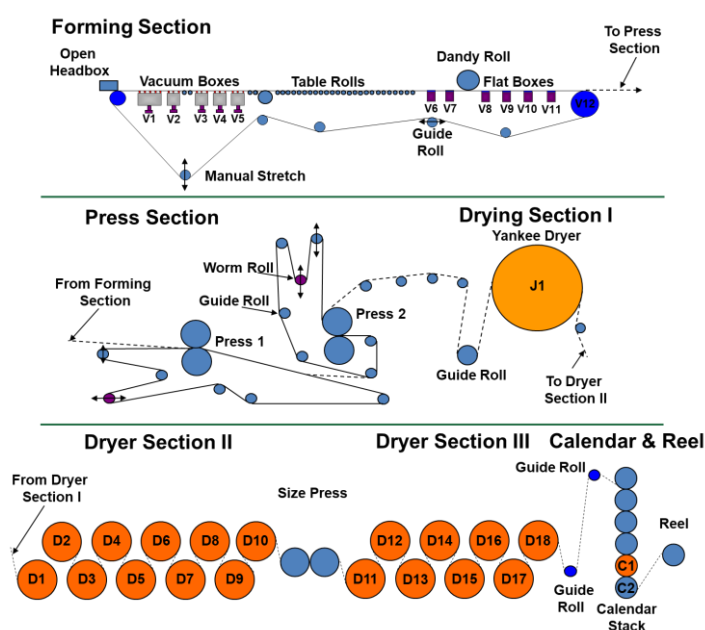


Fig. 3. Fourdrinier Pilot Paper Machine Schematic [25]

Third, the FPM paper machine run was conducted containing the following:

The LFPM was operated at a speed of 1.6 m/min for all production runs. Vacuum levels for the fourdrinier table were set at 0 for the 1st, 27579 Pa for the second vacuum section, 0 for the 3rd to 6th, 13789 Pa for the 7th, 27579 Pa for the 8th, 48263 Pa for the 9th, and 0 for the 10th vacuum section. The fiber flow to the headbox at a consistency of 1% was set at 2.82 l/min initially and increased up to 3.95 l/min to achieve the desired basis weight of the paper product.

The 1st and 2nd press was operated at 206843 Pa and 275790 Pa respectively for all adjustment of the grades. The heat of the Yankee-Dryer (J1) in dryer section 1 was kept at 50°C (122°F). The heat for the dryers in dryer section 2 is kept at 148.9°C (300°F) for the 1st to the 4th dryer (D1-D4), 143°C (290°F) for the 5th to 10th (D5-D10) dryer. The heat in dryer section 3 was kept at 148.9°C (300°F) for the 11th to the 16th (D11-D16) dryer, and 50°C (122°F) for the 17th and 18th (D17-D18) dryer. The calendar section for all furnishes is operated without pressure for all calendar rolls and without heat for calendar rolls C1 and C2.

3. RESULTS AND DISCUSSION

All tests for this research were performed in according to the in Section 2.3. referenced TAPPI methods. All results stayed in the precision statements for the referenced TAPPI methods.

3.1 Fourdrinier Pilot Paper Machine Operation

The operational parameters were kept the same for the entire LFPM runs. The base run consisted of a 100% EC fiber and 100% HP fiber suspension in the following charts shown as “EC” and “HP”. From the remaining EC and HP pulp suspension a mixture containing 82% EC pulp fiber suspension and 18% HP suspension was prepared and a LFPM run conducted with a theoretical filler content based on OD fiber content of 7.50%. This run is shown in the charts as “EC + HP”. For the following LFPM runs the filler content was adjusted by adding commercial PCC powder to the pulp suspension based on OD fiber content to achieve a theoretical filler content of 10%, 20%, 30% and 40% above the EC+HP pulp suspension during the production run. These runs are shown in the charts as

“EC+HP+PCC+10%”, “EC+HP+PCC+20%”, “EC+HP+PCC+30%”, and “EC+HP+PCC+40%” respectively.

3.1.1 Laboratory fourdrinier paper machine dry content

The measured dry content based on oven dry (OD) material (fiber and filler material) of the paper product is shown in Fig. 4. and measured according to TAPPI test method T 240 om-07 of the individual process stages of the LFPM.

The head box OD content for the EC fiber suspension was 0.2%. The HP pulp fiber-filler suspension OD content was 0.2%. The EC+HP suspension containing 18% HP and 82% EC OD content was 0.1%. The OD content of the EC+HP+PCC fiber filler suspension having 10%, 20%, 30%, and 40% filler content target was at 0.1% for the 10% PCC addition and 0.3% for the 10%, 20%, and 40% PCC addition.

The OD content at the couch of the LFPM fourdrinier section was 15.8% for the EC fiber suspension. No filler material was present to improve dewatering of the pulp suspension, leading to a higher water content of the pulp sheet at the couch roll [7]. The HP pulp fiber-filler suspension OD content was 18.2%. The EC+HP suspension containing 18% HP and 82% EC OD content was 17.5%. The OD content of the EC+HP+PCC fiber filler suspension having 10%, 20%, 30%, and 40% filler content target was at 17.9%, 18.8%, 21.5%, and 23.3% respectively.

