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FINAL THESIS

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The effects of filler on the properties of SCO paper

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Commissioning Company Kaolin International

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ABSTRACT

In this work there were studied the effects of three different filler prototype grades on the properties of SCO A+ paper. The target of this research was to evaluate the performance of those fillers. The examined fillers are separated from each other by particle size distribution. Prototype fillers were Brazilian kaolin from Rio Capim area, with high brightness and narrow particle size distribution.

The work was carried out in the paper laboratory of Tampere Polytechnic. With every filler there were sheets prepared by the sheet former, and after calandering different properties of paper were measured with laboratory equipment.

The results of the work show that the prototype fillers increased the paper brightness and tearing resistance compared to reference filler. In addition, the surface strength of paper increased, except with the finest prototype that gave even surface strenght with the reference filler. Due to higher brightness of the prototype fillers opacity decreased even though fillers were finer than the reference.

In the future, a same kind of study should be carried out with the higher filler content. Then the results of these two studies could be compared and more reliable conclusions of fillers performance could be made.

FOREWORD

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Tampere, 5.5.2006

Jussi Suutari

1. INTRODUCTION

Fillers are used in paper because they improve the paper printing properties and lower manufacturing costs. Paper strength properties and dusting are the main factors that limit the amount of filler in paper.

Under tight competition, paper producers are continually trying to improve the properties of papers and decrease manufacturing costs. Quality of raw materials has a big effect on the properties of SC paper. Being filler an integral part of SC paper, improved filler quality will always lead to improved paper quality.

The goal of this research was to evaluate the performance of three high brightness filler prototypes from the Rio Capim area in Brazil. In practice the effects of the fillers on the properties of the laboratory prepared SCO paper were studied. The filler samples presented narrow particle size distribution but also differed from each other by the particle size distribution. The three filler prototypes were compared against a commercial filler product from Cornwall-England taken as the reference.

2. SC OFFSET PAPER

2.1 SC paper generally

SC (supercalendered) papers are uncoated, supercalendered magazine papers where mechanical pulp dominates. High filler content with the fine mechanical pulp and heavy supercalandering result in a dense, smooth and glossy paper.

SC paper is one of the most difficult products to manufacture within printing and writing paper grades. The paper quality is largely determined by the quality and Z-directional distribution of raw materials. The sub grades of SC papers are SC-A+, SC-A, SC-B and SC-C, separated by brightness and quality. SC-A+ differs from SC-A with higher brightness (69-71 % for SC-A and over 72 % for SC-A+) and unprinted gloss (around 50 % for A+). In addition, SCA+ formation is improved,

resulting in a smoother, more even print surface. Due to improved quality and lower price and weight, SC paper has become a real competitor of LWC paper (light weight coated). In addition, SC paper producers are continually trying to improve the qualities and SCA++ is breaking through presently.

For the needed low two-sidedness, SC-A and SC-A+ offset grades are manufactured with the twin wire machine, where hybrid and gap former are the most common solutions. The press section often contains four nips for the same reason. In the calandering process, steam showers are used for two-sidedness control as well as gloss CD control. Normally basis weight area of SC-papers is from 39 to 80 g/m², and the most typical basis weights are 52, 56 and 60 g/m². /2; 3; 8; 10; 12/

2.2 Important properties of SC offset paper

At the moment about 20 % of SC papers is printed with offset, while 80 % goes for rotogravure. Though the quality of printed image could be competitive with LWC, the inferior runnability of SC has delayed it by mushrooming in offset printing. The offset grade is used successfully for products where a good information capacity is needed, such as direct advertisement products and TV guides.

The SC offset grade has been generated from the SC gravure printing grade. It has been made usable to offset by a separate pulp preparation. Offset and rotogravure grades have same properties, but some qualities have to be improved when transferring to offset. The properties that have to be decreased are linting, two-sidedness and water absorption, while brightness and gloss in the print quality should be improved. Other very important properties in offset grade are good surface strengths (both dry and wet), dimension stability, heat resistance, even setoff, and low and even ink absorption. /8; 12; 16/

2.2.1 Strength properties

It is very important that paper web runs well in a printing machine. Web breaks or lower running speed always create lower capacity of production. Paper must have good enough strength properties for the web not to break during printing and high enough web tension could be used. These strength properties depend pretty much on the quality and amount of chemical pulp and filler in the paper. Other factors to strength properties are wet pressing, stretches in the drying part and calandering. Fiber orientation has matter to strengths interrelationship between CD and MD.

Because paper is as strong as the weakest part of it, it should be equal in quality and there should be as less failings as possible in the web. Paper values in the measurements of tearing resistance and fracture toughness gives information about paper permeance if there is a fault in the web.

The printing ink that is used in the offset printing is sticky, and the ink splits in the printing nip, which inflict big separation forces on the paper. Therefore, a good surface strength (both dry and wet) is necessary. The surface of paper must not detach or lint, and paper must also not delaminate during printing. Water is always part of offset printing which is the reason for needed wet strength. Starch is used with offset grades to decrease linting and increase strengths.

If paper is linting, fibre material and filler particles start to accumulate on the printing blanket. That lessens ink transferring to paper, resulting to degrade of print quality. In addition, that necessitates stopping the machine for cleaning up. /2; 9; 12/

2.2.2 Absorption properties

Low water absorption is important because water is always participant in offset printing and moisture inflicts the dimension changes in paper and weaken its' strengths. The register is not successful if the measurement changes caused by moisture are too big.

Low ink absorption prevents print through, and even ink absorption is necessary for the homogeneous printing result. Low ink absorption gives also better density and gloss of the print quality. /9; 12/

2.2.3 Gloss and roughness

Good gloss and smoothness of the paper are derived from calendering and raw materials. Gloss in the print quality is a result of paper and ink properties. Paper properties that are affected are gloss, smoothness and surface absorption. In addition, for a good final printability, the paper has to be compatible with the ink. High paper gloss lessens ink surface scattering resulting in better density contrast in the print quality. High paper gloss increases also colour and purity in the print quality. Gloss in the print quality is most important in magazine end use where there is a lot of advertisements. /9; 12/

2.2.4 Brightness and opacity

Fillers quality and amount in paper have a big effect on paper optical properties. High brightness with the high light scattering is necessary for good print quality. Those properties give better density and colouring in the print quality. Opacity has become more and more important while paper basis weight has been tried to get generally lower. /9; 12/

2.3 Raw materials

The quality of raw materials play a very important role on the quality of SC-paper. SC-paper consists of mechanical pulp (70-90% of fibers), chemical pulp and filler. Recycled fibers (up to 80 %) could also be used. Fillers are widely used (15-40% of paper) and the filler loads have constantly been increased as the technique is developing. Additives, such as retention aid and dye are also used, but these are not discussed in this chapter. /2; 8; 17/

2.3.1 Chemical pulp

Chemical pulp is used to increase strength and to warrant both paper and printing machines runnability. Because price issues and poor printing properties of chemical pulp, its use is minimised. Chemical pulp gives better brightness to paper, but due to the higher brightness and lower light scattering it decreases opacity. /2/

2.3.2 Mechanical pulp

Mechanical pulp (GW, PGW or TMP) gives paper a good printability and good opacity, even at low basis weight. TMP provides better strength properties, whereas PGW improve optical properties. Mechanical pulp is usually cheaper than chemical pulp. Freeness of mechanical pulp has a big impact on the properties of paper. Typically freeness is 30 – 70 CSF. Lower freeness gives better values to all other SC-paper properties except tearing resistance. Compression is another important quality of SC papers particularly during supercalandering process. Properties of mechanical pulp that interact with compression are high bulky and moderate stiffness. Noteworthy is also reversible thickness of mechanical pulp while compress it. /2; 6; 12/

2.3.3 Filler

The use of fillers generally improves the printability of paper. Fillers improve paper smoothness, gloss, brightness and maintain opacity. Those properties are important when good printing results are expected. Other positive effects include improvement of formation, better dimensional stability and lower and more even absorption. The use of fillers in SC papers is extremely cost effective, not only because fillers are cheaper than fibers but its presence is usually associated to higher dry content after the wire and press section in the paper machine. In addition water evaporates more easily from the filler particle than from the inside of the fiber leading to energy savings. Filler decreases the strengths of paper whereupon

tensile strength set limits of filler proportion in paper. In addition, if filler particles are not well bonded in the web, tendency of linting increases.

Fillers used in SC papers are kaolin (clay), talc and calcium carbonate. Kaolin is the most commonly used. Talc is a poor option for offset grades because of its increased linting tendency in printing. It is not uncommon to blend different filler grades in order to optimise the paper properties. Mixing kaolin with PCC for example, increases paper bulk and light scattering resulting in improved opacity and brightness. Disadvantages of the use of PCC are detrimental effect on the properties such as gloss, porosity and printability. Table 1 shows how some of the most important properties of filler influence the paper properties or manufacturing process. /2; 7; 13; 14/

Table 1 Important properties of filler /7/

Characteristic of filler	**Effect on paper properties or manufacturing process**
Optical properties	Optical properties
Particle size and shape	Optical properties, smoothness, retention
Abrasivity, proportion of coarse particles	Abrasion of wire, foils, rolls and ceramics
Solubility	pH of white water (increase while solubility increase resulting a higher solubility of mechanical pulp, lignin become more yellow etc.)
Purity	Brightness, solubility, abrasion
Price	Production cost

3. KAOLIN AS A FILLER

Kaolin is widely occurring natural mineral almost all around the world. Its particles shape is platy (Figure 1) which gives it an advantage in retention, gloss, pores coverage and lowering of ink absorption. Therefore kaolin is popularly used in SC papers. Disadvantages of platy shape are slower water removal and evaporation in the drying part. Kaolin is available in different brightness and particle sizes.

Kaolin is easy to handle and disperse. It is almost insoluble in water (solubility approximately 0,1 %) and unaffected by pH. It is also soft resulting to a low abrasion to the wire and dewatering device. The principal constituent of kaolin is kaolinite, which is a layered aluminosilicate. Its chemical formula is $Al_4Si_{10}(OH)_8$.

Kaolin is most largely produced in England, in Brazil and in the United States. English kaolin is primary type, while American and Brazilian kaolin are secondary type. Secondary type means that the kaolin has been transported by water and laid down as sediments in its present location. Secondary type kaolin is typically less platy and finer than the primary type. Also particles shape factor (ratio of diameter and thickness) is lower. Therefore process called delamination is often done to secondary type kaolin, in order to increase their shape factor. In delamination sheets are split off, resulting in an increase to the shape factor.

Also between deposits there are differences between particle sizes, shape factors and mineralogical comparisons. Typical shape factor of English kaolin is between 10:1 and 80:1. Secondary kaolin from Georgia (USA) has a shape factor between 6:1 and 20:1 and kaolin from Jari River (Brazil) shape factor is as low as 10:1. Naturally delaminated kaolin from Capim River (Brazil) have better shape factor than other secondary types, ratio is between 15:1 and 25:1. /2; 7; 4; 11/

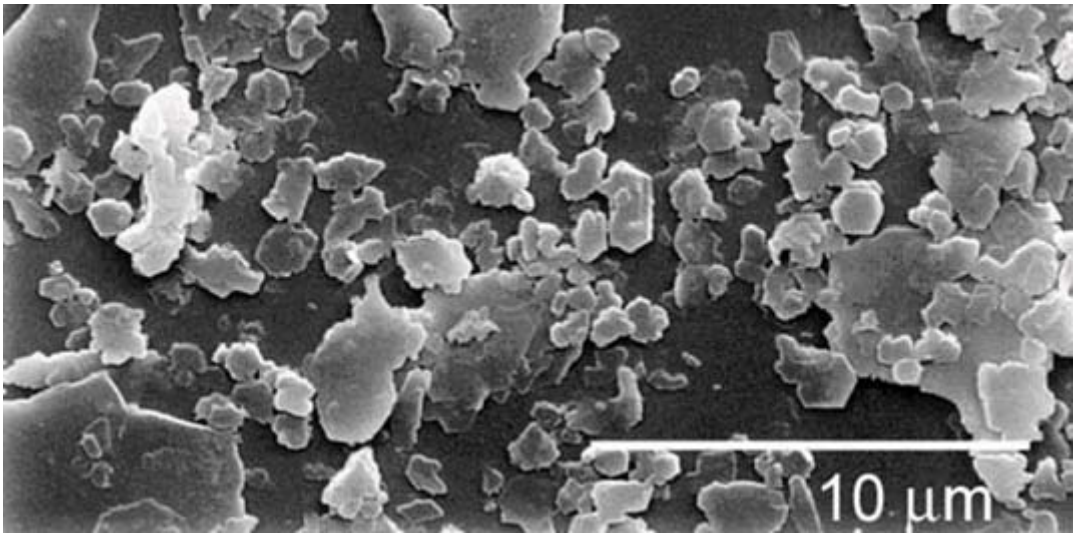

Figure 1 Microscope picture of kaolin /12/

4. A STRUCTURAL DIFFERENCES BETWEEN MILL AND LABORATORY PREPARED PAPERS

Properties of mill prepared paper cannot be directly compared with the properties of laboratory prepared paper even if the papers are prepared from same raw materials and with same contents. Biggest difference is due to structural differences in paper. In addition, for calendered papers, different calendering process between mill and laboratory creates differences especially on the surface properties.

Paper anisotropy means the differences between paper properties measured from the upper and the lower side or from MD and CD. In practice, the laboratory prepared papers have no anisotropy between different directions, while between upper and lower side they do. In proportion, anisotropy always exists between CD and MD in mill prepared papers, and attempts are constantly been made in order to minimise anisotropy between upper and lower side in SC papers. Different paper grades present different kind of anisotropy properties. /2/

4.1 Fiber orientation

In the paper machine, the fibres are always more orientated to MD than CD. This affects most of the paper physical properties, especially the strength properties. While orientation increases to MD, tearing resistance increases to CD, and other strength properties to MD. Effects are reversed to other direction. One reason for fibre orientation is that fibres orientate already in the slice of headbox where the speed of pulp flow is accelerating. On the wire section fibre orientation is caused by speed difference between pulp and already drainaged web. Speed difference occurs from difference between speed of wire and pulp discharging speed from slice. Also the gap forming causes additional speed difference in the infiltration area. The discharge ratio and pulp consistency are the most significant factors that affect the intensity of orientation. Lower pulp consistency in the headbox creates bigger orientation. The reason for this is that fibres can turn more easily.

Tensile strengths interrelationship between MD and CD is often used as criterion of orientation but other factors also affect it, e.g. the way of drying the paper.

When preparing paper with a sheet former, there is not that kind of dominant forces affecting the process as in the paper machine. A very diluted pulp drains slowly on a wire screen, and therefore no orientation will occur (Figure 2). Sheet strengths are equal in everyway. /1; 2; 5/

4.2 Z-directional material distribution

Z-directional material distribution is never homogeneous. The way of draining of water affect a lot the distribution of fine material in the paper. Figure 2 illustrate the distribution of fines and filler and the fibres orientation with different ways of draining of water.

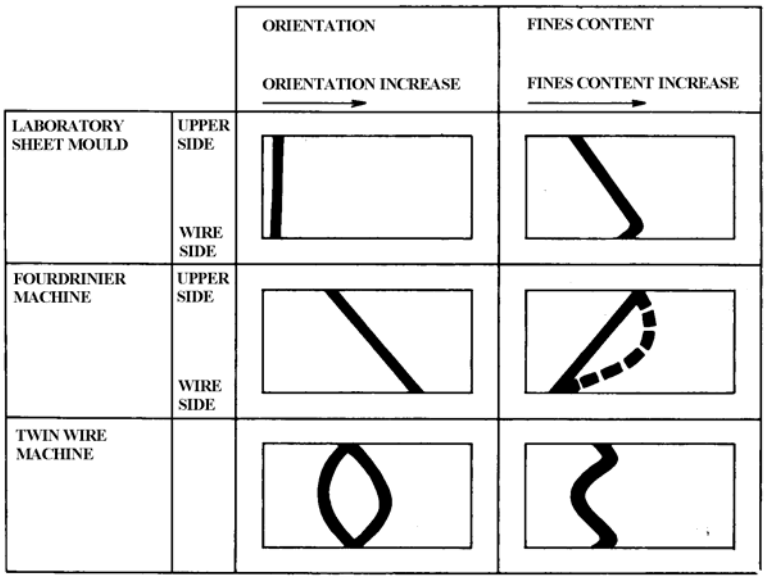

Figure 2 Orientation and fines content in different draining methods /1/

It can be seen in Figure 2 that the amount of fines and filler are increasing towards the surface from which the water has been removed continuously. Due to the constant dewatering pressure, the wire side of laboratory sheet has a higher fines content and density than upper side. Intense discontinuous forming causes the fines flushing off with the water, and fines content to be higher in the upper side of the

web. With the gap former could most even fines distribution in surfaces, and surface properties, be achieved.

