The Effect of Filler Distribution on Gravure Printability of SC paper

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ABSTRACT

PCC has become the preferred solution in uncoated woodfree papers and is now expanding into woodcontaining papers, specifically SC magazine papers. The replacement of kaolin fillers with $CaCO_3$ has been slower in wood-containing paper grades than in wood-free papers. This is mainly due to alkaline darkening and printability issues related to the higher permeability and rounded shape of calcium carbonate fillers. However, these obstacles can be overcome by applying new engineered calcium carbonates designed to improve printing properties. This paper is focusing on the interactions between filler types (engineered precipitated calcium carbonates and kaolin) and paper structure, in particular the Z-direction filler distribution on gravure print through of SC-papers.

Good printability in terms of low strike through and high ink hold out is a result of the ink staying on the surface of the paper – it is a paper surface property. Consequently, only filler present at or close to the surface can impact good ink strike through and hold out. But different formers can give significant differences in Z-direction filler distribution. These filler distributions were simulated in a Dynamic Sheet Former (DSF) by adjusting the filler dosing rate during the sheet forming process. With this procedure sheets with severe two-sidedness were produced. The felt side with high filler level thus simulates a paper with "smiling" filler distribution, while the wire side simulates a "frowning" filler distribution.

Significant differences in print through performance were observed between felt and wire side with high and low filler level. On the wire side with low filler level all PCC based fillers had equal performance, with both strike and show through being lower than clay reference. On the felt side with high filler levels there were significant differences observed between sheets filled with different pigments. Conventional filler PCC's had highest strike through, engineered PCC's had lower strike through while reference clay had lowest ink strike through of all pigments tested. Lower ink strike through was however compensated by higher opacity in PCC filled sheets.

In addition carbonate filled sheets had pronounced brightness difference between sides. High brightness pigments increase sheet brightness when filler is concentrated towards the surface.

INTRODUCTION

High quality supercalendered (SCA, SCA+) paper competes with low weight coated (LWC) grades in the same printing applications (11,15). The trend is also towards lower basis weights (11) and improved brightness in SCA grades (15). In these markets surface structure of the SC sheet is extremely important in order to match the properties of coated papers. The surface of SC paper should be very smooth, dense, and formation must be very good (15, 2, 4, 5). High fines and filler content of the furnish are a necessity in order to achieve these properties. The filler and fines

material should be located on the outer surface of the sheet. Large pores on paper surface, caused either by large fibers of filler agglomerates, are the main reason for missing dots in rotogravure printing (17).

Placing filler and fines on uncoated paper surface is not a simple task in practice. The forming section of the paper machine plays crucial role in determining the filler distribution of paper. This paper shows that with a different filler distribution in the z-direction of paper, i.e. different type of paper machine forming section, a different filler solution might be required in order to improve paper properties.

BACKGROUND

Rotogravure printability

Many of the recent articles around SCA paper fillers have concentrated on replacement of all or a part of clay with precipitated calcium carbonate (PCC) fillers. The primary driver for this development is the improved brightness and opacity with PCC (6, 7, 8, 11, 15, 18). The use of PCC also improves bulk/compressibility and smoothness leading to a reduction in gravure missing dots (6, 7, 8, 11, 15, 12) which are also drivers for this trend. It has been well established that PCC gives higher porosity and higher compressibility to the SC sheet than clay (7, 8, 6, 10, 12, 13, 18, 16). This higher porosity of SC sheets with PCC filler is due to the smaller pores or loose packing of PCC (9, 16, 14). However, the higher porosity also leads to higher ink absorption with PCC (7, 8, 10). Higher porosity and ink absorption decrease the print density in gravure printing (12, 14) and also ink demand and print mottle can be higher (7, 8).

It has been reported that that PCC filled papers give improvement in print-through, strike-through, and show-through over clay filled paper (8, 7) or that the print-through is equal with PCC or clay filled papers (6). The reasons for this are improved opacity and higher ink absorption with PCC. Very often the reported experiments were done at rather high basis weight range 52g/m² +, where print-through is usually not a concern. However, print-through can be a severe problem in gravure printing of low basis weight SCA papers. This is especially true if one replaces coated grades with uncoated SC grade. The requirements for the rotogravure paper are thus different for heatset offset printing, where the surface strength of the paper is crucial.