For the 1st and second press operation of the LFPM the OD content was 30.0%, 31.3% and 15.8% for the EC fiber suspension. The HP pulp fiber-filler suspension OD content was 29.8% and 31.3%. The EC+HP suspension containing 18% HP and 82% EC OD content was 30.6% and 30.4%. The OD content of the EC+HP+PCC fiber filler suspension having 10%, 20%, 30%, and 40% filler content target was at 29.3% and 29.9%, 28.3% and 32.6%, 29.6% and 31.3%, and 30.0% and 33.9% respectively.

The OD content after the dryer section was targeted at 95% for the paper product. The produced EC paper material had an OD content of 97.1%. The HP paper product OD content was 96.2%. The paper product containing EC+HP suspension of 18% HP and 82% EC OD content was at 96.5%. The OD content of the EC+HP+PCC paper material having a filler target of 10%, 20%, 30%, and 40% was at 97.0%, 96.8%, 94.6%, and 95.2% respectively.

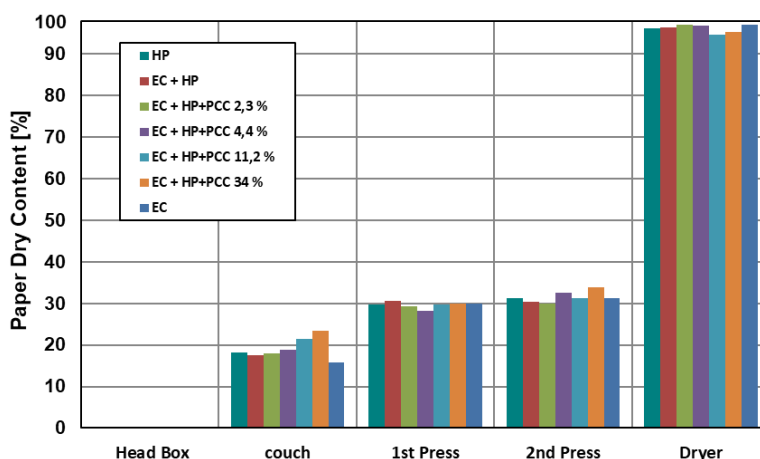


Fig. 4. Fourdrinier pilot paper machine dry content

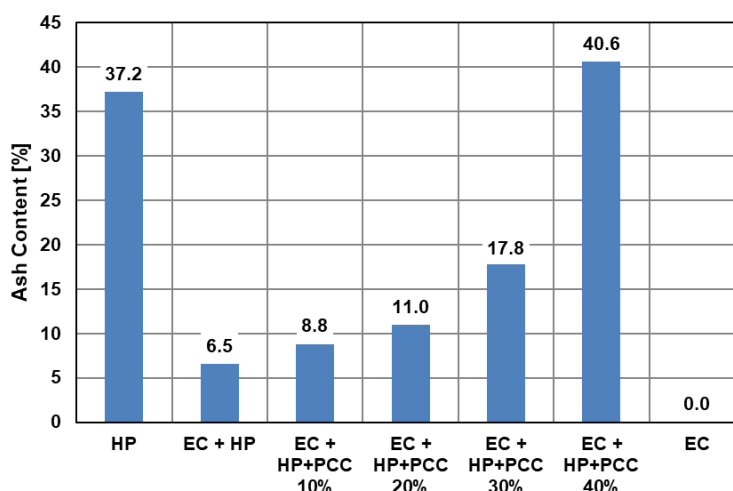


Fig. 5. Paper Ash content

3.1.2 Fourdrinier pilot paper machine ash content

Fig. 5. Shows the ash content measured according to TAPPI test method T 211 om-02 for the individual produced paper products.

The EC fiber only containing paper product had a filler content of 0.0%. The HP pulp fiber-filler suspensions filler content was 37.2% in the produced paper product. This resulted in an ash retention of 90.7% based on the 41% ash content of the HP used.

The filler content of the paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension was at 6.5% reflecting

a ash retention of 87.8% based on an ash content of 7.4% of the EC+HP pulp mixture.

The filler content of the EC+HP+PCC paper product with a targeted filler content of 10%, 20%, 30%, and 40% was 8.8% for the 10% PCC filler addition, 11.0% for the 20% PCC filler addition, 17.8% for the 30% PCC filler addition and 40.6% for the 40% PCC filler addition. The addition of PCC filler material of 10%, 20% and 30% resulted in a filler increase compared to the EC+HP suspension of 2.3%, 4.5%, and 11.3% respectively. The addition of 40% PCC to the EC+HP suspension increased the filler content to 40.6% reflecting a 34.1% increase. The ash retention of the added industrial PCC was based on the additional ash added during paper

manufacturing and was 2.3%, 4.4%, 37.6% and 85.3% for the 10%, 20%, 30% and 40% addition respectively. The total ash retention of the EC+HP pulp and the PCC addition was 50.6%, 40.1%, 47.5%, and 85.64% for the 10%, 20%, 30% and 40% addition respectively.

The manufactured HP fiber suspension features a higher ash retention of the powdered PCC filler material added prior to sheet forming. Adding powdered PCC can help to increase the filler level but has a lower ash retention value at the addition between 10% and 30%. At an addition of 40% the ash retention value is increased to the same level as the HP suspension.

Fig. 6. a) shows the HP filler particle on the paper surface. Filler particles caught in a fibril web like structure and on fibrils like pearls on a

neckless are shown if Fig. 6 b). The increased ash retention is caused by the increased micro fibrillation of the HP pulp suspension during precipitating filler particles followed by a beating process. The fiber surface and refining which helps to improve the retention behavior of the PCC particles.