Sheet former causes loss in fines content especially in papers that are prepared from pulps with high fines and/or filler content. If white water circulation is not possible or otherwise not used, the result is a sheet where the fines and filler content is lower than in original pulp. This is a result from the low retention of the fines, and could usually be solved by using white water circulation during sheet preparation. When using circulation, the fines content of the sheet comes closer to that of the original pulp, but some low retention fractions are still lost for the overflow from the circulation system.

Because metal ion content and pH of the water influence pulp brightness, used water can create differences in reflectance properties and ISO-brightness of a pulp. Using a Büchner funnel and a filter paper for the sheet forming this effect could be controlled better, because controlling the water quality is easier than controlling a sheet former. The problem with a Büchner funnel is very uneven z-directional fines material distribution. /1; 5/

4.3 Differences caused by drying

On the pressing and drying part of the paper machine paper web stretch to MD and shrink to CD. Therefore fibres that are set to CD are usually more curved than fibres to MD. Paper anisotropy and MD tensile strength, tensile stiffness and stiffness increase, and extension decrease, when the web MD stretch is increased and/or let it shrink more in CD. Respectively if web is let shrink less in CD during drying, CD tensile strength, tensile stiffness and stiffness increase and stretch decreases'. /2/

If laboratory prepared paper sheets are dried in the drum dryer, sheets shrink quite freely to both ways. Therefore there is no difference in fibres curve between different ways.

5. WORK DESCRIPTION

The work was performed in the paper laboratory of Tampere Polytechnic. The filler samples tested were denominated filler A, filler B, filler C and reference filler. Pulps were manufactured in one Finnish paper mill and the mechanical pulp used was TMP (thermo mechanical pulp). The starch used was Emcat C 3. Mill prepared SCO paper (54 g/m²) where the reference filler was used for filling was also analysed for comparison properties. This is refered as “mill paper” in this work. Water used to dilute the raw materials was normal tap water that was not subject to any cleaning treatment.

5.1 PAPER PREPARING

5.1.1 Filler dispersing

Approximately 500 g (dry weight) of each filler grade were dispersed to approximately 45 %-solids content using 3000 rpm for 30 minutes after all filler were added in the mixer. The Filler samples were dispersed without any added dispersing agent. NaOH was used to control pH close to 11. Mixer and impeller detail are shown in the Figure 3.

Figure 3 Mixer and impeller details

5.1.2 Mixing the pulps

Mechanical pulp was delivered from the mill in the consistence of 30,4 %, and chemical pulp in the consistence of 4 %. Wet disintegration was made for mechanical pulp and after that both pulps were diluted to approximately 1 % - consistency. After dilution the exact consistency of pulps was determined and starch was mixed in the mechanical pulp.

The target material content of the paper was 55 % of mechanical pulp (TMP), 13 % of chemical pulp, 32 % of filler and 0,5 % of starch. The target basis weight was 54 g/m² and the moisture content 6,5 %, achieved in preliminary trial. Dimensions of dry sheet were 0,163 m x 0,163 m. The target dry weight was calculated from the formula (1).

$$x = w \cdot A \cdot c \qquad (1)$$

Where:
x = the target dry weight of the sheet, g
w = the target basis weight of the paper, g/ m²
A = area of the dry sheet, m²
c = dry content of the sheet (93,5 % = 0,935)

The needed amount of dry matter of each component was worked out from the same formula when added target content (0,55; 0,13 or 0,32) on it.

Starch was added to mechanical pulp before mixing the other components. For sheet preparation were pulp batches prepared, that included right amount of pulps and filler for the 25 sheets. Batches were diluted to 25 dm³ in the mixing bowl.

5.1.3 Preparation of paper sheets

Paper sheets were prepared with circulation water sheet former (Figure 4), and white water recycling was used during sheet making (except for retention sheets). Under the sheet former there was a pool which collected white water. A pump

recycled water between the pipe system and the pool, and mixed it at the same time. The volume of the pool was 26 dm^3 and the additional water escaped through the leak-off pipe. Sheet former was filled over top with wire water and pulp. After forming, the sheets were couched from the wire to blotters. The pH of the wire water was always set to approximately 5,3.

Figure 4 Used sheet mould

After the sheets were formed, two step wet pressing was performed. The pressure used in the first press was 4 bar and the pressing time 4 minutes, whilst 4 bar and 2 minutes were used in the second press. After wet pressing the sheets were dried in a drum dryer. The drying time was 4 h and the temperature was approximately 62 ^oC.

At first 75 sheets were prepared with each filler grade. Variation of basis weights between sheets was quite wide. Therefore with the fillers A and C there was a need to prepare 50 additional sheets, so that enough number of sheets in basis weight 54 g/m^2 was achieved.

5.1.4 Calendering

After preparation, sheets were calendered with laboratory calender (Figure 5). At first the target was to calender papers to same gloss than mill paper was, but it was not possible to do soundly with the calender. Therefore papers were decided to calender close to same smoothness than mill paper was. The right calendering amount was found to be 16 nips with the maximum temperature (65 ^oC) and nip pressure (70 bar).

Calendering speed was approximately 0,32 m/s (calculated by perimeter and time it took for one circle). The width of the nip was approximately 3,5 mm. The wire sides of sheets were calendered against hard cylinder because of the higher filler and fines content. That resulted to higher smoothness on the wire side of paper. Calendering was performed with stable circumstances for each grade.

Figure 5 Used calander

The lower cylinder of the calander was hard and heated up by hot water which circulated between water heater and cylinder. The diameter of the cylinder was 0,20 m. Upper cylinder (diameter 0,275 m) was soft, its surface was made of cotton, and it was without independent heating system. During calendering upper cylinder was warmed by lower. Therefore, before actual calendering the calender was rolled while warming up the lower cylinder. By doing this the circumstance variation during calendering was decreased. Another variable was the surface condition of upper cylinder. Before starting calendering, the upper cylinder was changed to the new, grinded one because of the bad condition of the old one. However, surfacing of cylinder was too soft and little bit too inelastic, resulting to dents on the surface during calendering. Papers were calendered in turns, one per time of each grade which eliminated differences of circumstance between different grades.

5.2 MEASUREMENTS

All the measurements, except fillers particle size distribution measurements, were carried out in the paper laboratory of Tampere polytechnic. Filler particle size distribution measurements were carried out in a Sedigraph equipment by the filler samples supplier.

Every measurement with different grades was carried out with the stabile circumstances. Because of the old air conditioner, standard circumstances (23 ºC and 50 % of moisture) could not be assured. However, each measurement from each grade was carried out in the same day, so there was no variation in circumstances between different grades.

5.2.1 pH and dry content measurements from filler slurries

After fillers were dispersed, pH and dry content of slurry were measured. Drycontent was measured with the equipment Mettler Toledo HG53 and Denver Instrument IR-30 (Figure 6), and pH with Mettler Toledo MP 225 pH Meter (Figure 7).

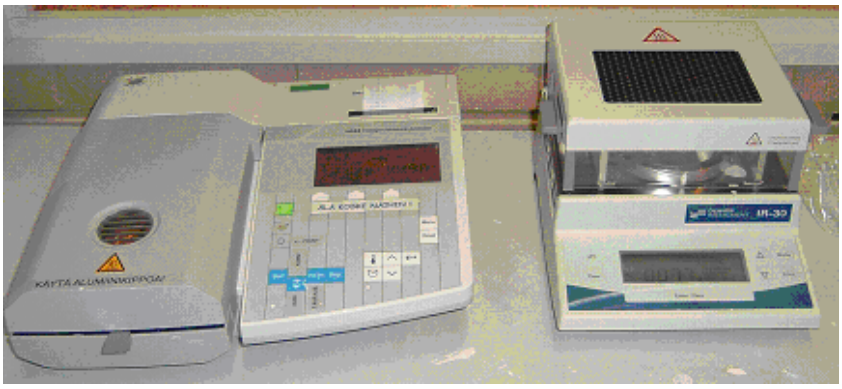

Figure 6 Equipment used in dry content measurements

Figure 7 pH meter used in the tests

5.2.2 Drainage time of the sheets

Drainage on the paper machine wire part is interacted to running speed of the machine. If water is not removed from the web quickly enough, it limits the machine running speed.

Drainaged amount of pulp for each sheet was 8 dm^3. Amount of dry matter in that was 1,34 gram plus dry matter that came with the recycled wire water. Drainage time was measured from 11 – 15 sheets for each grade. Those sheets were between 50 and 65 in preparing order.

5.2.3 Filler losses due to burning

In these measurements the same crucibles were used as in retention measurements. Before the first retention measurement, crucibles were burned 15 minutes at the temperature of 900 ºC +-25 ºC. After that crucibles were let to cool down for 45 minutes in the desiccator and then weighed. After every measurement, empty crucibles were weighed and the weights used in the next measurements. Crucibles weight variation was very small.

Loss measurements due to burning were made for the fillers to find out the possible differences between them. It's important to consider loss due to burning when calculating retention from ash content. Filler loss due to burning is a consequence of evaporation of combined water, and it does not have an effect on the paper properties.

Fillers were first dried up in the drying oven and then weighed. After that fillers in the crucible were burned at the temperature of 900 ºC +- 25 ºC. Burning continued 2 hours after heating furnace had reached the right temperature. After burning crucible was cooled down in the desiccator and weighted. Ash content was calculated with formula (2).

$$x = \frac{b - c}{d(a - c)} \cdot 10000 \qquad (2)$$

Where:

x = ash content, %

a = weight of crucible + weight of filler sample, g

b = weight of crucible + weight of ash, g

c = weight of empty crucible, g

d = dry matter content of filler sample, %

Filler loss percent due to burning got natural when ash content percent was reduced from 100 %. Measurements from reference filler, total of three, were made from slurry, because all the reference powder was used in that slurry. From fillers A, B and C one measurement was carried out from the powder and also from the slurry, to find out if there were differences between slurry and powder. Dry matter content of filler samples was 100% for each time because first samples were dried up and weighed after that. Dry matter content was checked also from comparison sample with same equipment as dry matter content was measured from filler slurries after dispersing. Used procedure in fillers ash content measurements followed standard SCAN-P 40:80.

5.2.4 Retention

Retention was measured in two different ways. The first method was to measure the ash content from the paper that had been prepared with clean water and retention was counted from that and original filler content of the pulp. Used procedure in ash content measurements was an accordant with standard SCAN-P 5:63. Sheets were dried up in the drying oven and dry weight was taken down. Papers in the crucible were added in the cold burning furnace (Figure 8) and furnace was turned on. Papers burned in the crucible with the top for one hour after all organic material has burned. After that the top was taken off and burning was continued for a half an hour. Burning temperature was 900 ºC +- 25 ºC. After burning crucible was cooled down in the desiccator and weighed. Ash content in the sheets was counted from formula (3).

$$x = \frac{a}{m} \cdot 100\% \qquad (3)$$

Where:

x = ash content, %

a = weight of ash, g

m = weight of dry sample, g

Fillers retention was calculated from formula (4).

$$x = \frac{a/k}{f} \cdot 10000 \qquad (4)$$

Where:

x = retention, %

a = weight of ash in the sheet, g

k = filler ash content from filler loss due burning measurement, %

f = weight of filler in the pulp that used to prepare the sheet, g

The second method was to find out the consistency of the white water and count the retention from that. After 75 sheets were prepared two water samples were taken from the white water. First sample was taken from shower (white water for each sheet preparing was taken from it) and another from the recycling pool. The volume of each sample was 500 ml. Water samples were filtered through the filter paper and after that burned the same way as retention sheets.

Amount of recycled water for each sheet was 7 dm^3, so the amount of recycled filler was 14 times the filler amount in 500ml. Retention was calculated from formula (5).

$$x = \frac{w1}{\left(a/k \ \cdot 100 \cdot 14 + w2\right)} \qquad (5)$$

Where:

x = retention, %

a = weight of ash in the 500 ml of white water, g

k = filler ash content, %

w1 = 54 g/m^2 * 0,163^2 * 0,935 * 0,30 = real amount of filler in the sheets

w2 = 54 g/m² * 0,163^2 * 0,935 * 0,32 = added filler amount for the each sheet

Figure 8 Experimental burning furnace used

5.2.5 Grammage

After preparing and conditioning of papers (before calandering), each sheet was weighed and grammages were calculated from the formula (6).

$$x = 10000 \cdot \frac{m}{A} \qquad (6)$$

Where:
w = grammage, g/m²
m = weight of the sheet, g
A = area of the sheet, cm²

Otherwise the used procedure for grammage measurements followed standard SCAN-P 6:75, except the dimensions of the sheets that were 16,3 cm x 16,3 cm (compared to 25 cm x 30 cm in standard). Grammages of the sheets were needed in measurements of different properties of the sheets.

5.2.6 Density

Before calendering, the thickness was measured from the sheets that had exact grammage of 54,0 g/m². After calendering thickness was measured again from the

same sheets and density before and after calendering was calculated. Changes in thickness and density by percents were also calculated. Thickness was measured from formula (7).

$$x = 1000\frac{w}{t1} \qquad (7)$$

Where:

x = density, kg/m³

w = grammage, g/m²

t1 = thickness, µm

Thickness and density measurements were accordant with standard SCAN-P 7:75.

5.2.7 Measurements of optical properties

After calendering the optical properties (except gloss) were measured with Minolta Spectophotometer CM-3610d equipment (Figure 9). It measured other optical properties at the same time from the stack of papers, that was as thick that light couldn't permeated it, except opacity that has to be measured from one sheet per time.

Figure 9 Spectophotometer CM-3610d

Opacity measurements were carried out from 15 sheets, basis weight exactly 54 g/m². Other measurements were carried out 20 times from a stack, thus the sheet on the top moved to bottom for each measuring.

5.2.8 The interdependence of brightness and opacity

The interdependence of brightness and opacity was specified from the results of opacity, brightness and filler particle size distribution measurements. First the equation was determined whereby opacity alternated between fillers A, B and C (between different particle sizes). Equations were determined separately from amount of particles under 10 µm, 5 µm, 2 µm, 1 µm, 0,5µm, 0,2µm. The results and equations are shown in Figures 10 and 11.

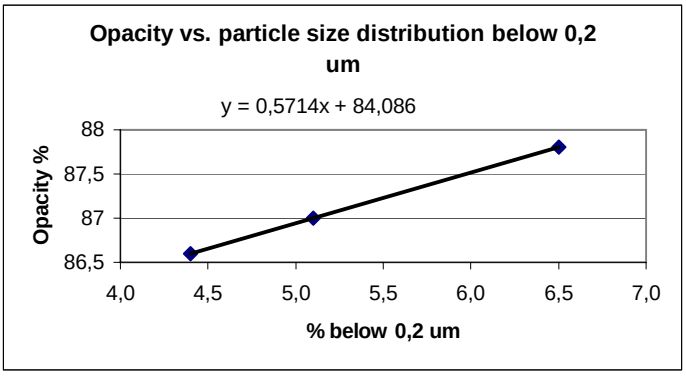

Figure 10 Opacity vs. particle size distribution, below 0,2 µm

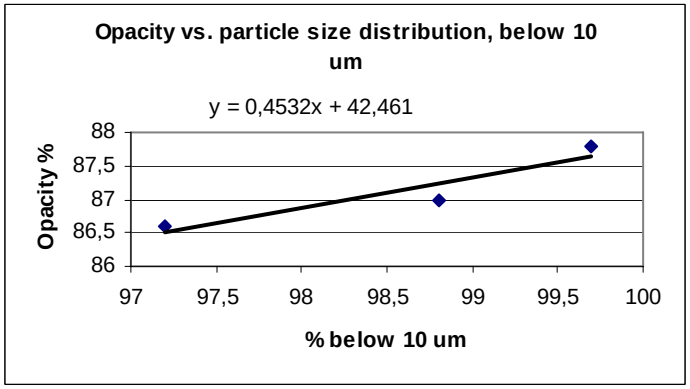

Figure 11 Opacity vs. particle size distribution, below 10 µm

In the equations:

y = opacity, %

x = amount (%) of particles below specified size in micrometers

The results were obtained by replacing “x “ by the amount (%) of reference filler’s particles below specified size. The average value of the 6 results was used to

predict opacity in paper where reference filler was replaced by as coarse filler as reference but with the same optical properties as prototype filler.