Print through can be considered as composed of two components: Show Through and Ink Strike Through. Show Through is the ink density measured on the back side of an unprinted sheet placed on top of a printed sheet and is the print through of a sheet where all ink stays on the surface. Show Through is of course controlled by opacity of the sheet. Ink Strike Through is the additional print through originating from ink penetrating into the paper. It is calculated by subtracting Show through from Print Through. In the worst cases the ink bleeds all the way through the paper. Figure 2. Sheet with low ink strike through. Courtesy of Seppo Sarelin, UPM.) shows how ink has penetrated into a paper with a tendency toward high Ink Strike Through. Ink Strike Through is a more severe problem in low grammage grades. Not only is the opacity lower in low grammages, but if the ink penetrates to a certain depth will the ink penetration be relatively higher in thin sheets. In worst case when the paper is so thin that ink penetration equals paper thickness will bleed through occur. While it is obvious that good (low) ink strike through is a paper surface property, because the ink only is in contact with surface, a further deduction from this is that only filler located at or close to the surface can have an impact on good Ink Strike Through.

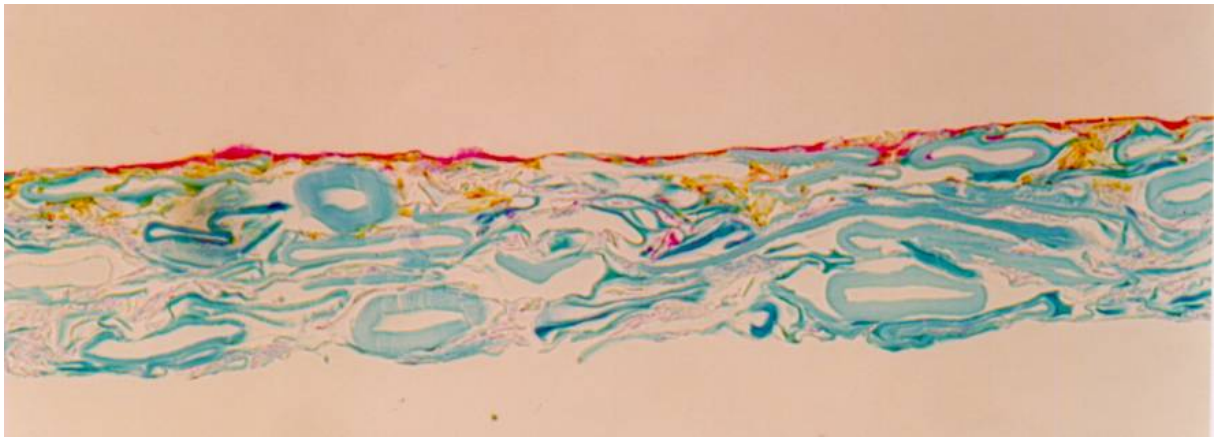


Figure 1. Ink penetration in sheet with high ink strike through. Courtesy of Seppo Sarelin, UPM

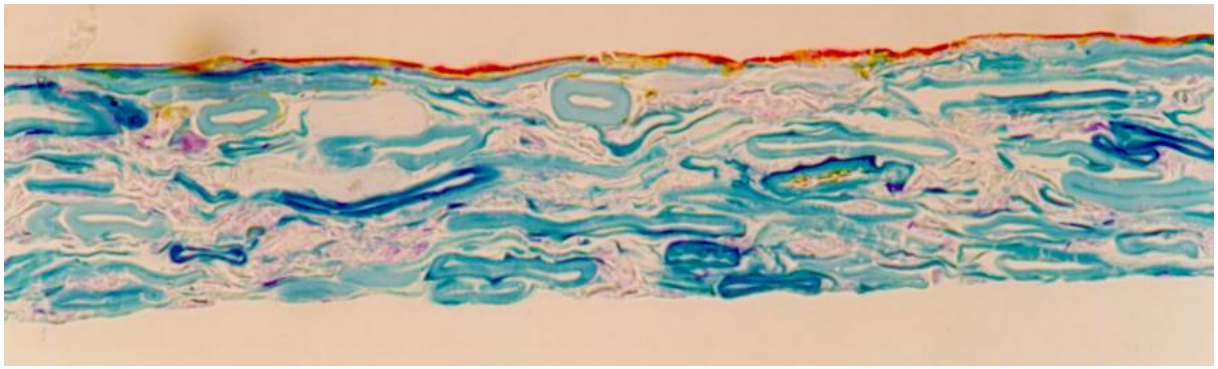


Figure 2. Sheet with low ink strike through. Courtesy of Seppo Sarelin, UPM.