Similar behaviors have been found by Klungness and Subramanian [27,28,29,30]

3.1.3 Fourdrinier pilot paper machine basis weight

The Basis Weight (BW), shown in Fig. 7., was measured according to TAPPI test method T 410 om-08 for the individual produced paper products.

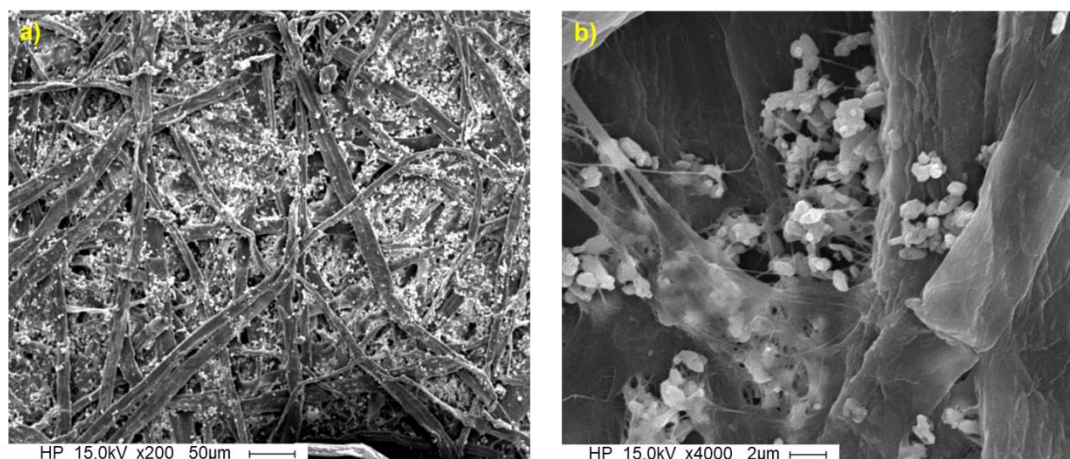


Fig. 6. Hybrid Pulp Paper at a magnification of a) x200, and b) x4000 [26]

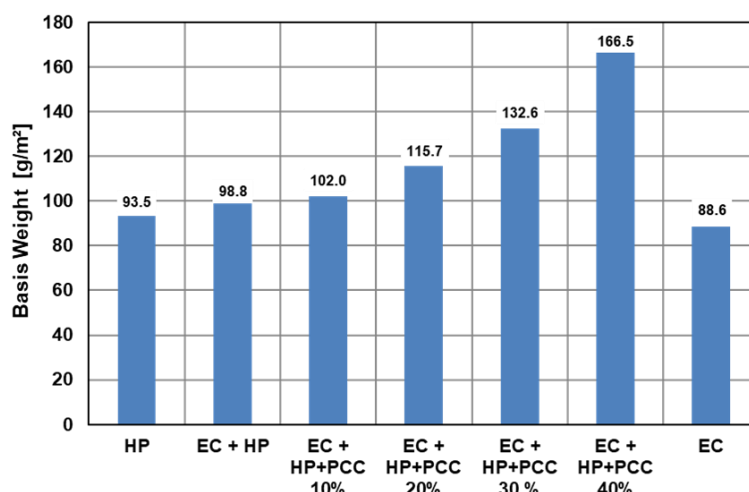


Fig. 7. Paper basis weight

The BW of the EC fiber only containing paper product resulted in 88.6 g. The BW of the paper product of the HP pulp fiber-filler suspensions was 93.5g. The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension was 98.8 g. The EC+HP+PCC paper product BW with a targeted filler content of 10%, 20%, 30%, and 40% was 102 g for the 10% PCC filler addition, 115.7 g for the 20% PCC filler addition, 132.6 g for the 30% PCC filler addition and 166.5g for the 40% PCC filler addition. The basis weight increased with increasing filler content as expected from the targeted paper sheet basis weight of 90 g/m² due to the higher calcium carbonate density of 2.60 to 2.95 g/cm³ [31] compared to the EC fibers 0.474 to 0.575 g/cm³ [32].

3.1.4 Fourdrinier pilot paper machine paper thickness

The thickness, shown in Fig. 8. of the produced paper product was measured according to TAPPI test method T411 Om-05 for the individual produced paper products.

The EC fiber only containing paper had a thickness of 161 µm. The thickness of the paper product containing the HP pulp fiber-filler suspensions was 160 µm. The produced paper product containing the EC+HP suspension with

18% HP and 82% EC pulp fiber suspension resulted in a thickness of 177 µm. The thickness of the EC+HP+PCC paper product with a targeted filler content of 10%, 20%, 30%, and 40% was of 191 µm for the 10% PCC filler addition, 216 µm for the 20% PCC filler addition, 227 µm for the 30% PCC filler addition, and of 294 µm for the 40% PCC filler addition.

It is known adding filler material to the pulp suspension will result in an increased thickness of the paper product [7], which can be seen as a negative manufacturing effect, because more pressing and calendaring may be needed during the manufacturing process. Results confirmed that for the EC+HP suspension and all EC+HP+PCC additions the thickness increased. Contradictory, the HP only suspension showed a comparable thickness to the EC pulp suspension, having a positive effect on the thickness development.