After that the difference between predicted opacity and real opacity in the reference paper was calculated. Also the difference between brightness of papers prepared with reference filler and with filler B was calculated. From those two values could the interdependence between brightness and opacity been calculated in this work. From that interdependence, was predicted how paper brightness and opacity would change if filler B brightness would change. This could work the same way in practice too, but it necessitates that other optical properties of filler B are identical with reference filler in the same level of brightness.

5.2.9 Gloss

After the other optical properties were measured, gloss was defined with Hunter D 48-7 gloss measuring equipment, shown in Figure 12. Gloss measurements were carried out in 43 to 50 sheets for each grade and from both sides of the paper. Gloss was measured out from papers in the same way to calendering direction. Measuring method was accordant with equipment's guideline.

Figure 12 Hunter gloss equipment

5.2.10 Roughness -pps

Figure 13 Messmer Büchel equipment

PPS-values were measured with equipment of Messmer Büchel, shown in Figure 13. PPS-equipment of Messmer Büchel conform standards P19:78 and ISO 8791-4. Roughness was measured in 42 – 47 sheets, each from five points, and the average for each sheet was calculated and used.

5.2.11 Air permeance

Air permeance measurements were also carried out with Messmer Büchel equipment. Air permeance was measured with both methods, Gurley and Bendtsen. Gurley air permeance was measured in 43 – 49 sheets, five points each, and the average for each sheet was calculated and reported. Bendtsen air permeance was also measured in 43 – 49 sheets, but only from one point of each sheet and average calculated after each 10 measurements. Sheets average grammages in this measurement are shown in Table 2.

Table 2 Average basis weights of the sheets in air permeance measurements

	Filler A	Filler B	Filler C	Reference
Basis weight, g/m²	54,1	54,4	54	54,5

5.2.12 Tensile strenght and fracture toughness

Tensile strength and fracture toughness were measured with L&W Tensile tester equipment, shown in Figure 14. Before measuring, the right size of strips were cut from the sheets. For tensile strength tests strips must be 15 mm wide and for fracture toughness 50 mm wide. Tensile strength was measured from 25 strips, and

fracture toughness from 18 strips for each grade. Average basis weight of the sheets in tensile strength measurements were 53,9 g/m² of each grade, and 54,0 – 54,1 g/m² in fracture toughness measurements.

Figure 14 Used L&W Tensile tester

5.2.13 Tearing resistance

Dimensions of paper samples used for tearing tests were 50 mm wide and 62 mm long. Tearing test was performed along the longer side of paper. Length of the tear was 47 mm. For each measurement four samples were used, and a total of 15 measurements were carried out for each grade. Average basis weights of the used sheets were 53,9 g/m² for filler A and 53,8 g/m² for fillers B, C and reference. Deviations by standard was tear length (43 +-0,5 mm in standard) and friction resistance of the equipment was 5,0 (2,0-2,5 in standard). Otherwise measurements were accordant with standard SCAN-P 6:75. Used equipment is shown in Figure 15.

Figure 15 Used tearing equipment

5.2.14 IGT picking

IGT picking test measures the surface strength of paper. In practice it means how well fibres and filler particles are bound on the surface. IGT picking test carried out from a-side of the sheets. In the test 10 mm wide aluminium printing cylinder (402.301) and low viscosity printing ink (404.004.010) was used. Ink was applied with the IGT inking equipment. At first 0,28 cm^3 ink was added on the inking reels and let applied 10 minutes on the reels. Next, the ink was applied on the printing cylinder. Application time was 90 seconds. After that printing on the 50 mm wide paper sample was performed. Used printing pressure was 350 N and printing speed 1 m/s. Print speed increased evenly during printing catching up the maximum value after 200 mm from starting point. After every fourth print 0,0168 cm^3 (6 % of original amount) ink was added on the inking reels and let apply for 10 minutes. This operation resulted to 8 µm layer of ink on the printing cylinder for each print.

From the imprint the distance between starting point of the printing and point where picking started was measured. Starting point of picking was evaluated visually with the pick viewer equipment. Picking speed and picking resistance of the distance were also calculated. The picking resistance is also called VVP (viscosity-velocity product).

Picking speed was calculated from formula (8).

$$V_p = \frac{v_e \cdot d}{200} \qquad (8)$$

V_p = speed on the point d, m/s
V_e = set end speed, m/s
d = distance from starting point of printing, mm

VVP- value was calculated by multiplying picking speed (m/s) with ink viscosity (Pas) and the result expressed as N/m. Air temperature during these measurements was 23 ºC resulting in a viscosity of 17,5 Pas for the printing ink. IGT equipment is shown in Figure 16.

Figure 16 Used IGT equipment

5.2.15 IGT linting

IGT linting test also measures the strength of paper surface but the test differs from IGT picking. In IGT linting test the amount of damages on the surface is evaluated, not the starting point. The method is very effective if the paper samples tested have low surface strengths.

IGT linting tests were carried out from a-side of the sheets. Used printing cylinder was 50 mm wide and gum-covered (RUBBER 65 SHORE A no. 402,087). Normal tack printing ink (408002) was used for the tests. Ink was applied with the IGT inking equipment. First 0,35 cm^3 of ink was added on the inking reels and let it to apply for 20 seconds on the reels. Next the ink was applied on the printing cylinder and application time was 20 seconds. After every print 0,088 cm^3 of ink was added on the reels. That assured a 8 µm layer of the ink on the printing cylinder for each print. Because of the fast drying of the ink, which affects ink tack, inking reels were cleaned up after every fourth print. By doing this operation the differences in the ink between different prints were minimized.

Every grade was printed four times, once of each position of group, for both speed 1,5 m/s and 2,0 m/s. Table 3 illustrates printing order in every group:

Table 3 Printing order in IGT linting test

Printing group 1				
Printing position	**1**	**2**	**3**	**4**
Grade	Filler A	Filler B	Filler C	Reference
Printing group 2				
Grade	Filler B	Filler C	Reference	Filler A
Printing group 3				
Grade	Filler C	Reference	Filler A	Filler B
Printing group 4				
Grade	Reference	Filler A	Filler B	Filler C

Printing positions were changed after every print because of the drying of the printing ink. The bigger separation force affected to the paper which was printed last of the group than to the first of the group. After every group inking reels were cleaned up and fresh ink was added and applied on the reels. Printing speed increased evenly during printing catching up the maximum value after 200 mm from the starting point.

After each group was printed, samples were put in order of superiority. Best sample was placed first (one point) and poorest fourth (four points). After that, all the total points from four groups were summarized and the best grade got lowest points. The samples that were printed on the same position were put in order and pointed same way too.

Last way to evaluate the grades was to give the grade (4-10) to every single sample. Finally total points were calculated. The grade that got most points was the best one in this test.

5.2.16 Oil absorption

Oil absorption was measured from a-side of the sheets with the Unger oil absorption equipment, shown in Figure 17. For measurements, first task was to cut the right sized paper samples. Used absorption time was 6 seconds. Paper sample was weighted before and after absorption, and oil absorption was calculated from the weight difference.

Oil absorption was calculated with formula (9).

$$CU_6 = \frac{G_2 - G_1}{A} \quad (9)$$

Where:

CU_6 = Cobb-Unger oil absorption, g/m²
G_2 = weight of sample before absorption, g
G_1 = weight of sample after absorption, g
A = absorption area (0,0100 m²)

With every grade 8 measurements were made. Average basis weight of used papers was 55,3 g/m² for each grade.

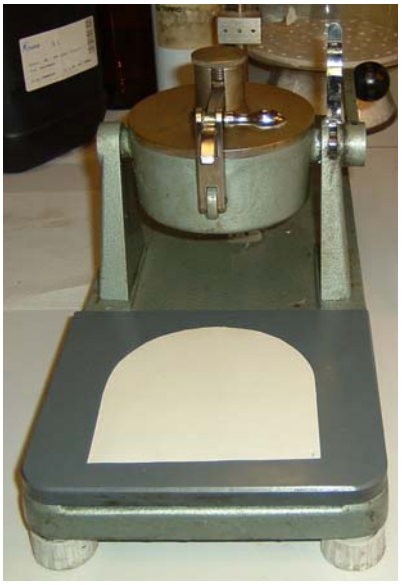

Figure 17 Unger oil absorption equipment

5.2.17 Real filler content in the papers

For the reliability of the results filler content of the papers used in measurements of strength properties (except surface strength), was measured. Measurements were carried out from three samples of the papers. The same papers were used for measurements of optical properties, gloss, roughness and air permeance before

strength measurements. Filler content was measured in the same way than filler content from retention sheets.

6. RESULTS AND DISCUSSION

Used methods and equipments are described in chapter 5. Single measurement results are shown in appendix part of the work.

6.1 pH and dry content of filler slurries

Table 4 Filler slurries pH values and dry contents.

	Filler A	Filler B	Filler C	Reference
pH	7,5	7,54	7,47	7,42
Dry content, %	43,8	44,4	44,2	45,1

In Table 4 it is shown that filler slurries pH and dry contents were very close to desired value.

6.2 Particle size distribution

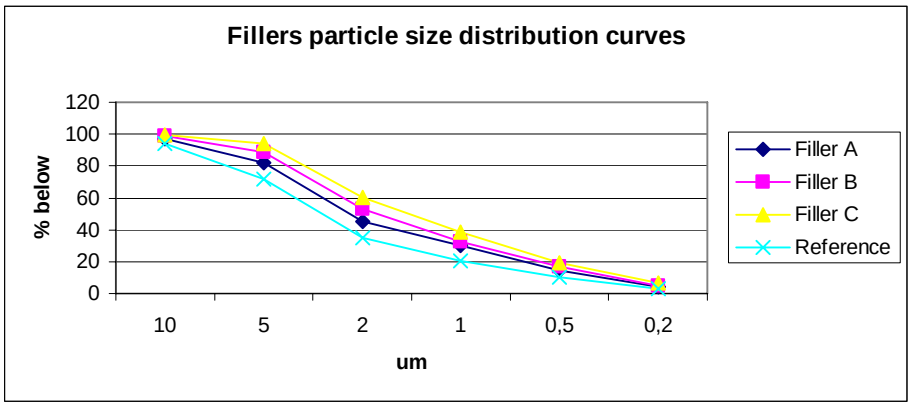

Figure 18 Fillers particle size disribution curves

Table 5 Particle size distributions, % below

Particle size distribution, % below				
	Filler A	Filler B	Filler C	Reference
10µm	97,2	98,8	99,7	94,2
5µm	81,9	88,4	94,1	71,8
2µm	45,3	52,9	60,4	35,1
1µm	29,9	32,8	38,3	20,7
0,5 µm	14,4	16,6	19,4	10,1
0.2µm	4,4	5,1	6,5	3,2

Figure 18 and Table 5 show the particle size distribution of each filler sample tested. The data clearly show Reference Filler as the coarsest and Filler C the finest.

Table 6 Particle size distribution, % between

Particle size distribution, % between				
	Filler A	Filler B	Filler C	Reference
> 10 µm	2,8	1,2	0,3	5,8
5 - 10 µm	15,3	10,4	5,6	22,4
2 - 5 µm	36,6	35,5	33,7	36,7
1 - 2 µm	15,4	20,1	22,1	14,4
0,5 - 1 µm	15,5	16,2	18,9	10,6
0,2 - 0,5 µm	10	11,5	12,9	6,9
< 0,2 µm	4,4	5,1	6,5	3,2

Table 6 also shows that reference filler and filler A have both as much particles between 2 – 5 µm (36,6 % and 36,7 %), but there are differences below 2 µm and over 5 µm. Particle size under 0,2 µm is not desirable, because of nonexistent light scattering and low retention.

6.3 Fillers losses due to burning

Fillers A, B and C losses due to burning were even, and presented an average result of 13,87 %, which was used when retention results were calculated from those fillers. Reference filler loss due to burning was about 3,5 % lower than others,

leading to the conclusion that reference filler contains less combined water than fillers A, B and C. Fillers' losses due to burning are shown in Table 7.

Table 7 Fillers' losses due to burning

%	Filler A	Filler B	Filler C	Reference
	13,98	13,78	13,83	9,94
	13,88	13,82	13,91	10,38
				10,33
Average	**13,93**	**13,8**	**13,87**	**10,22**

6.4 Drainage time of the sheets

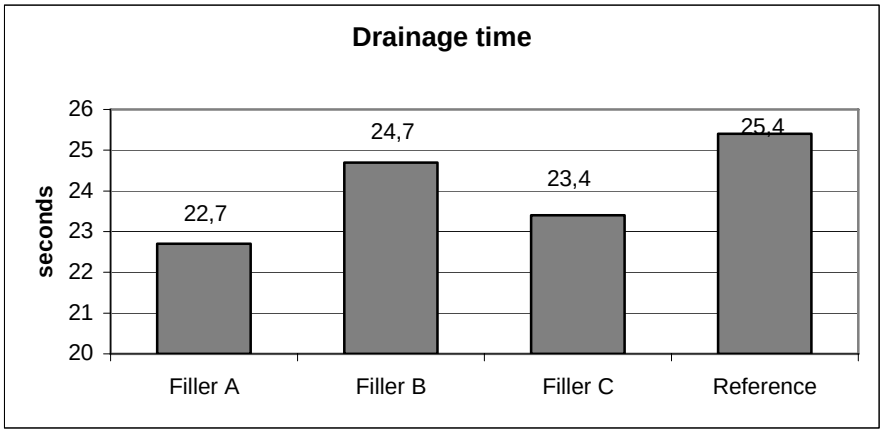

Figure 19 Drainage times

In the measurements fillers A and C had lower dewatering time than filler B and the reference filler (Figure 19). The lower time means that water escaped faster trough the wire and sheet, however the following factors could create measuring errors to results: manual timing, volume and consistency of used pulp and volume and consistency of recycled wire water.