If filler amount on paper surface affects the behavior of paper in printing, which is a surface phenomenon, then one filler pigment might be good for a paper with low filler content on surfaces and another pigment for paper with high filler content on surfaces. The results presented in this paper show that this is the actually the case.

Effect of paper machine on z-directional filler distribution

Filler distribution in SC-papers is former driven. Older, twin-wire formers give a low surface filler and fines content, see Figure 3a. Newer forming technology, i.e. gap formers, gives high filler and fines content on the paper surfaces, see Figure 3.b. The difference in the filler content on paper surface with these two former types is obvious.

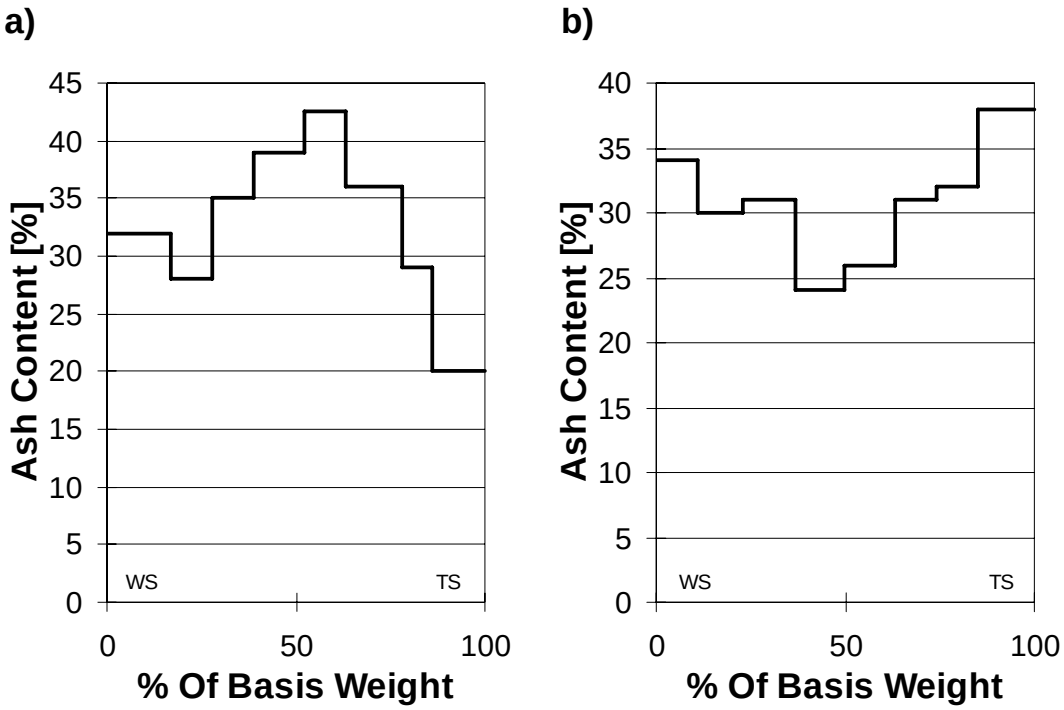


Figure 3. Filler distributions on commercial SC magazine papers a) Twin former-type b) Gap former-type forming section.

Changing the z-directional fines or filler distributions is difficult without affecting other important paper properties (2). TMP and SGW/PGW furnishes give different z-directional filler distributions to the sheet. Typically, sheet produced with TMP furnish gives higher filler content on paper surfaces whereas SGW/PGW based sheet has fairly flat filler distribution.