3.1.5 Fourdrinier pilot paper machine breaking length index

The Breaking Length Index (BLI) for the seven copy paper compositions is shown in Fig. 9. and Fig. 10. For the Machine Direction (MD) and Machine Cross Direction (MCD). The Breaking length index was measured according to TAPPI test method T494 om-06 for the produced paper products.

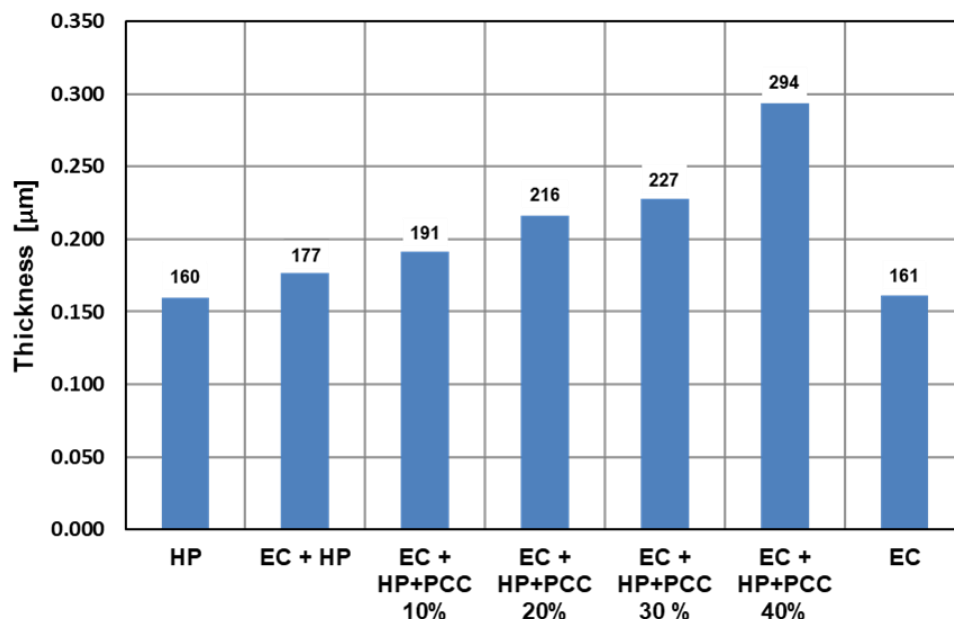


Fig. 8. Paper thickness

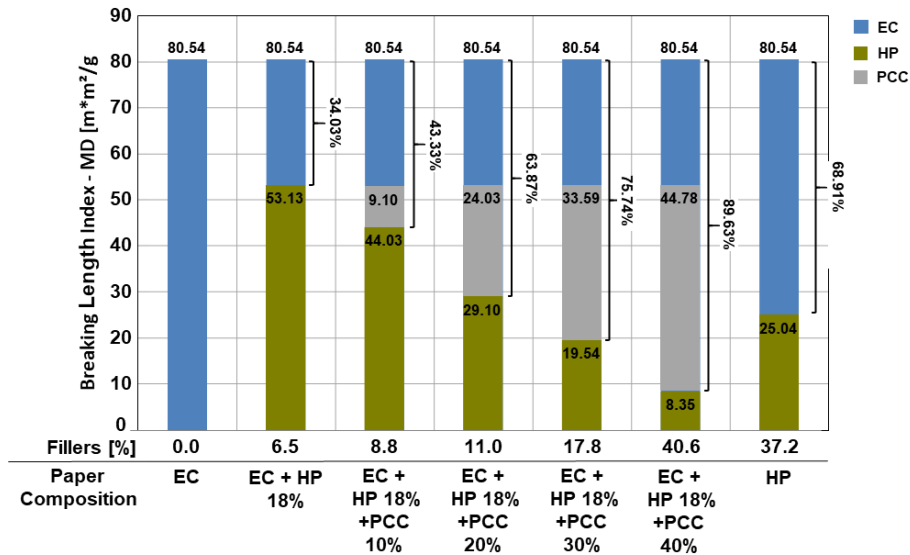


Fig. 9. Breaking length index – machine direction

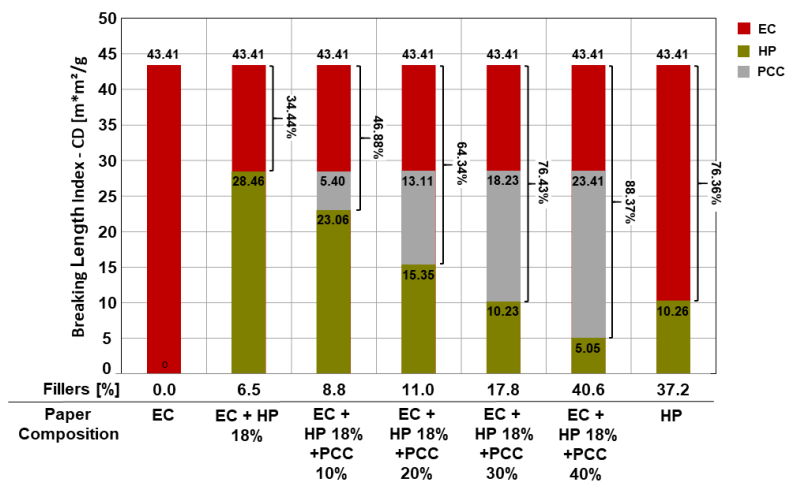


Fig. 10. Breaking length index – machine cross direction

The BLI for the EC containing paper product without filler content resulted in 88.54 m²m²/g for the MD and 43.41 m²m²/g MCD. The BLI for the paper product containing only HP fiber-filler suspensions was 25.04 m²m²/g for the MD and 10.26 m²m²/g MCD for a filler content of 37.2%. The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension had a BLI of 53.13 m²m²/g for the MD and 28.46 m²m²/g MCD for a filler content of 6.5%. The EC+HP+PCC paper product BLI with a targeted filler content of 10%, 20%, 30%, and 40% was 44.03 m²m²/g for the MD and 23.06 m²m²/g for the MCD for the 10% PCC filler addition having a 8.8% final filler content. For the 20% PCC filler addition with a final filler content of 11.0% the BLI was 29.10

m²m²/g for the MD and 15.35 m²m²/g for the MCD. The paper product with a targeted 30% PCC filler addition with a final filler content of 17.8% had a BLI of 19.54 m²m²/g for the MD and 10.23 m²m²/g for the MCD. The paper product with an additional filler content of 40% PCC filler and an actual filler content of 40.6% had a BLI of 8.35 m²m²/g for the MD and 5.05 m²m²/g for the MCD.

The total reduction in BLI for the filler containing pulps in comparison to the EC pulp without filler was 33.03% for the MD and 34.34% for the MCD for the paper product containing EC+HP suspension with 18% HP and 82% EC pulp fiber suspension and a total filler content of 6.5%. The paper product containing filler only from HP was

68.91% for the MD and 76.36% for the MCD with a total filler content of 37.2%.

The BLI reduction for the EC+HP+PCC paper product with an additional filler content of 10%, 20%, 30%, and 40% compared to the EC+HP paper product with 6.5% filler resulted for the 10% PCC filler addition or 2.3% filler increase to 8.8% in a reduction of the BLI of 43.33% for the MD and 46.88% for the MCD.