6.5 Retention

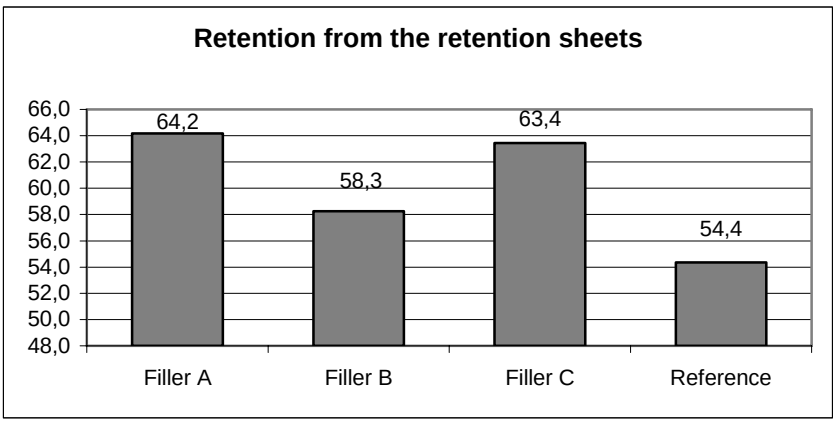

Figure 20 Retention results from retention sheets

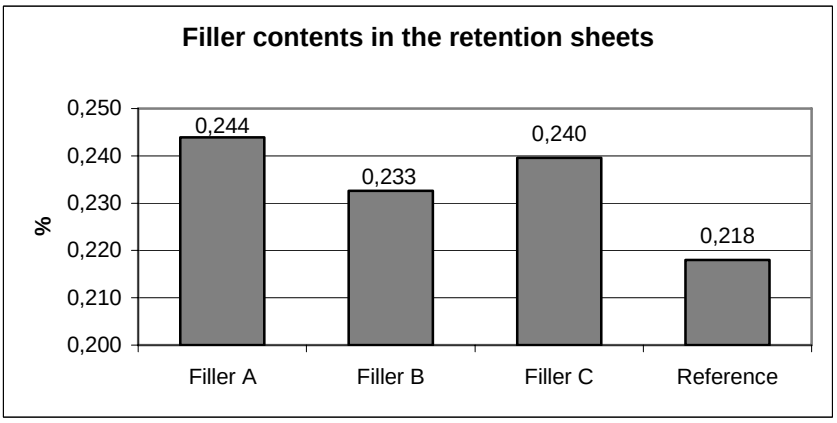

Figure 21 Filler content in the retention sheets

Because fillers A, B and C had been made of the same raw material and the same way, the only thing in filler properties that could affect retention differences is particle size. However, retention results from the retention sheets (Figure 20) show that filler B had much lower retention than fillers A and C which cannot be truthful. Also retention of the reference filler is quite low, especially when considering that it had biggest particle size and lowest content of filler in wire water after 75 sheets were prepared. Variation could have occurred for several reasons. It can be seen in Figure 21 that filler B, and reference filler relative contents in the sheets were also lower than filler A and C. That excluded pulp diluting error, but opened the possibility of the error of filler amount in the pulp.

One possible explanation could be attributed to the differences in used uncleaned pipage water. Pulp batches with filler B and reference filler were diluted on Sunday ready for sheet preparing next day. On Saturday supposedly no one used the laboratory, and that have resulted to water been in pipage for two days before using. It might be possible that solute matter from pipage created changes to filler properties in those batches. Afterwards the test from water quality was made. Water samples were taken on Monday morning. First sample was taken after couple litres was running from water tap, and second after a couple minutes. Measurement done to water was conductivity, that delineate amount of a solute matter in water /15/. Results from that shows that water conductivity had actually increased 10 µS/cm due to water run. Higher value means more positive ions in the water. Because filler particles and fibres both have negative charges, more positive ions in the water result in a lower repellence forces between particles and fibres, and therefore retention gets better (compare the effect of use of retention aid alumen). Conductivities were 187 µS/cm (25 ºC) and 197 µS/cm (25 ºC). It is, however, difficult to know precisely the differences in water when retention sheets were prepared and how much it effects the retention results. Because the measuring instrument was located in another laboratory, there was 5-10 minutes interval between sampling and measurements. That with the cleanness of the bowl created measuring errors.

Pulp batches were under heavy mixing while pulp was taken from it for sheet preparing. Therefore it can be assumed that filler content was even in the pulp.

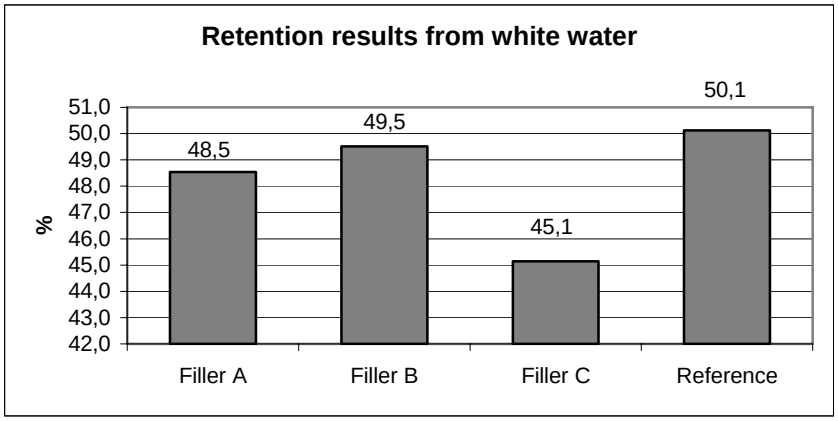

Figure 22 Fillers retention results from white water

The reason that retention was lower when measured from white water (Figure 22) is low retention of the finest particles. In practice, the biggest part of filler that was recycled with wire water was very fine. Retention results from consistency of white water are quite even between reference, and filler B, whereas filler C had poorest retention. Only two studied samples and very low amount of ash (0,02 – 0,03 g) in each created unreliability for this measurement. Also, very small part of filler particles could have gone through the filter paper. However, result from this method looks more reliable than from retention sheets. Both, retention from retention sheets and retention from white water consistency, are shown in Figure 23.

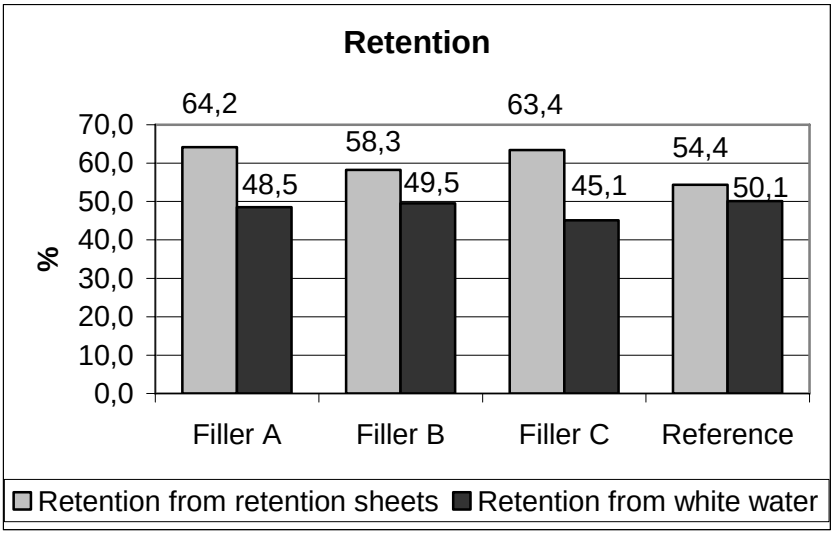

Figure 23 Retention results

6.6 Filler contents in the paper samples

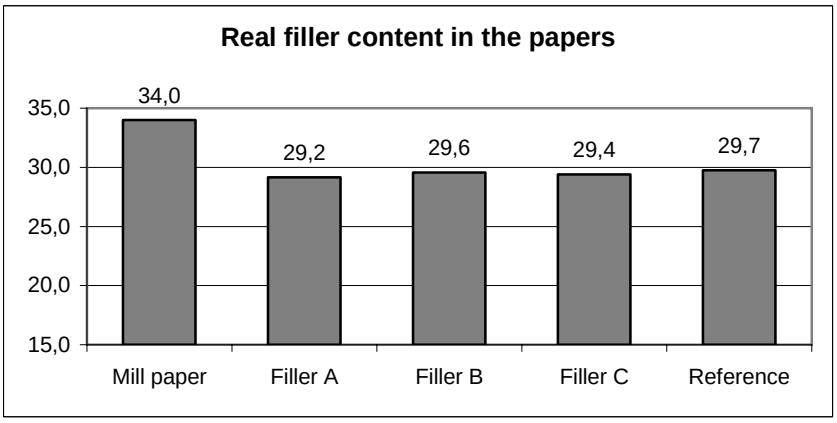

Figure 24 Real filler content in the papers

Filler contents in the papers are shown in the Figure 24. Filler contents were little bit lower than the target value was. Reason for this was lower retention than excepted, resulting in higher consistency in white water and thereby higher low retention fractions lost for overflow. This overflow lost has not been taken into account when filler amount in pulp was calculated. From “retention from white water consistency” -measurements could see that one litre of white water (that were lost per each sheet) included about 0,05 – 0,065g of filler, and that showed couple percent lower content in the sheets than the target was.

6.7 Density

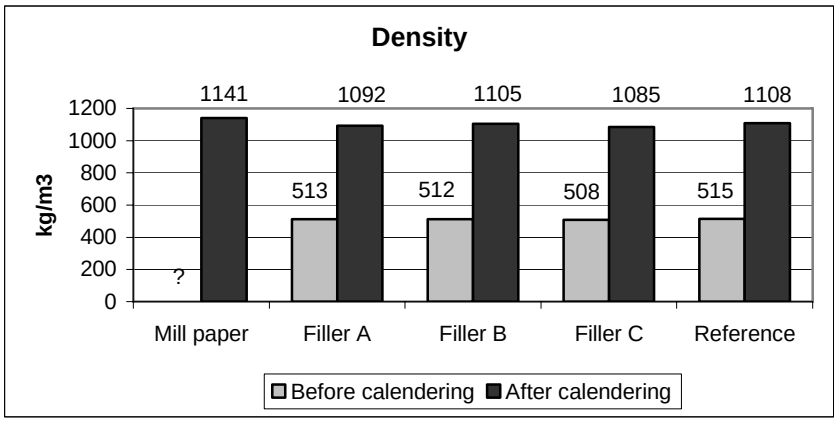

Figure 25 Papers density before and after calendering

Table 8 Changes of thickness caused by calendering

	Mill paper	Filler A	Filler B	Filler C	Reference
Thickness before calendering, µm	?	105,3	105,4	106,2	104,8
Thickness after calendering, µm	47,3	49,4	48,9	49,8	48,7
Change of thickness, %	?	53,0	53,7	53,1	53,5

Table 9 Changes of density caused by calendering

	Filler A	Filler B	Filler C	Reference
Change of density, kg/m³	579,4	593,3	576,3	593,1
Change of density, %	112,9	115,8	113,4	115,1

It can be seen from Figure 25 that laboratory prepared papers did not present appreciable differences between density before calendering nor after calandering.

Naturally there were not either differences between changes of thickness (Table 8) or density (Table 9). Mill paper's higher density can be explained by 4 – 5 % higher filler content and possibly by harder calandering process.

6.8 Optical properties

In this chapter, the following properties are discussed: ISO-brightness, L-value, b-value, light scattering, light absorption and opacity. Other results are shown in Appendix 4.

6.8.1 ISO-brightness, L-value and b-value

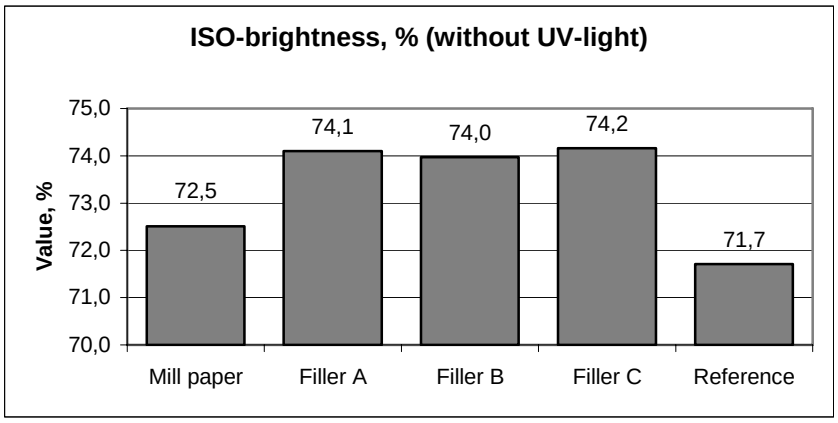

Figure 26 Papers ISO-brightness values (without UV-light)

Fillers A, B and C gave 2,3 – 2,5 % better ISO-brightness to paper than reference filler (Figure 26). Difference in ISO-brightness between reference and mill paper could be explained as follows: the mill paper had four percent more filler than reference, and that could upraise brightness a little bit. Another reason could be related to the pulps storage time. Pulps used for laboratory sheets were prepared over two weeks before using, and even if them had been stored in the fridge, brightness of pulps could have decreased during that time. In addition, used uncleaned pipage water doubtless included metal ions, which also influences pulp brightness.

Figure 27 shows again better brightness values displayed by papers prepared with fillers A, B and C. Because of the colouring by blue colour of the mill paper (Figure 28) its L-value is lower than reference.

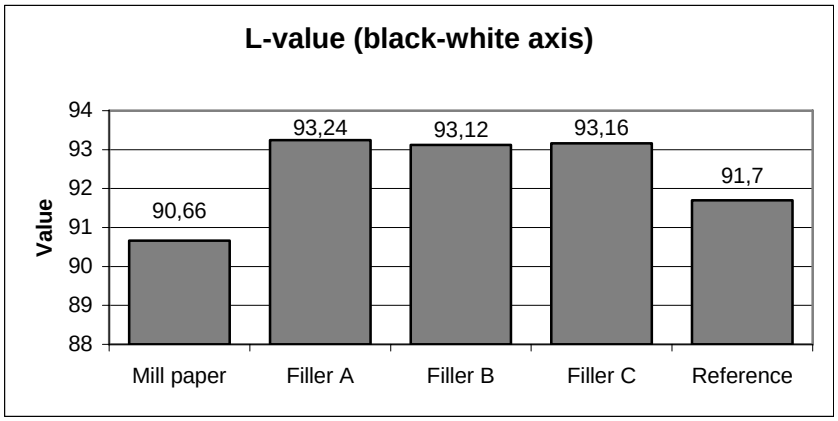

Figure 27 L-values of the papers

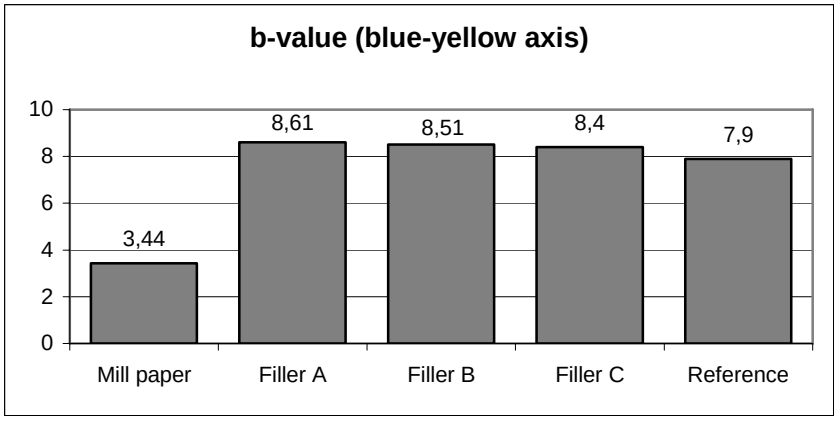

Figure 28 b-values of the papers

6.8.2 Light scattering and light absorption

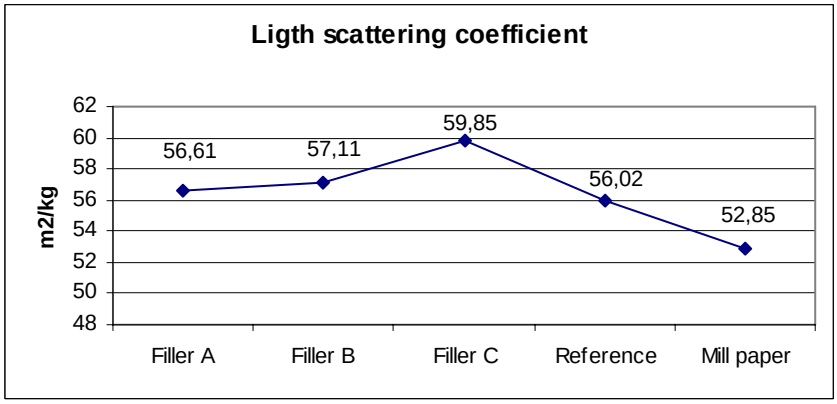

Figure 29 Light scattering coefficients

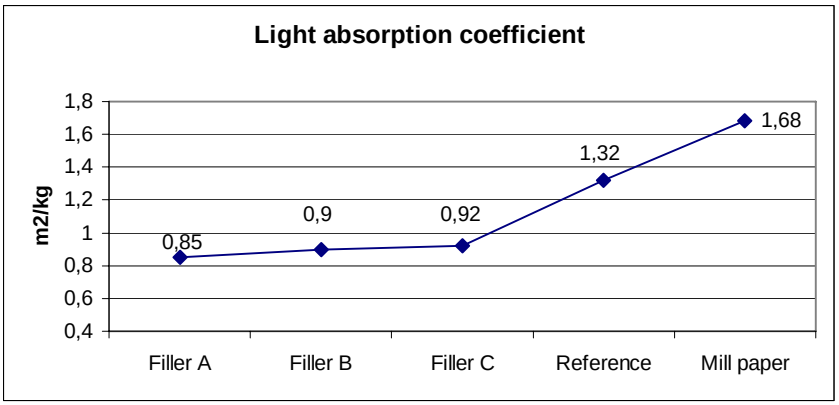

Figure 30 Light absorption coefficients

It can be seen from Figure 29 that with finer filler in the A, B and C series, that higher light scattering coefficients are achieved. This behavior could be explained in therms of the presence of higher number of scattering interfaces in papers prepared with finer filler grades. Better scattering did not appear in brightness values, because at the same time light absorption rose too and compensated the effect to brightness. Light absorption coefficients are shown in Figure 30.