A new development in gap forming technology is layering of filler on paper surfaces. Higher filler content, and thus denser surface, can be achieved in SC papers (2). This can be seen in printing properties as higher print gloss and better dot gain. Higher brightness can be achieved without opacity loss by layering filler to the paper surface. It has been even said that layering filler on SC paper surfaces can make the print similar to print of LWC paper (3). Filler layering on paper surfaces might require different properties from the filler than in normal one-layer application.

EXPERIMENTAL

Sheets were prepared on a Dynamic Sheet Former (DSF) from Fiber Tech AB.
In using the DSF usually, the whole furnish is added to the machine chest of the handsheet former in the beginning of sheet making. With this method a fairly flat filler distribution is obtained in the sheets, Figure 4. In the studies described in this paper this method was modified by adding the filler in 4 steps during sheet forming. All other components including retention polymer were added in the beginning of sheet making.

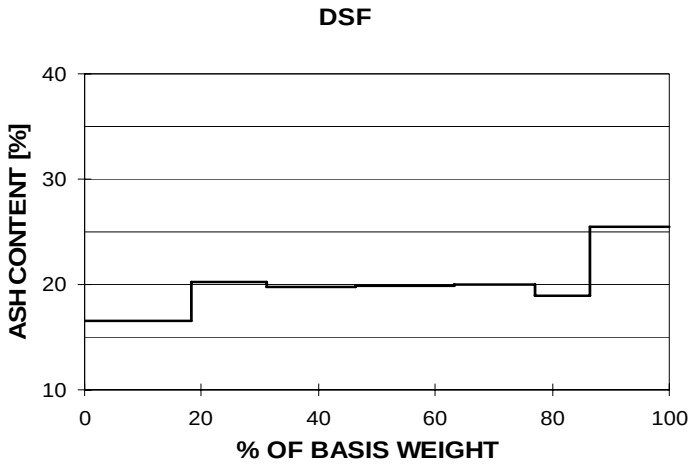


Figure 4. Filler distribution in a conventional DSF sheet where all filler was added to the furnish before sheet making.

Sheets with severe two-sidedness can be produced with this procedure and when compared with adding different furnish mixture for instance for top, middle, and bottom it is much simpler. Filler addition sequence was modified so to obtain either steep (big difference in filler content of the surfaces) or shallow (smaller difference in filler content of the surfaces) filler distributions. See Figure 5 for examples of z-directional filler distributions in handsheets produced with steep or shallow filler distributions.