For the 20% PCC filler addition with a final filler content of 11.0% and an increase of 4.5% above the EC+HP filler content of 6.5% the BLI reduction was 63.87% for the MD and 64.34% for the MCD.

At a 30% PCC filler addition with a final filler content of 17.8% or 11.3% above the EC+HP filler content resulted in a BLI reduction 75.74% for the MD and 76.73% for the MCD.

A PCC filler addition of 40% with an actual filler content of 40.6% and a 34.3% filler increase to the EC+HP filler content resulted in a BLI reduction of 89.63% for the MD and 88.37% for the MCD.

It is known adding filler material to the pulp suspension will result in a decrease in mechanical properties of the paper product [7]. As expected, the BLI development for the MC and MCD paper direction showed and overall reduction with increased filler content for both the HP pulp suspension and the added commercial PCC.

3.1.6 Fourdrinier pilot paper machine tear index

The Tear Index (TI) for the seven copy paper compositions is shown in Fig. 11. and Fig. 12. For the MD and MCD. The Tear index was measured according to TAPPI test method T414 om-04 for the produced paper products.

The TI for the EC containing paper product without filler content resulted in 7.64 mN*m²/g for the MD and 7.91 mN*m²/g MCD. The TI for the paper product containing only HP fiber-filler suspensions was 1.32 mN*m²/g for the MD and 1.63 mN*m²/g MCD for a filler content of 37.2%. The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension had a TI of 5.32 mN*m²/g for the MD and 5.97 mN*m²/g for the MCD for a filler content of 6.5%. The EC+HP+PCC paper product TI with a targeted filler content of 10%, 20%, 30%, and 40% was 4.15 mN*m²/g for the MD and 4.68 mN*m²/g for the MCD for the 10% PCC filler addition having a 8.8% final filler content. For the 20% PCC filler addition with a final filler content of 11.0% the TI was 3.00 mN*m²/g for the MD and 3.57 mN*m²/g for the MCD. The paper product with a targeted 30% PCC filler addition with a final filler content of 17.8% had a TI of 2.03 mN*m²/g for the MD and 2.38 mN*m²/g for the MCD. The paper product with an additional filler content of 40% PCC filler and an actual filler content of 40.6% had a TI of 1.26 mN*m²/g for the MD and 1.30 mN*m²/g for the MCD.