Reason for higher absorption of the mill paper as compared to the reference is that the mill paper was coloured by blue colour and possibly more intensive calendering in the mill than in the lab. Lower light scattering in the mill paper could have occurred in harder wet pressing, higher paper moist in calendering process and also possibly more intensive calendering in the mill. In addition, if chemical pulp content of the mill paper was higher, it would decrease the light scattering. /2/

6.8.3 Opacity

The reason for better opacity of reference (Figure 31) is its higher light absorption (lower brightness). The reason for differences between fillers A, B and C are differences between light scattering and absorption. When one or both of them increase, opacity also increases. In practice, better opacity was overtaken with finer filler. Figures 32 and 33, show the alternations of opacity in function of particle size distribution between fillers A, B and C.

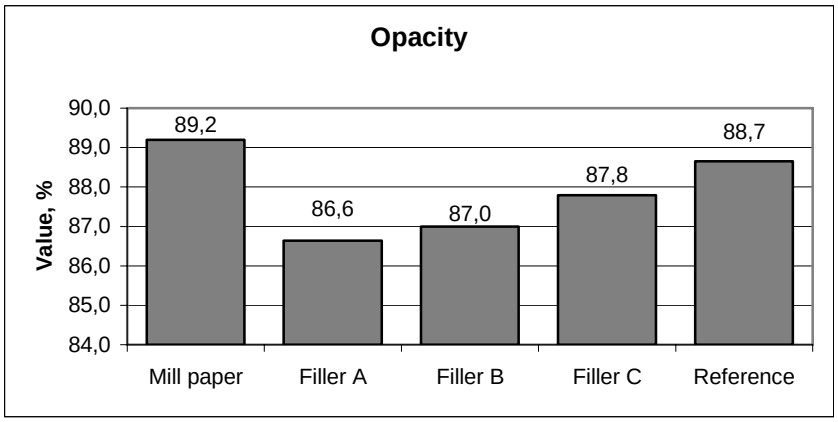

Figure 31 Opacity

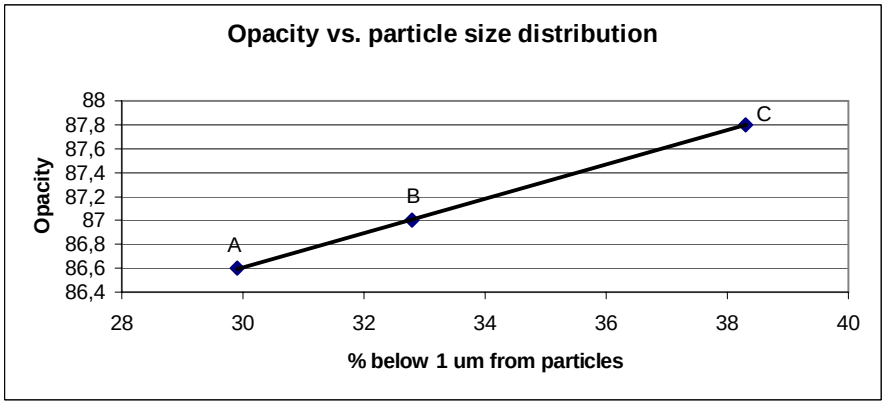

Figure 32 Opacity vs. particle size distribution, (below 1 µm)

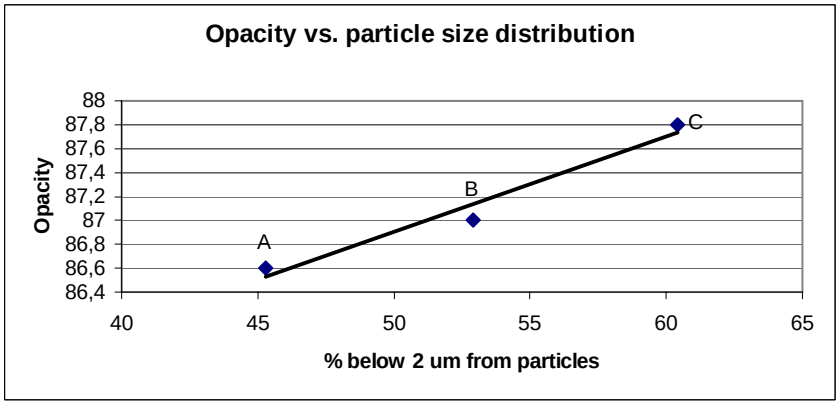

Figure 33 Opacity vs. particle size distribution, (below 1 µm)

6.9 The interdependence of brightness and opacity

The interdependence between opacity and ISO-brightness was approximately 1,38 (opacity change 1,38 % while brightness 1%). Figure 34 shows the prediction how opacity and brightness of paper might change if the brightness of paper is changed by changing the brightness of filler B. The values in the prediction of the mill prepared paper are 0,5 % better for opacity and 0,8 % for ISO-brightness. Those were the differences between the laboratory-prepared paper with reference filler and with mill prepared papers.

Without studying, it is difficult to predict how the change of the brightness of mechanical pulp would affect the interdependence.

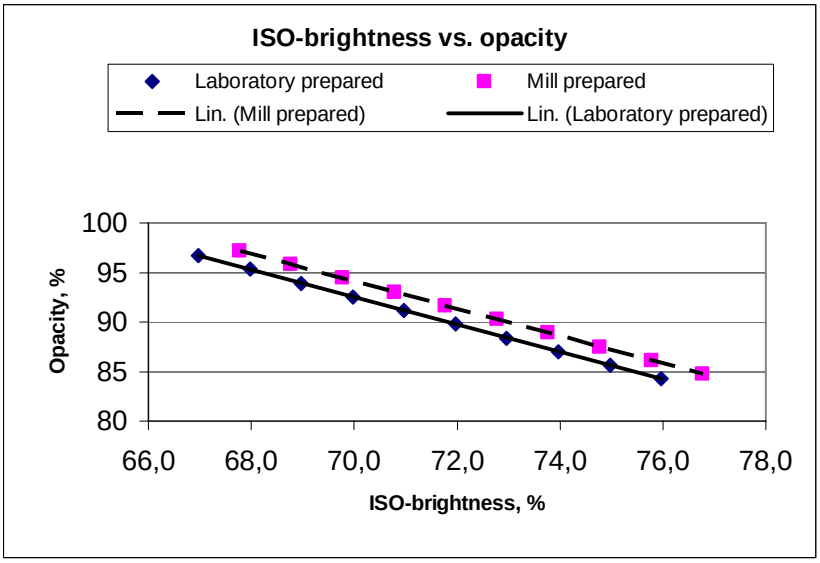

Figure 34 Interdependence of brightness and opacity

6.10 Gloss

Figure 35 Gloss

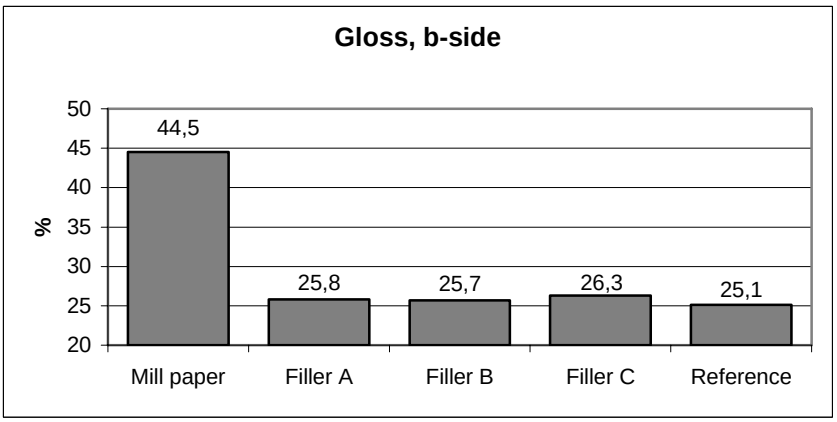

Figure 36 Gloss on the b-side of papers

The laboratory calendar used does not reproduce the mill conditions, therefore it was impossible to get as high gloss in the Lab as the mill paper had. Between different grades there were no differences, but between a- and b-side of the sheets differences occurred. Gloss values are shown in Figures 35 and 36.

6.11 Roughness

Like gloss, also roughness values were even between different grades, and between a- and b-sides there were big differences (Figures 37 and 38). A-side roughness was almost even with roughness of b-side of mill paper.

Reasons for asymmetric surfaces were found in the calender (difference between cylinders), in calendering (wire side against hard cylinder) and in filler z-directional content difference in sheets.

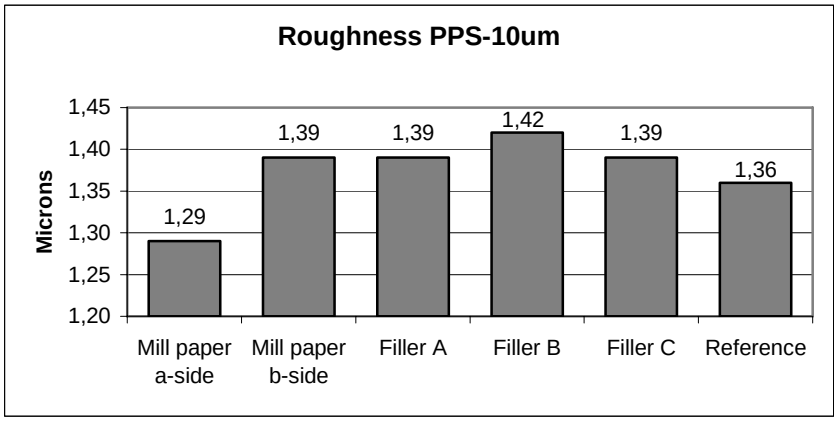

Figure 37 Roughness (on the a-side of laboratory prepared papers)

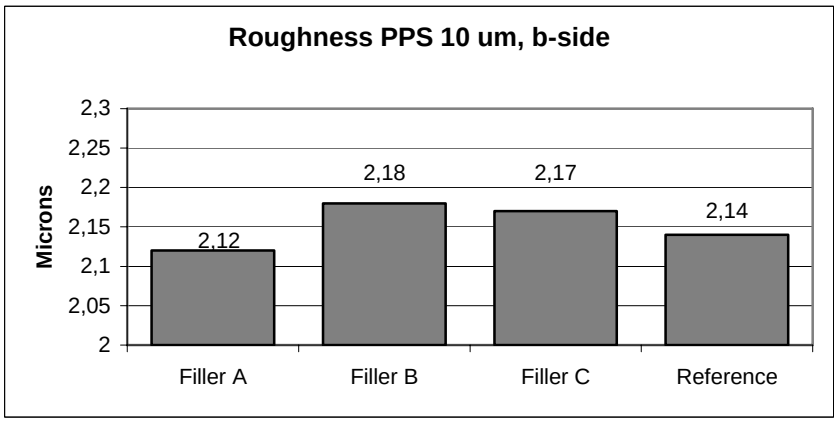

Figure 38 Roughness on the b-side of laboratory prepared papers

6.12 Air permeance

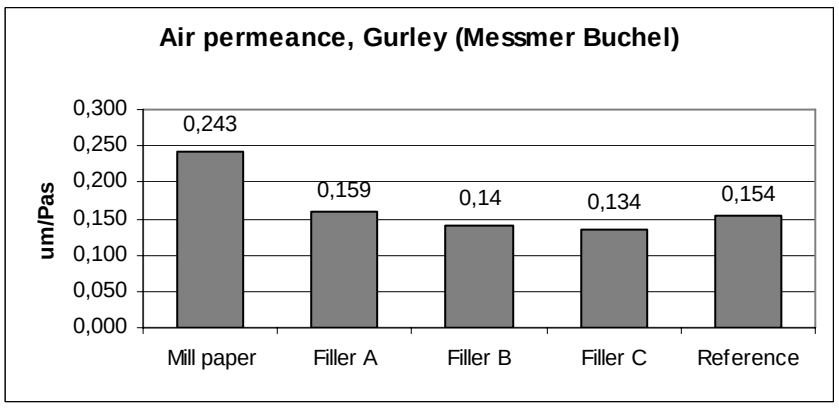

Figure 39 Air permeance, Gurley (Messmer Büchel)

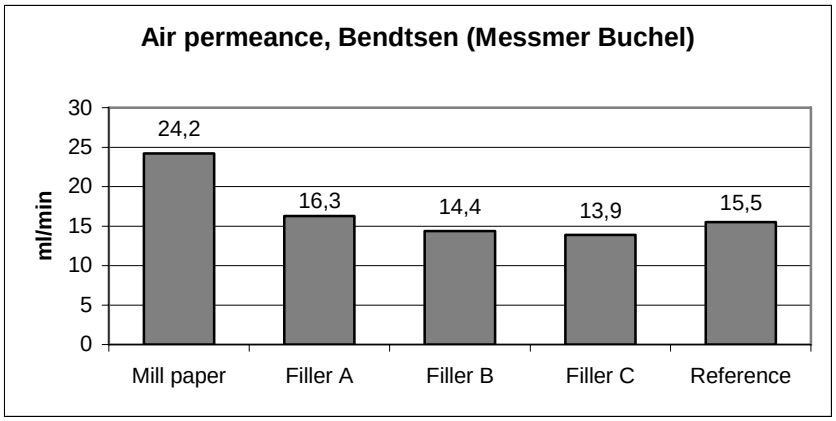

Figure 40 Air permeance, Bendtsen (Messmer Büchel)

The comparison Fillers A, B and C show that filler A presented the highest air permeability whereas filler C had the lowest (Figures 39 and 40). Reference filler's air permeability was between fillers A and B. Air permeance decreased from coarser to finer in the series A,B, C and the lower permeability of the reference compared to filler A could be attributed to 0,4 g/m² higher basis weight in this measurement, and approximately 0,5 % higher filler content. Mill paper had higher air permeance even if it had higher density and higher filler content. The reason for that could be found in fines and filler Z-directional distribution in the sheets. The wire side of laboratory prepared sheets had much higher fines and filler content than upper side, resulting to a higher density and lower pore volume on that side. Because there is a layer where permeability is very low, it results to a lower air permeance.