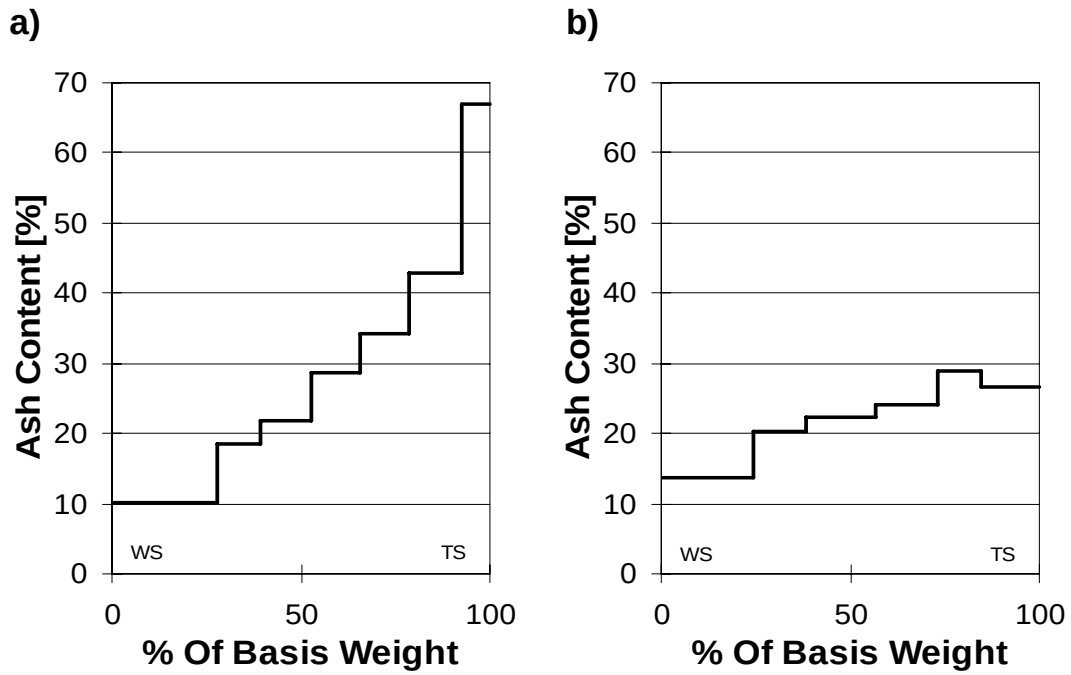


Figure 5. Filler distributions of handsheets produced in DSF using modified filler distribution technique using a) steep and b) shallow filler addition profile during sheet making.

This handsheet making procedure results in sheets that have low filler content on wire side of the samples, which is often the case on Twin-wire forming. While filler content on wire side is low,

filler content on top side is high. The felt side of the sheet having the high filler content on surface simulates the surface properties of papers produced on modern gap former paper machines. Surface filler content can be made unrealistically high compared to papers produced on full-scale paper machines, but in lab experiments this can actually be beneficial in order to clearly detect the differences in the sheets.

Pulp fines distribution was not controlled in this handsheet making procedure; which constitutes a difference to sheets formed on paper machine. The purpose of this study was to highlight the differences in properties affected by fillers, but it should be noted that the differences detected between the fillers might be diluted in real life due to the fact that pulp fines are located in the same z-directional position as fillers.

Materials

The pulp was a SC paper furnish obtained from from a Finish SC-mill consisting of mostly mechanical pulp (TMP) plus a little chemical fibers is used in the sheets.
The fillers used in the handsheet studies were filler kaolin for SCA papers, and precipitated calcium carbonates (PCC), and 2 engineered PCC pigments, Table 1.

Pigment	Description	MPS	BET	R457
Filler Kaolin	Intramax			80
PCC 1	Discrete calcite	0.9 µm	8	96.2
PCC 2	Aragonitic PCC	1.99 µm	6.8	94.8
PCC 3	PCC mixture	1.2 µm	12	96
PCC 4	PCC composite	1.1 µm	14.2	96.8

Table 1. Fillers used in hand sheets.

Sheets were produced with an average of 42.3 gsm ±0.7 gm with a total filler load of 25.3 % filler ±0.7%

Filler were dosed to the machine chest with following procedures:
1. Steep profile
- Add 25% of total filler to the pulp in feeding tank
- Add 25% of total filler at 2, 4, and 6 minutes after the beginning of sheet making

2. Mild profile
- Add 55 % of total filler to the pulp in feeding tank
- Add 15% of total filler at 2, 4, and 6 minutes after the beginning of sheet making

Dosing of retention aid:
- 200 g/t Percol 47 was added to the pulp in the beginning

Sheets were calendared on a Gradek laboratory calendar using constant conditions for all sheets:
- Steel roll temperature 80 °C
- Pressure 80 bar
- 2+3 nips. 3 nips for wire side of the sheet. First nip top side against steel roll, then wire side, top side, wire side, wire side

Z-directional ash distribution of the handsheets was measured by VTT in Jyväskylä. The method utilizes tape sheet splitting and ashing of the layers. According to our experiences, the method is reliable when accepting a little inaccuracy on the filler content of outermost surfaces.

Rotogravure printing tests were done at J.M Huber printing lab in Macon, GA with a special procedure developed to investigate print through, in particular ink strike through.
The printing device is fairly simple using a single gravure roll with 5 wedges of different ink amount, and a commercial rotogravure ink that is used in industrial high speed gravure printing.

RESULTS

Ash distribution measurements revealed that filler distributions generally were steeper in sheets with PCC fillers compared to the distributions in kaolin filled sheets. Top surface ash results were especially high in some sheets up to 60%, Figure 5.a. Backscattered SEM images of the top side of the paper surfaces also illustrate that surface filler levels were quite high in some of the samples Figures 6-8.