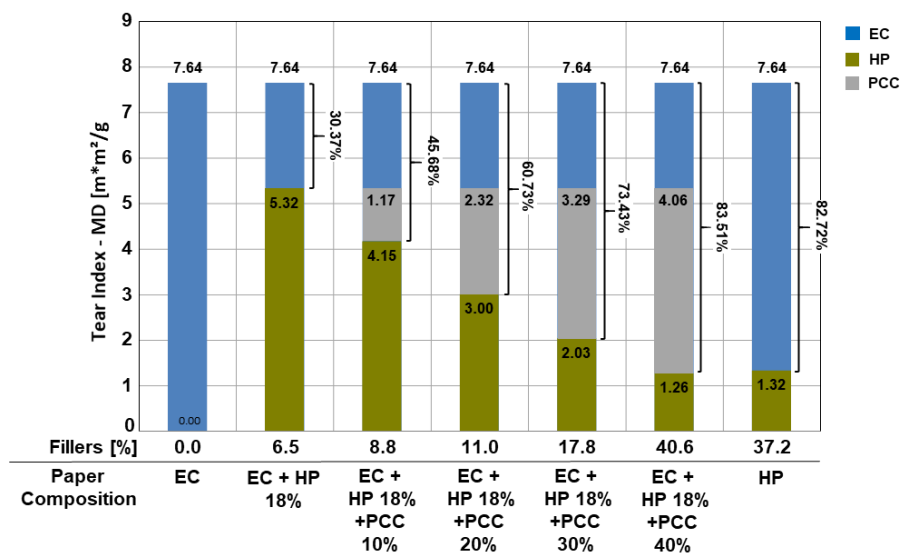


Fig. 11. Tear index – machine direction

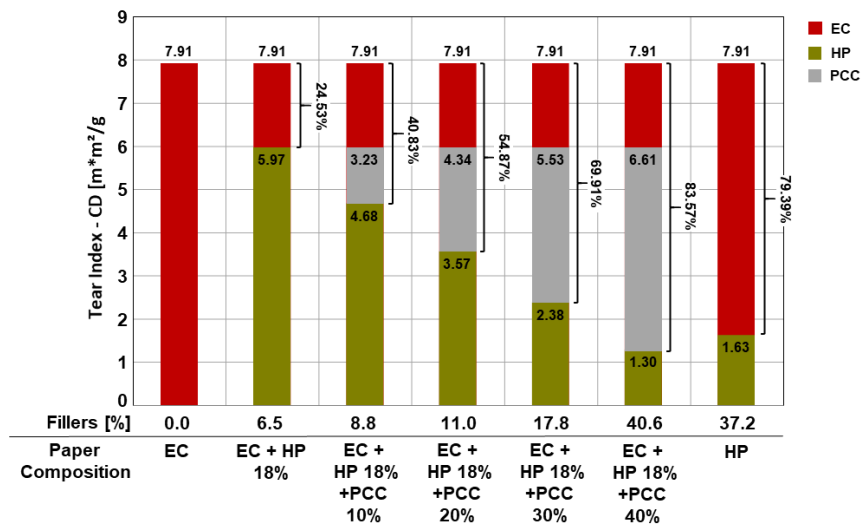


Fig. 12. Tear index – machine cross direction

The total reduction in TI for the filler containing pulps in comparison to the EC pulp without filler was 30.37% for the MD and 24.53% for the MCD for the paper product containing EC+HP suspension with 18% HP and 82% EC pulp fiber suspension and a total filler content of 6.5%. The reduction for the paper product containing filler only from HP was 82.72% for the MD and 79.39% for the MCD with a total filler content of 37.2%.

The TI reduction for the EC+HP+PCC paper product with an additional filler content of 10%, 20%, 30%, and 40% compared to the EC+HP paper product with 6.5% filler resulted for the 10% PCC filler addition or 2.3% filler increase to 8.8% in a reduction of the TI of 45.68% for the MD and 40.83% for the MCD.

For the 20% PCC filler addition with a final filler content of 11.0% and an increase of 4.5% above the EC+HP filler content of 6.5% the TI reduction was 60.73% for the MD and 54.87% for the MCD.

At a 30% PCC filler addition with a final filler content of 17.8% or 11.3% above the EC+HP filler content resulted in a TI reduction 73.43% for the MD and 69.91% for the MCD.

A PCC filler addition of 40% with an actual filler content of 40.6% and a 34.3% filler increase to the EC+HP filler content resulted in a TI reduction of 83.51% for the MD and 83.57% for the MCD.

It is known adding filler material to the pulp suspension will result in a decrease in

mechanical properties of the paper product [7]. As expected, the TI development for the MC and MCD paper direction showed and overall reduction with increased filler content for both the HP pulp suspension and the added commercial PCC.

3.1.7 Fourdrinier pilot paper machine burst index

The Burst Index (BI) for the seven copy paper compositions is shown in Fig. 13. for the MD and MCD. The Tear index was measured according to TAPPI test method T403 om-02 for the produced paper products.

The BI for the EC containing paper product without filler content was measured at 3.52 kPa*m²/g. The BI for the paper product containing only HP fiber-filler suspensions was 0.62 kPa*m²/g. The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension had a BI of 2.15 kPa*m²/g. The EC+HP+PCC paper product BI with a targeted filler content of 10%, 20%, 30%, and 40% was 1.71 mN*m²/g for the 10% PCC filler addition having a 8.8% final filler content. For the 20% PCC filler addition with a final filler content of 11.0% the BI was 1.15 kPa*m²/g. The paper product with a targeted 30% PCC filler addition and a final filler content of 17.8% had a BI of 0.83 kPa*m²/g. The paper product with an additional filler content of 40% PCC filler and an actual filler content of 40.6% had a BI of 0.46 kPa*m²/g.