6.13 Tensile strenght

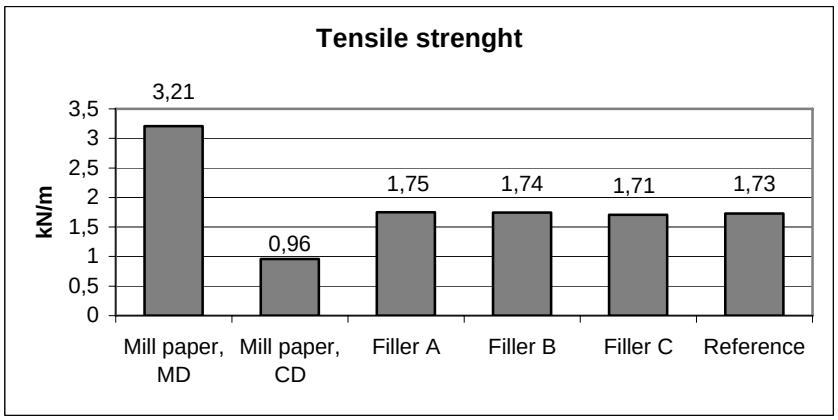

Figure 41 Tensile strenght

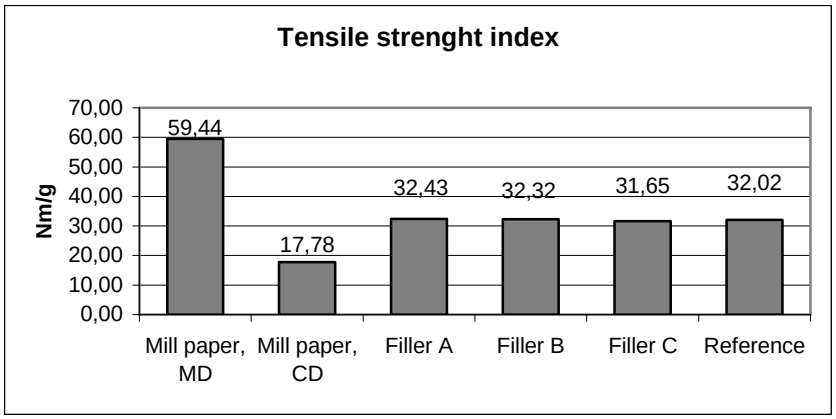

Figure 42 Tensile strenght index

As shown in Figures 41 and 42 laboratory prepared papers did not present notable differences in tensile strength.

6.14 Fracture toughness

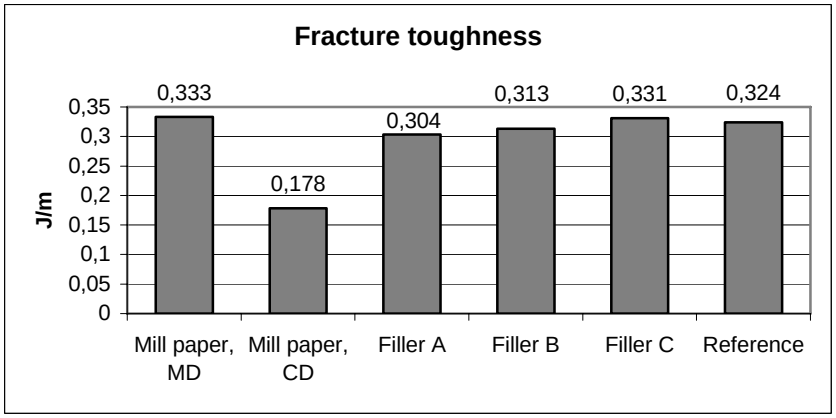

Figure 43 Fracture toughness

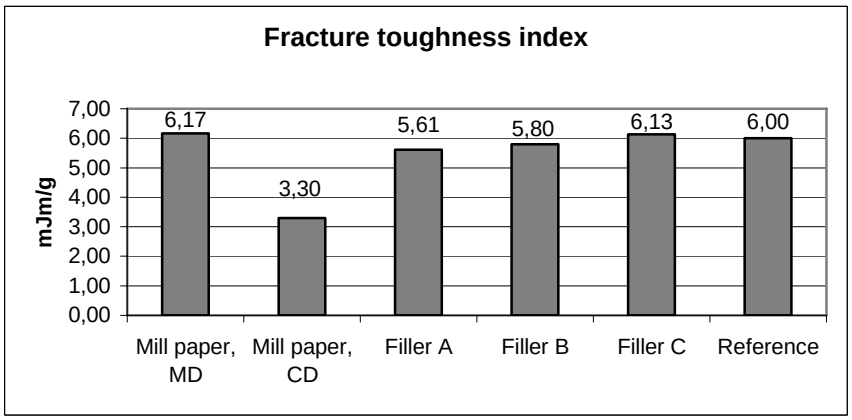

Figure 44 Fracture toughness index

Figures 43 and 44 show that filler C gave better fracture toughness to the paper than other grades. The results also indicate that better fracture is obtained when the filler gets finer in the Fillers A, B, C series.

6.15 Tearing resistance

Results of measurements of tearing resistance are shown in Figure 45 and tearing resistance index in Figure 46. Paper prepared with reference filler had about 20 mN lower tearing resistance than the others. In addition, reference grade did not catch a single time as high value as other grades averages. If reference filler particles are less platy than the others, it could slightly explain that difference. Possibly prototype fillers even possess bonding capability and/or had better effect to the size retention.

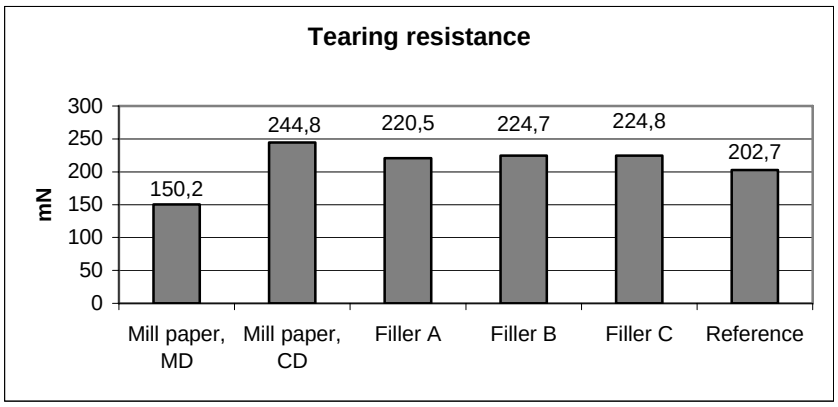

Figure 45 Tearing resistance

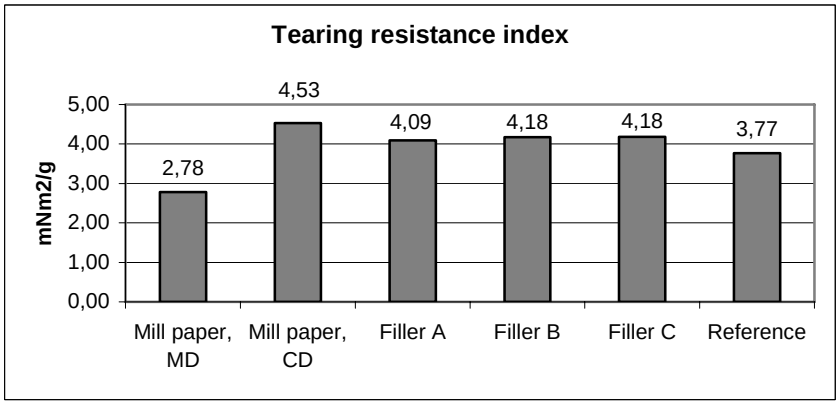

Figure 46 Tearing resistance index

6.16 IGT picking

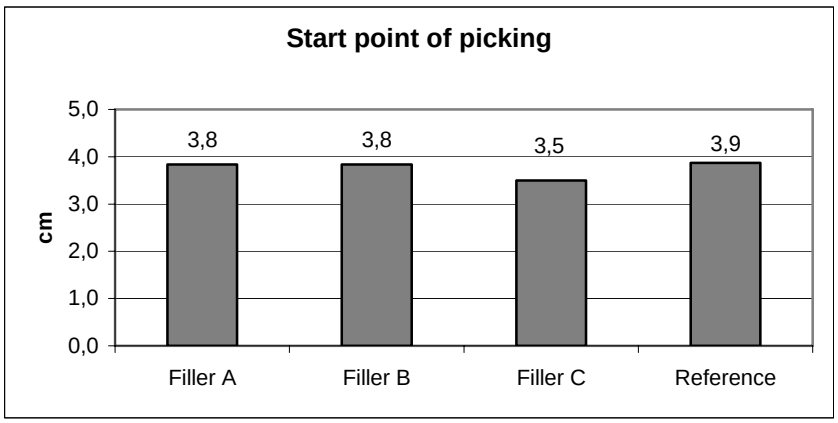

Figure 47 Starting point of picking

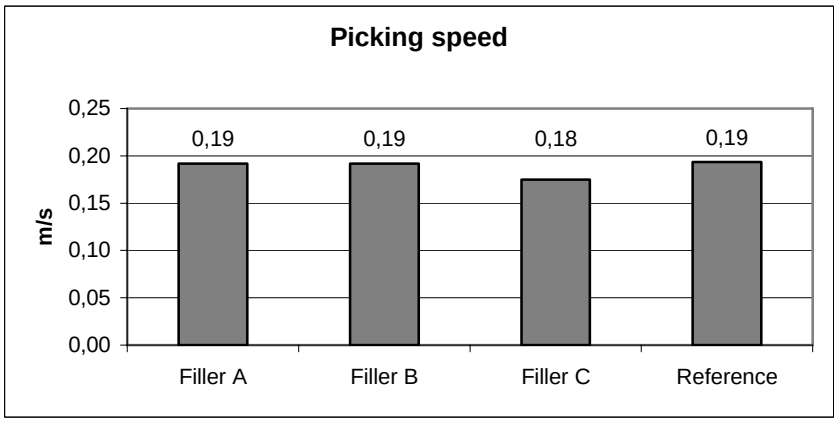

Figure 48 Picking speed

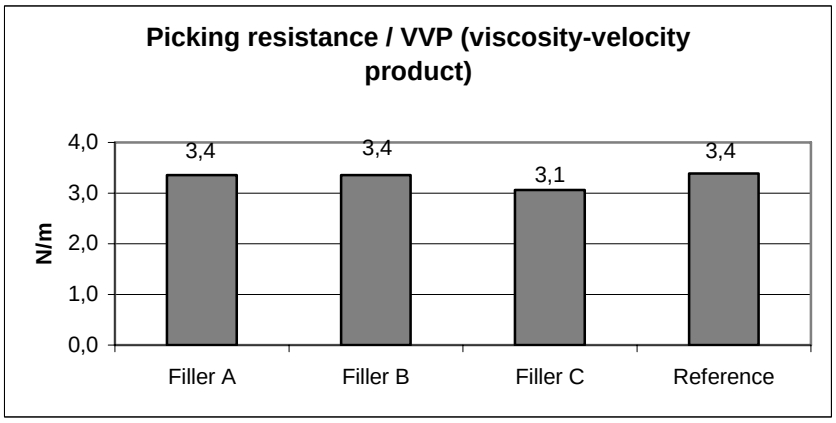

Figure 49 Picking resistance

Examined papers had so low surface strength that IGT picking test did not show any differences between different grades (Figures 47-49).

6.17 IGT linting

From the results of linting test, it could be seen that papers prepared with filler A presented the best surface strength followed by filler B. Surface strengths of papers that were prepared with filler C and with reference filler were almost even. Test results are shown in Tables 10 – 12. Explanations, how grades have pointed in different tables, has been described in chapter 5.2.15

Table 10 Order of superiority of print quality for each printing group

1,5 m/s

Printing group	**1**	**2**	**3**	**4**	**Total**
Filler A	1	3	1	1	**6**
Filler B	2	1	2	3	**8**
Filler C	3	4	4	2	**13**
Reference	4	2	3	4	**13**
2,0 m/s					
Printing group	**1**	**2**	**3**	**4**	**Total**
Filler A	4	1	1	1	**7**
Filler B	3	3	2	2	**10**
Filler C	1	4	4	3	**12**
Reference	2	2	3	4	**11**

Table 11 Order of superiority between in the same position printed samples

2,0 m/s

Printing position	**Filler A**	**Filler B**	**Filler C**	**Reference**
1	1	3	2	4
2	1	3	4	2
3	1	2	4	3
4	2	1	3	4
Total	**5**	**9**	**13**	**13**
1,5 m/s				
Printing position				
1	1	4	3	2
2	2	1	4	3
3	2	1	3	4
4	1	4	2	3
Total	**6**	**10**	**12**	**12**
Total of both	**11**	**19**	**25**	**25**

Table 12 Grades of print quality

1,5 m/s				
Degrees of print quality	**Filler A**	**Filler B**	**Filler C**	**Reference**
	9	8	8	7
	8	8	6	7
	8	9	8	8
	9	8	8	7
Total	**34**	**33**	**30**	**29**
2,0 m/s	6	7	7	7
	9	7	6	8
	9	8	6	7
	9	8	8	5
Total	**33**	**30**	**27**	**27**
Total of both	**67**	**63**	**57**	**56**

6.18 Oil absorption

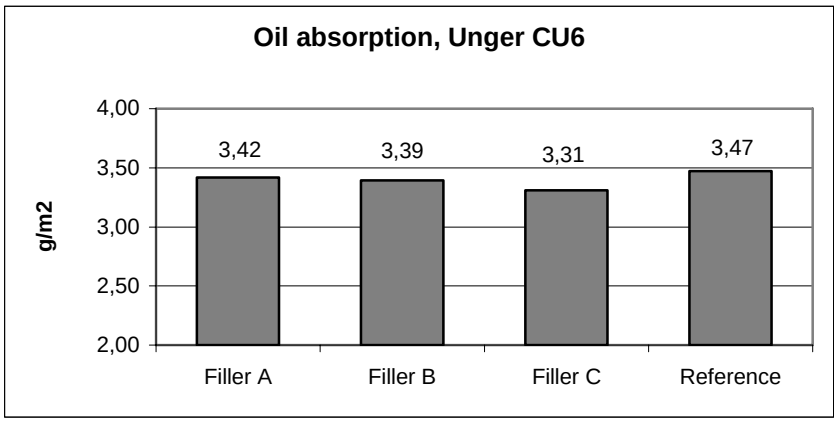

Figure 50 Oil absorption

From results of oil absorption (Figure 50) could be seen that absorption was lowest with finest filler and highest with the roughest one. The reason is the smaller pore volume in the paper surface catch with the finer filler.

7. CONCLUSIONS

The comparison of Fillers A,B,C with the Reference Filler used in this work show that fillers A, B and C improve paper properties such as brightness, tearing resistance and surface strength, but decrease opacity. ISO-brightness increased about 2.5 percentage units while opacity decreased 0.9 – 2.1 percentage units depending on the filler. Tearing resistance increased 20 Nm, which is approximately 10 % more than with reference.

The particle size distribution of the fillers seem to be the variable that most affect paper opacity, surface strength and paper porosity.

Because of the better tearing resistance, freeness of mechanical pulp could possibly be decreased and that would make it possible to increase filler content in the paper. Furthermore, higher filler content would increase paper opacity and brightness. In addition, with higher filler content not even linting should be a problem with fillers A and B which gave better surface strength to paper than reference filler. The retention ability of the filler samples tested could not be properly evaluated and it is still a point that requires further investigation.

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LIST OF APPENDICES

Single results from the measurement of drainage time of the sheets

Drainage times, seconds				
	Filler A	Filler B	Filler C	Reference
	20,38	24,47	21,75	23,91
	20,12	24,44	24,16	28,03
	23,15	25,12	21,28	25,56
	27,31	23,75	22,94	25,72
	27,9	25,44	22,03	25,13
	20,91	25,47	23,16	24,87
	19,62	24,75	22,72	23,03
	21,94	26,69	23,87	24,53
	23,31	22,22	26,07	23,69
	22,44	25,37	25	27,71
	21,53	25,91	24,54	26,79
	23,13	25,35		
	23	22,44		
		24,22		
		25,47		
Average	**22,7**	**24,7**	**23,4**	**25,4**
SD	2,5	1,2	1,5	1,6

Single results from retention measurements

Single retention results from the retention sheets				
	Filler A	**Filler B**	**Filler C**	**Reference**
%	69,2	61,6	65,9	53,9
	59,4	60,1	68,0	53,7
	63,9	57,9	61,6	55,2
	68,7	54,5	59,1	53,9
	59,7	57,3	62,6	55,1
Average	**64,2**	**58,3**	**63,4**	**54,4**
SD	4,7	2,7	3,5	0,7

Single retention results from the white water				
	Filler A	**Filler B**	**Filler C**	**Reference**
%	48,3	49,0	45,9	51,6
	48,7	50,0	44,4	48,7
Average	**48,5**	**49,5**	**45,1**	**50,1**
SD	0,3	0,7	1,1	2,1

Single measurement results from measurement of ash content in the used papers

Single results from ash content measurements				
	Filler A	**Filler B**	**Filler C**	**Reference**
%	29,5	30,0	29,6	29,5
	29,4	28,8	29,5	29,5
	28,6	29,9	29,0	30,3
Average	**29,2**	**29,6**	**29,4**	**29,7**
SD	0,5	0,6	0,3	0,5

Results from measurement of optical properties

Filler A

Results from paper filled by filler A				
	Average	**min**	**max**	**SD**
L* D65/10	**93,24**	93,03	93,38	0,11
a* D65/10	**-1,12**	-1,21	-1,05	0,05
b* D65/10	**8,61**	8,47	8,8	0,13
h D65/10	**97,4**	96,98	98,05	0,3
R457 D65/10 + UV	**73,98**	73,59	74,43	0,32
R457 D65/10 - UV	**74,1**	73,71	74,57	0,32
Fluorescence R457 D65	**-0,12**	-0,55	0,23	0,28
Opacity	**86,64**	85,96	87,23	0,48
Transparency	**22,75**	22,12	23,46	0,51
YI DIN6167 D65/10	**15,33**	15,06	15,65	0,23
WI CIE D65/10 + UV	**43,67**	42,61	44,69	0,77
WI CIE D65/10 - UV	**45,15**	44,06	46,14	0,77
Dominant Wavelenght C/2	**573,7**	573,5	573,8	0,1
Purity C/2	**7,99**	7,83	8,17	0,13
Scattering coefficient	**56,61**	54,63	58,44	1,45
Absorption coefficient	**0,85**	0,82	0,88	0,02
WI CIE C/2 + UV	**44,65**	43,55	45,72	0,77
WI CIE C/2 - UV	**45,15**	44,03	46,16	0,78
L* C/2	**93,49**	93,26	93,63	0,12
a* C/2	**-1,91**	-2	-1,84	0,05
b* C/2	**8,39**	8,24	8,58	0,13
h C/2	**102,85**	102,5	103,47	0,28
YI DIN6167 C/2	**14,47**	14,2	14,79	0,23
R457 C/2 + UV	**74,11**	73,7	74,59	0,33
R457 C/2 - UV	**74,1**	73,71	74,57	0,32
Fluorescence R457 C/2	**0,01**	-0,41	0,37	0,28

Results from measurement of optical properties

Filler B

Results from paper filled by filler B				
	Average	**min**	**max**	**SD**
L* D65/10	**93,12**	92,84	93,33	0,15
a* D65/10	**-1,16**	-1,36	-1,01	0,12
b* D65/10	**8,51**	8,24	8,88	0,2
h D65/10	**97,79**	96,48	99,21	0,91
R457 D65/10 + UV	**73,85**	73,41	74,16	0,26
R457 D65/10 - UV	**73,97**	73,57	74,31	0,25
Fluorescence R457 D65	**-0,13**	-0,45	0,12	0,21
Opacity	**87**	84,46	87,66	0,71
Transparency	**22,49**	21,79	25,15	0,75
YI DIN6167 D65/10	**15,12**	14,62	15,89	0,41
WI CIE D65/10 + UV	**43,82**	42,59	45,01	0,76
WI CIE D65/10 - UV	**45,34**	44,01	46,44	0,74
Dominant Wavelenght C/2	**573,6**	573,1	574	0,3
Purity C/2	**7,9**	7,65	8,22	0,17
Scattering coefficient	**57,11**	50,15	59,2	2,05
Absorption coefficient	**0,9**	0,79	0,93	0,03
WI CIE C/2 + UV	**44,85**	43,39	46,08	0,8
WI CIE C/2 - UV	**45,37**	43,94	46,51	0,77
L* C/2	**93,36**	93,08	93,57	0,16
a* C/2	**-1,95**	-2,14	-1,83	0,1
b* C/2	**8,27**	7,99	8,68	0,21
h C/2	**103,26**	101,93	104,71	0,91
YI DIN6167 C/2	**14,25**	13,77	15,06	0,42
R457 C/2 + UV	**73,98**	73,56	74,31	0,25
R457 C/2 - UV	**73,97**	73,57	74,31	0,25
Fluorescence R457 C/2	**0,01**	-0,31	0,27	0,21

Results from measurement of optical properties

Filler C

Results from paper filled by filler C				
	Average	**min**	**max**	**SD**
L* D65/10	**93,16**	92,96	93,34	0,12
a* D65/10	**-1,1**	-1,23	-0,99	0,07
b* D65/10	**8,4**	8,16	8,64	0,15
h D65/10	**97,44**	96,77	98,39	0,44
R457 D65/10 + UV	**74,04**	73,49	74,36	0,24
R457 D65/10 - UV	**74,16**	73,61	74,48	0,24
Fluorescence R457 D65	**-0,12**	-0,35	0,39	0,21
Opacity	**87,79**	87,2	88,34	0,38
Transparency	**21,6**	21	22,24	0,41
YI DIN6167 D65/10	**14,98**	14,6	15,38	0,26
WI CIE D65/10 + UV	**44,45**	43,36	45,38	0,64
WI CIE D65/10 - UV	**45,9**	44,85	46,83	0,63
Dominant Wavelenght C/2	**573,7**	573,4	573,9	0,1
Purity C/2	**7,79**	7,57	7,99	0,14
Scattering coefficient	**59,85**	57,94	61,74	1,28
Absorption coefficient	**0,92**	0,89	0,95	0,02
WI CIE C/2 + UV	**45,43**	44,44	46,34	0,62
WI CIE C/2 - UV	**45,91**	44,86	46,83	0,63
L* C/2	**93,41**	93,22	93,58	0,12
a* C/2	**-1,87**	-1,99	-1,76	0,07
b* C/2	**8,17**	7,94	8,41	0,15
h C/2	**102,88**	102,27	103,84	0,44
YI DIN6167 C/2	**14,13**	13,79	14,52	0,25
R457 C/2 + UV	**74,19**	73,68	74,47	0,22
R457 C/2 – UV	**74,16**	73,61	74,48	0,24
Fluorescence R457 C/2	**0,03**	-0,22	0,53	0,21

Results from measurement of optical properties

Reference

Results from paper filled by reference filler				
	Average	**min**	**max**	**SD**
L* D65/10	**91,7**	91,42	91,89	0,16
a* D65/10	**-1,28**	-1,39	-1,14	0,06
b* D65/10	**7,9**	7,58	8,11	0,14
h D65/10	**99,21**	98,12	99,99	0,49
R457 D65/10 + UV	**71,61**	70,89	71,99	0,35
R457 D65/10 - UV	**71,71**	71	72,13	0,34
Fluorescence R457 D65	**-0,1**	-0,19	0,64	0,32
Opacity	**88,65**	87,41	89,31	0,53
Transparency	**21,97**	21,21	23,35	0,6
YI DIN6167 D65/10	**14,11**	13,54	14,57	0,26
WI CIE D65/10 + UV	**42,94**	41,51	44,15	0,7
WI CIE D65/10 - UV	**44,44**	43,06	45,63	0,69
Dominant Wavelenght C/2	**573,2**	572,9	573,5	0,1
Purity C/2	**7,45**	7,09	7,64	0,16
Scattering coefficient	**56,02**	52,43	58,15	1,59
Absorption coefficient	**1,32**	1,23	1,37	0,04
WI CIE C/2 + UV	**44,07**	42,64	45,2	0,7
WI CIE C/2 - UV	**44,58**	43,16	45,79	0,7
L* C/2	**91,92**	91,65	92,12	0,16
a* C/2	**-1,98**	-2,09	-1,86	0,06
b* C/2	**7,64**	7,34	7,85	0,13
h C/2	**104,49**	103,47	105,33	0,48
YI DIN6167 C/2	**13,25**	12,72	13,68	0,25
R457 C/2 + UV	**71,74**	71,05	72,17	0,34
R457 C/2 - UV	**71,71**	71	72,13	0,34
Fluorescence R457 C/2	**0,03**	-0,06	0,78	0,32

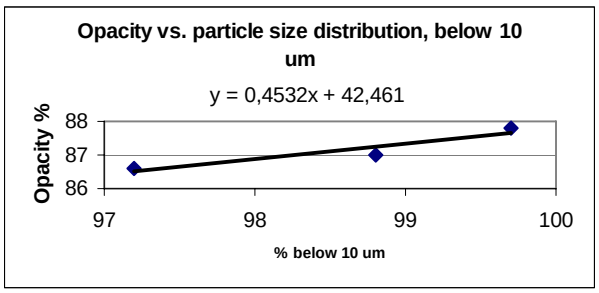
Results from measurement of optical properties

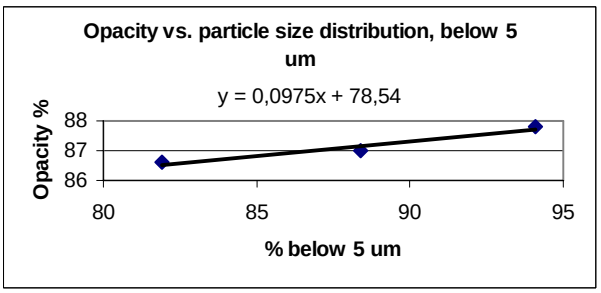
Mill paper

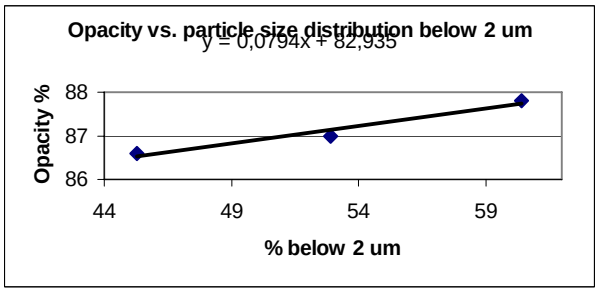
Results from mill paper				
	Average	**min**	**max**	**SD**
L* D65/10	**90,66**	90,54	90,74	0,07
a* D65/10	**-0,99**	-1,01	-0,97	0,01
b* D65/10	**3,44**	3,37	3,54	0,06
h D65/10	**106,11**	105,47	106,55	0,41
R457 D65/10 + UV	**74,8**	74,47	74,99	0,17
R457 D65/10 - UV	**72,51**	72,21	72,72	0,17
Fluorescence R457 D65	**2,3**	2,2	2,6	0,14
Opacity	**89,2**	88,41	90,12	0,55
Transparency	**22,3**	21,2	23,22	0,64
YI DIN6167 D65/10	**6,06**	5,9	6,25	0,13
WI CIE D65/10 + UV	**61,4**	60,76	61,8	0,34
WI CIE D65/10 - UV	**53,92**	53,33	54,63	0,39
Dominant Wavelenght C/2	**573,4**	573,3	573,5	0,1
Purity C/2	**3,66**	3,6	3,77	0,05
Scattering coefficient	**52,85**	50,66	55,64	1,6
Absorption coefficient	**1,68**	1,61	1,77	0,05
WI CIE C/2 + UV	**59,74**	59,14	60,11	0,33
WI CIE C/2 - UV	**55,21**	54,61	55,85	0,37
L* C/2	**90,67**	90,56	90,75	0,07
a* C/2	**-0,94**	-0,97	-0,92	0,01
b* C/2	**3,74**	3,68	3,85	0,06
h C/2	**104,15**	103,74	104,46	0,25
YI DIN6167 C/2	**6,75**	6,65	6,96	0,11
R457 C/2 + UV	**73,84**	73,53	74,02	0,16
R457 C/2 - UV	**72,51**	72,21	72,72	0,17
Fluorescence R457 C/2	**1,33**	1,24	1,66	0,15

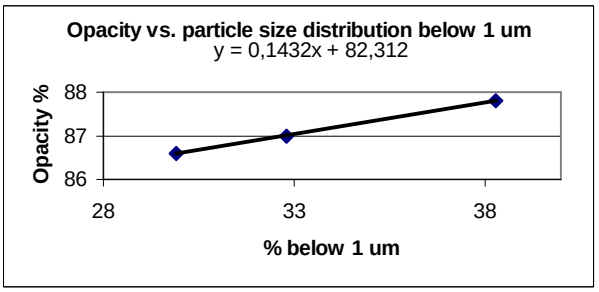
The interdependence of brightness and opacity

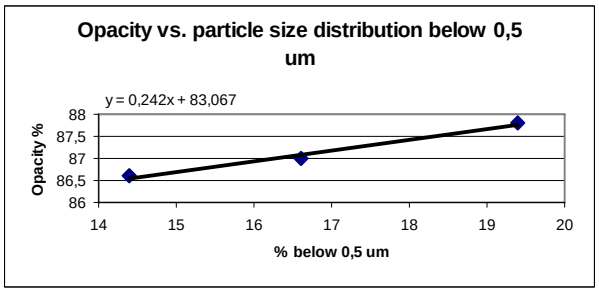
Alternations between opacity and particle size distribution

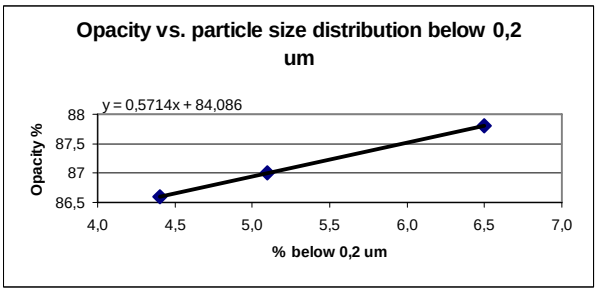












Results from each formula when “x” is replaced by the amount (%) of reference filler’s particles below specified dimension

Prediction of opacity	
10 µm	85,2
5 µm	85,5
2 µm	85,7
1 µm	85,3
0,5 µm	85,5
0.2 µm	85,9
Average	**85,5**
SD	0,3