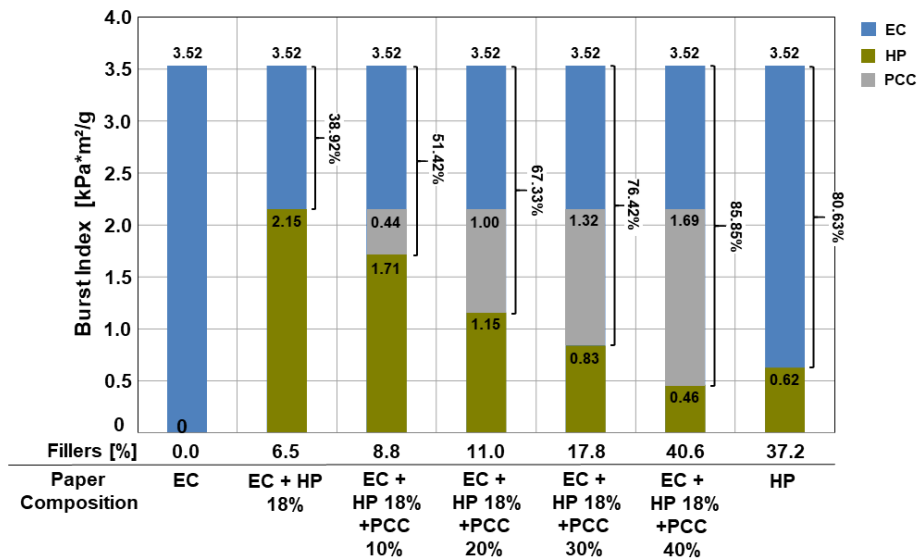


Fig. 13. Burst index

The total reduction in BI for the filler containing pulps in comparison to the EC pulp without filler was 38.92% for the paper product containing EC+HP suspension with 18% HP and 82% EC pulp fiber suspension and a total filler content of 6.5%. The reduction for the paper product containing filler only from HP was 80.63% with a total filler content of 37.2%.

The BI reduction for the EC+HP+PCC paper product with an additional filler content of 10%, 20%, 30%, and 40% compared to the EC+HP paper product with 6.5% filler resulted for the 10% PCC filler addition or 2.3% filler increase to 8.8% in a reduction of the BI of 51.42%.

For the 20% PCC filler addition with a final filler content of 11.0% and an increase of 4.5% above the EC+HP filler content of 6.5% the BI reduction was 67.33%.

At a 30% PCC filler addition with a final filler content of 17.8% or 11.3% above the EC+HP filler content resulted in a BI reduction of 76.42%.

A PCC filler addition of 40% with an actual filler content of 40.6% and a 34.3% filler increase to the EC+HP filler content resulted in a BI reduction of 85.85%.

It is known adding filler material to the pulp suspension will result in an decrease in mechanical properties of the paper product [7]. As expected, the BI development for the MC and MCD paper direction showed and overall reduction with increased filler content for both the

HP pulp suspension and the added commercial PCC.

3.1.8 Fourdrinier pilot paper machine optical properties

Optical properties of the produced seven paper products, shown in Fig. 14. were measured according to TAPPI and ISO standards. Color (L, a, b) was measured according to TAPPI T557 om-07, Opacity was measured according to ISO 2471, Brightness was measured according to ISO 2469.

3.1.8.1 Color

L, a, b - Color was measured for the EC congaing paper product without filler was at 95.70, -.75, 3.69 respectively.

For the paper product containing only HP fiber-filler suspensions the L, a, b color was 96.57, -0.56, 2.92 respectively for a filler content of 37.2%.

The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension had a L, a, b - Color of 96.08, -0.57, 3.36 respectively.

The EC+HP+PCC paper product with a targeted filler content of 10%, 20%, 30%, and 40% had for the 10% PCC filler addition with 8.8% final filler content a L, a, b - color of 96.39, -0.49, 3.07 respectively.

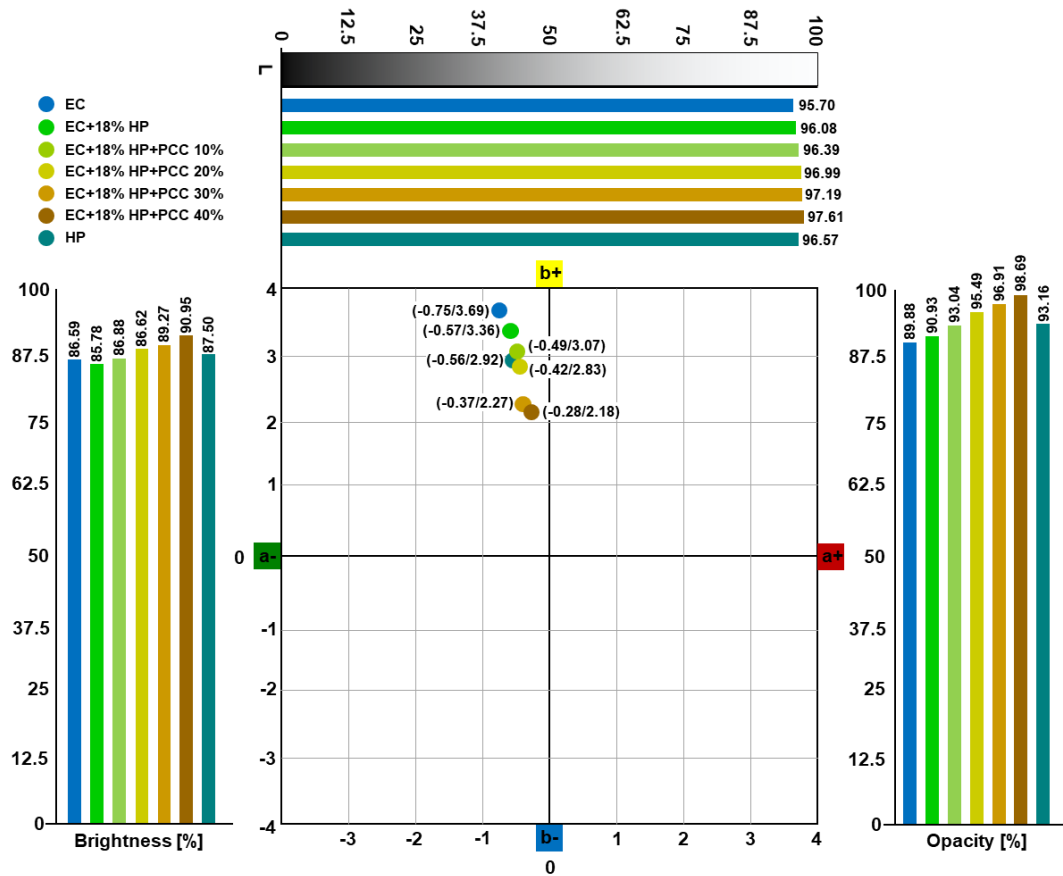


Fig. 14. Optical properties

For the 20% PCC filler addition with a final filler content of 11.0% the L, a, b – color was measured 96.99, -0.42, 2.83 respectively.

The paper product with a targeted 30% PCC filler addition and a final filler content of 17.8% had a L, a, b – color of 97.19, -0.37, 2.27 respectively.

The paper product with an additional filler content of 40% PCC filler and an actual filler content of 40.6% had a L, a, b – color of 97.61, -0.28, 2.18 respectively.

The color spectrum of the paper product containing HP filler compared to the EC paper product. Addition of commercial PCC improved the color spectrum even further towards the neutral spectrum of the blue spectrum of the b-color.

3.1.8.2 Brightness

The resulting Brightness was measured for the produced seven paper products on a 100% scale.

The EC containing paper product without filler had a brightness of 86.59%.

The paper product containing only HP fiber-filler suspensions at a filler level of 37.2% had a brightness of 87.50%.

The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension and a filler content of 6.5% had a brightness of 85.78%.

The EC+HP+PCC paper product with a targeted filler content of 10%, 20%, 30%, and 40% had for the 10% PCC filler addition with 8.8% final filler content a brightness of 86.88%.

For the 20% PCC filler addition with a final filler content of 11.0% the brightness measured was 86.92%.

The paper product with a targeted 30% PCC filler addition and a final filler content of 17.8% had a measured brightness of 89.27%.

The paper product with an additional filler content of 40% PCC filler and an actual filler content of 40.6% resulted in a brightness of 90.95%.

The brightness of the paper products containing HP filler and commercial PCC product compared to the EC paper product improved from an initial value of 86.59% to a value of 90.95% at a filler content of 40.6%.

3.1.8.2 Opacity

The resulting opacity was measured for the produced seven paper products on a 100% scale.

The EC containing paper product without filler had an opacity of 89.88%.

The paper product containing only HP fiber-filler suspensions at a filler level of 37.2% had a opacity of 93.16%.

The produced paper product containing the EC+HP suspension with 18% HP and 82% EC pulp fiber suspension and a filler content of 6.5% had a opacity of 90.93%.

The EC+HP+PCC paper product with a targeted filler content of 10%, 20%, 30%, and 40% had for the 10% PCC filler addition with 8.8% final filler content a brightness of 93.04%.

For the 20% PCC filler addition with a final filler content of 11.0% with an measured opacity of 96.49%.

The paper product with a targeted 30% PCC filler addition and a final filler content of 17.8% had a measured opacity of 96.91%.

The paper product with an additional filler content of 40% PCC filler and an actual filler content of 40.6% resulted in a opacity of 98.69%.

Opacity values increased as expected with filler content allowing less light to be transmitted through the paper product. However increased filler resulted in a thicker paper sheet which contributed to the improved opacity values.

4. CONCLUSION

Paper manufacturing on a global scale is a highly competitive market which is requires to constantly improve the manufacturing process to be competitive despite constantly changing and

increasing raw materials and utility costs, increasing environmental regulations in a worldwide trade market.

A 12' (304mm) wide laboratory Fourdrinier paper machine run was used to evaluate the in-situ produced calcium carbonate filler produced together with eucalyptus fiber material at a filler level of 41%. The evaluation included in-situ precipitated, non-filler containing eucalyptus fiber material and a mixture of eucalyptus, in-situ and commercially available calcium carbonate filler material.

The manufactured in-situ manufactured fiber suspension features a higher ash retention of the powdered PCC filler material added prior to sheet forming. Adding powdered PCC can help to increase the filler level but has a lower ash retention value at the addition between 10% and 30%. At an addition of 40% the ash retention value is increased to the same level as the HP suspension.

In-situ produced filler particles are caught in a fibril web like structure and on fibrils and form neckless like structures which tend to increase ash retention.

Basis weight increased with increasing filler content as expected from the targeted paper sheet basis weight and thickness of 90 g/m² due to the higher calcium carbonate density and filler particles in the paper sheet structure.

Mechanical paper properties of breaking length, burst, and tear showed an improvement for in-situ precipitated filler material compared to commercial filler material addition.

The color spectrum of the paper product containing HP filler compared to the EC paper product. Addition of commercial PCC improved the color spectrum even further towards the neutral spectrum of the blue spectrum of the b-color.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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