Single results from gloss measurements

%	Mill paper		Filler A		Filler B		Filler C		Reference	
	A-side	B-side	A-side	B-side	A-side	B-side	A-side	B-side	A-side	B-side
	46,5	44,7	37,7	26,2	39,3	26,3	37	26,1	38,4	24
	46,5	43,9	36,8	25,6	40	30,3	37,5	26,6	38,5	25,5
	45,9	42,3	36,9	24,8	37,3	27	36,1	24	38,3	25,9
	46,7	45,2	39,1	25,9	34,5	25	36,4	21,8	38,7	25,4
	48,3	44,8	38,7	23,6	36,3	24,5	34,6	23,4	38,7	26,4
	45,4	44,5	35	24,1	37,5	26,4	34,8	24,2	37,7	24,6
	46,4	45,2	37,8	25,7	36,5	26,4	38,2	26,9	39,6	24,7
	44,6	45,1	37	26	36,5	25,9	36,2	26,4	38,1	24,2
	45,3	42,6	35,5	26,2	35,3	23	38,9	28,2	38,6	24,7
	46,5	43	37	25	36,9	24,6	34,7	23,5	39,1	23,9
	45,9	45,1	38,2	26,3	35,3	23,4	36,2	24,4	37,7	26,9
	45,9	44,8	38,5	27,8	38	24,1	38,4	26,1	36,6	25,5
	45,8	45,7	35,5	25,5	35	25,3	36,3	24,3	37,6	26,3
	45,5	46,8	38,3	25,8	36,5	27,5	36,8	23,2	38,6	28,1
	46,4	44,7	38,2	25,5	36,1	27,2	36,5	25,9	35,8	23,1
	46,5	43,8	38,3	25,3	36	25,2	37,7	25,4	39,2	25,6
	45,8	45,1	40	26,7	38,3	25,2	37,9	25,6	38,7	25,2
	45,3	43,9	37,6	26,9	36	25	34,3	25,8	38	26,6
	46,8	44	37,3	25,9	37,5	22	37,8	27,9	39,2	25,4
	44,5	44,6	39,1	26,2	36,2	24,7	37,3	26	38,5	25,9
	46,7	43,3	37,2	26,2	39,6	29,7	39,1	26,5	37,2	24,6
	46,4	43,1	38,7	28,5	38,4	25,9	37,3	24,2	35,3	23,5
	45,4	43,2	37,7	25,3	37,5	26,4	35,1	24,2	36,1	22,7
	45,4	42,1	38,6	24,4	38,9	27	38,2	24,7	36,7	23,2
	44,3	45,2	35,9	23,1	38	25,1	36,3	23,3	36	23
	45	44,2	37,4	24,5	40	26,7	35,1	24,8	35,5	22,5
	44,4	41,7	36,5	21,1	39,1	26,3	37,8	27,2	35,1	22,6
	45,1	45,6	36,6	25,2	38,9	26,3	37,1	27,7	38,5	26,6
	45,7	46,1	35,9	24,2	39,2	25,7	37,3	26,5	37,4	24,4
	46,6	45,1	35,3	22,5	39,1	24,5	37,1	26	38,2	25
	46	45,1	39,2	26,7	38,4	25	38,5	29,6	39,2	26,2
	44,6	44,2	36,3	26,7	35,7	23,5	35	26,4	37,8	24,6
	45	45	34,4	26,6	37,3	25,4	38,5	27,4	37,9	24,4
	46,3	46,1	36,3	22,1	39,9	24,5	38,5	27	37,5	25,6
	45,8	46,2	37,9	26,3	36,7	25,3	39,1	28,1	37,3	25,9
			36,9	24,8	36,8	24,5	36,9	28,5	39,5	25,9
			36,9	24,7	40,1	25,8	38,6	25,4	38,5	25,4
			36	25,3	37,7	25,1	36,8	26,5	38,2	27,1
			36,4	23,8	38,9	26,5	38,1	28	39,7	26,3
			37,7	27,8	36,3	23,7	37,1	29,5	38,9	25,1
			37,3	26,7	37	26,1	41	29,2	37,5	25,2
			35,8	27,7	41,5	29	38,8	29,2	39,1	26,1
			37	26,3	37,6	26,2	37,8	26,6	39,6	27
			37,7	25,5	37,7	25,6	38,7	26,5		
			36,5	27,3	37	25,7	39,7	27,6		
			38,3	26,2	38,2	26,8	40,3	28,3		
			38,5	28,1	37,2	25	40,4	30,1		
			38,6	27,2	40	27,7				
			38,7	30,5	36	25				
			37,2	28	38,9	26,1				
Average	**45,8**	**44,5**	**37,3**	**25,8**	**37,7**	**25,7**	**37,4**	**26,3**	**38,0**	**25,1**
SD	0,8	1,2	1,2	1,7	1,6	1,5	1,6	1,9	1,2	1,3

Single results from roughness measurements

µm	Mill paper		Filler A		Filler B		Filler C		Reference	
	A-side	B-side	A-side	B-side	A-side	B-side	A-side	B-side	A-side	B-side
	1,26	1,34	1,36	2,17	1,39	2,07	1,33	2,37	1,39	2,2
	1,28	1,39	1,31	2,3	1,49	1,98	1,33	2,32	1,36	2,16
	1,29	1,4	1,33	2,14	1,42	2,19	1,35	2,37	1,37	2,12
	1,25	1,34	1,34	2,2	1,45	2,1	1,38	2,23	1,36	2,11
	1,36	1,43	1,35	2,16	1,44	2,2	1,37	2,27	1,31	2,04
	1,27	1,41	1,32	2,08	1,49	2,27	1,33	2,15	1,32	2,06
	1,29	1,37	1,42	2,11	1,44	2,24	1,31	2,13	1,3	2,19
	1,28	1,41	1,45	2,06	1,36	2,03	1,38	2,18	1,35	2,1
	1,32	1,41	1,43	2,25	1,42	2,04	1,37	2,18	1,33	2,08
	1,27	1,41	1,34	2,05	1,34	2,15	1,46	2,36	1,37	2,14
	1,34	1,36	1,4	2,08	1,42	2,23	1,52	2,4	1,41	2,08
	1,26	1,43	1,38	2,1	1,42	2,29	1,42	2,26	1,38	2,36
	1,3	1,38	1,46	2,16	1,47	2,37	1,39	2,18	1,31	2,13
	1,28	1,39	1,4	2,15	1,4	2,21	1,43	2,16	1,35	1,9
	1,28	1,36	1,44	2,18	1,33	2	1,42	2,27	1,37	2,29
	1,29	1,39	1,36	2,02	1,32	2,12	1,32	2,21	1,35	2,19
	1,27	1,41	1,36	2,03	1,39	2,11	1,38	2,17	1,46	2,14
		1,39	1,44	2,15	1,41	2,07	1,39	2,13	1,57	2,11
			1,37	2,02	1,37	2,18	1,41	2,16	1,45	2,12
			1,4	2,12	1,37	2,06	1,35	2,19	1,39	2,14
			1,48	2,06	1,48	2,12	1,46	2,23	1,43	2,19
			1,41	2,15	1,58	2,13	1,45	2,23	1,39	2,15
			1,53	2,22	1,52	2,23	1,41	2,24	1,39	2,26
			1,52	2,24	1,46	2,19	1,43	2,25	1,35	2,29
			1,44	2,19	1,47	2,13	1,4	2,32	1,33	2,32
			1,49	2,27	1,41	2,3	1,34	2,36	1,32	2,35
			1,43	2,19	1,38	2,28	1,38	2,18	1,37	2,32
			1,4	2,25	1,45	2,29	1,32	2,12	1,26	2,01
			1,41	2,37	1,39	2,23	1,33	2,1	1,38	2,15
			1,41	2,16	1,41	2,25	1,33	2,05	1,28	2,14
			1,39	2,06	1,41	2,18	1,37	1,95	1,37	2,07
			1,46	2,08	1,39	2,19	1,41	2,12	1,3	2,1
			1,39	2,08	1,4	2,11	1,39	2,1	1,29	2,18
			1,25	2,04	1,51	2,2	1,48	2,04	1,33	2,11
			1,32	2,18	1,42	1,98	1,47	2,21	1,33	2,07
			1,35	2,22	1,41	2,19	1,52	2,15	1,38	2,14
			1,34	2,18	1,43	2,18	1,45	2,19	1,3	2,12
			1,37	2,2	1,4	2,1	1,4	2,08	1,32	2,01
			1,4	2,04	1,35	2,17	1,36	2,01	1,32	2,04
			1,32	2,04	1,48	2,11	1,37	1,97	1,32	2,1
			1,38	2,03	1,46	2,16	1,39	2,01	1,32	2,12
			1,41	2,15	1,36	2,21	1,45	2,13	1,36	2,08
			1,38	2,14	1,43	2,37	1,43	2,1		2,08
			1,35	1,98	1,45	2,33	1,4	2,11		
			1,37	2,05	1,31	2,35	1,41	2,03		
			1,35	1,96	1,33	2,33	1,37	2,02		
			1,36	2,08						
			1,45	1,88						
			1,38	2,08						
Average	**1,29**	**1,39**	**1,39**	**2,12**	**1,42**	**2,18**	**1,39**	**2,17**	**1,36**	**2,14**
SD	0,03	0,03	0,06	0,09	0,06	0,10	0,05	0,11	0,06	0,10

Single results from Gurley (Messmer Büchel) measurements

seconds / 100 ml	Mill paper	Filler A	Filler B	Filler C	Reference
	518,6	875,2	897,6	920,6	833,8
	518,1	714,8	785,7	927,2	788,2
	527,9	923,5	953,6	1032	736,8
	510,1	897,8	749,2	932,2	805,5
	512,5	968,8	797,6	935,8	843,3
	547,3	896,1	788,1	1110	793,6
	471,6	803	849,3	1020	822
	543,2	815,4	913,7	1271	762,1
	488,2	862,6	750,8	1075	781
	554,5	1034	950,6	1144	831,3
	564,3	850,3	802,5	1121	758,9
	516,8	987	781,6	812,3	821,1
	542,4	921,7	938,2	1040	897,1
	462,6	886	1188	955,6	750
	567,6	978,6	965,8	742,1	921,3
	502,4	871,2	881,1	868	791
	468,3	845,7	934,7	881,5	677,4
	546,1	913,5	938,8	1074	680,4
	523,9	862,1	1031	1051	781,3
	536,8	859,9	844,1	990,4	796,7
	596,7	870,2	900,6	910	756,3
	583,3	766,5	933,8	888,7	900,8
	533,3	754,7	921,3	973	908,9
	523,7	775,8	834,8	826,1	904,6
	502,3	820,9	947,1	829,9	911,2
	500	790,5	916,6	871,5	865
	513,3	819,3	938,5	1020	877,8
	577,1	814,9	1008	950,8	817,1
	465,8	685,8	1007	993,4	796,8
	513,6	801,9	1042	972,6	1007
	540,7	725	787,9	902,5	903,2
	567,1	833,3	819,5	932,9	923,6
	534,1	735,8	913,4	1078	927,7
	474	772,8	912,7	906,1	874,8
	592,7	749,7	924,7	984	843,9
	517,4	857,1	841,7	788	841,1
	529,3	792,3	830,7	980,3	832
	529,7	674,7	914,6	954,8	842,7
		678,5	934,9	927	884,7
		758,3	880,9	873,5	844,6
		696,8	1038	827,8	774,4
		693,6	998,7	1156	791,5
		658,8	839,9	898	728,9
		612,2	839,9	841,3	
		617,7	946,1	848	
		727,5	815,7	858,8	
		688,1	979,1		
		680,7	1195		
		796,4	1090		
Average	**526,8**	**804,4**	**912,1**	**954,3**	**828,6**
SD	34,4	98,7	99,5	108,3	69,6
Air permeance, µm/Pas	**0,243**	**0,159**	**0,14**	**0,134**	**0,154**
Ave. Basis weight, g/m²	54	54,1	54,4	54	54,5

Measurement results from Bendtsen (Messmer Büchel) measurements

ml / min	Mill paper	Filler A	Filler B	Filler C	Reference
	23,85	18,53	14,54	15,06	15,71
	24,78	16,8	14,19	14,56	15,02
	24,05	15,65	14,6	14,06	15,81
	24,16	15,69	15,6	12,95	15,43
		14,65	12,88	12,87	
Average	**24,2**	**16,3**	**14,4**	**13,9**	**15,5**
SD	0,4	1,5	1,0	1,0	0,4

Results from tensile strenght measurements

	Mill paper							
	MD	**CD**	**MD/CD**		**Filler A**	**Filler B**	**Filler C**	**Reference**
Maximum strenght, N	**48,2**	**14,3**	3,36		**26,2**	**26,1**	**25,6**	**25,92**
cv, %	4,34	5,06			6,73	5,97	4,36	6,33
Tensile strenght, kN/m	**3,21**	**0,96**	3,36		**1,75**	**1,74**	**1,71**	**1,73**
cv, %	4,34	5,06			6,73	5,97	4,36	6,33
Tens. strenght index Nm/g	**59,49**	**17,7**	3,36		**32,43**	**32,32**	**31,65**	**32,02**
cv, %	4,34	5,06			6,73	5,97	4,36	6,33
Breaking lenght, km	**6,07**	**1,8**	3,36		**3,3**	**3,28**	**3,22**	**3,26**
cv, %	4,34	5,06			6,73	5,97	4,36	6,33
stretch, mm	**1,15**	**1,76**	0,65		**2,09**	**2,12**	**1,96**	**2**
cv, %	7,31	10,36			12,7	10,57	10,97	10,68
stretch, %	**1,15**	**1,76**	0,65		**2,09**	**2,12**	**1,96**	**2**
cv, %	7,31	10,36			12,7	10,57	10,97	10,68
Breaking energy, J/m2	**22,33**	**11,58**	1,93		**24,47**	**24,95**	**22,47**	**23,28**
cv, %	11,75	15,78			19,48	15,96	14,98	16,47
Breaking energy index, mJ/g	**413,55**	**214,4**	1,93		**453,14**	**462,15**	**416,13**	**431,07**
cv, %	11,75	15,78			19,48	15,96	14,98	16,47
Elastic modulus, Gpa	**94,474**	**30,69**	3,08					
cv, %	2,53	4,6						
Tensile stiffness, kN/m	**444**	**144,2**	3,08		**221,9**	**228,3**	**232,3**	**239,3**
cv, %	2,53	4,6			4,07	5,03	4,12	4,91
Tensile stiffness index, kNm/g	**8,22**	**2,67**	3,08		**4,11**	**4,23**	**4,3**	**4,43**
cv, %	2,53	4,6			4,07	5,03	4,12	4,91

Results from fracture toughness measurements

	Mill paper							
	MD	**CD**	**MD/CD**		**Filler A**	**Filler B**	**Filler C**	**Reference**
Maximum strenght, N	**64,3**	**26,2**	2,45		**41,8**	**42,6**	**41,5**	**41,4**
cv, %	5,28	1,85			5,01	4,35	4,95	1,94
Tensile strenght, N/m	**1290**	**520**	2,45		**835,00**	**852**	**830,00**	**828**
cv, %	5,28	1,85			5,01	4,35	4,95	1,94
Tens. strenght index Nm/g	**23,81**	**9,71**	2,45		**15,48**	**15,77**	**15,36**	**15,34**
cv, %	5,28	1,85			5,01	4,35	4,95	1,94
Breaking lenght, km	**2,43**	**0,99**	2,45		**1,58**	**1,6**	**1,57**	**1,57**
cv, %	5,28	1,85			5,01	4,35	4,95	1,94
stretch, mm	**0,45**	**0,67**	0,68		**0,71**	**0,7**	**0,68**	**0,69**
cv, %	8,07	10,37			5,57	5,6	5,94	5,59
stretch, %	**0,45**	**0,67**	0,68		**0,71**	**0,7**	**0,68**	**0,69**
cv, %	8,07	10,37			5,57	5,6	5,94	5,59
Fracture toughness, J/m	**0,333**	**0,178**	1,88		**0,304**	**0,313**	**0,331**	**0,324**
cv, %	15,71	20,23			9,03	9,66	11,87	9,57
Fract. toughn. index mJm/g	**6,18**	**3,29**	1,88		**5,61**	**5,8**	**6,13**	**6**
cv, %	15,71	20,23			9,03	9,66	11,87	9,57

Single results from tearing resistance measurements

mN	Mill paper					
	MD	CD	Filler A	Filler B	Filler C	Reference
	152	242	204	230	242	201
	154	256	210	220	218	210
	142	252	222	228	212	180
	158	250	238	228	218	218
	164	260	222	222	240	216
	150	240	220	230	240	200
	140	248	216	230	230	214
	142	230	224	220	222	204
	150	240	232	228	224	200
	150	230	238	232	220	200
			222	222	222	198
			210	230	226	200
			220	214	216	182
			212	220	222	212
			218	216	220	206
Average	**150,2**	**244,8**	**220,5**	**224,7**	**224,8**	**202,7**
SD	7,5	10,2	9,8	5,8	9,2	11,0

Single results from IGT picking test

cm	Filler A	Filler B	Filler C	Reference
	3,3	3,6	3,5	5,2
	4,2	3,4	3	3,7
	4,8	3,6	3,1	4,1
	2,8	3,5	4	3,5
	3,6	4,4	4,2	3,5
	3,1	3,5	3,6	4,4
	4,8	4,5	2,5	3,8
	4,3	3,4	4,6	3,4
	3,6	3,6	3,1	3,3
	4	4	3,4	3,4
	3,7	4,7	3,6	4,3
Average	**3,8**	**3,8**	**3,5**	**3,9**
SD	0,7	0,5	0,6	0,6

Single results from oil absorption measurements

g/m²	Filler A	Filler B	Filler C	Reference
	3,8	3,8	4,0	4,1
	4,0	3,7	3,2	3,6
	2,9	3,4	3,3	3,7
	2,6	3,2	2,5	3,9
	2,9	3,3	3,4	2,9
	4,5	3,1	3,7	2,9
	3,2	3,5	3,1	3,4
	3,4	3,2	3,3	3,3
Average	**3,4**	**3,4**	**3,3**	**3,5**
SD	0,6	0,2	0,4	0,4