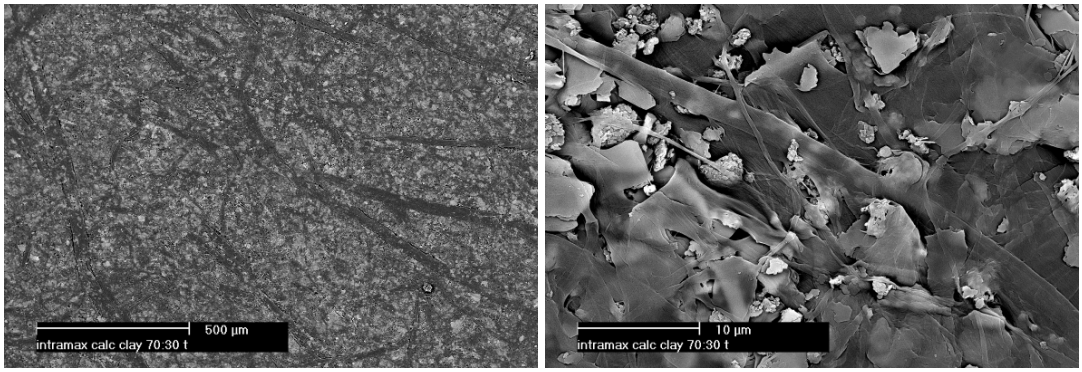


Figure 6. SEM of Kaolin filled sheet

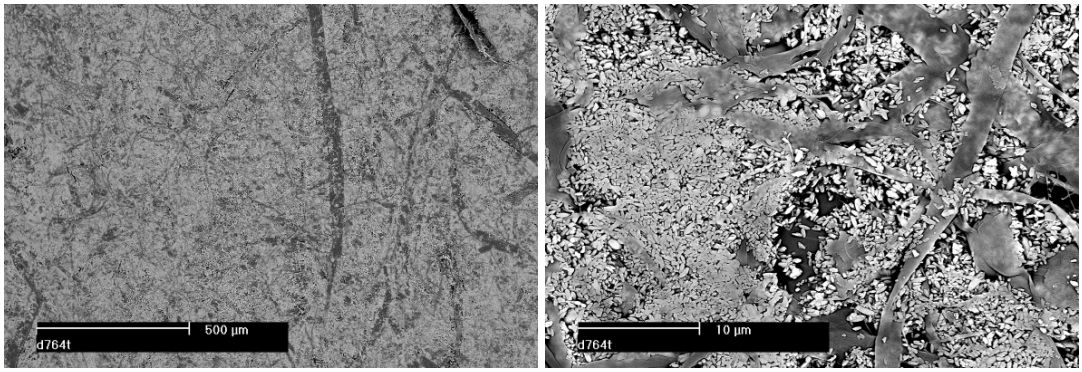


Figure 7. SEM of R-PCC filled sheet.

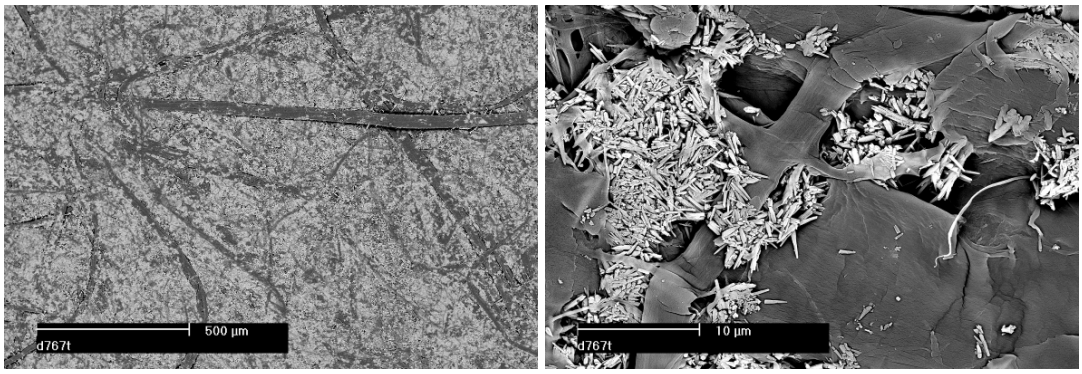


Figure 8. SEM of aragonite filled sheet.

The top sides with high filler level were smoother with higher gloss than the wire sides with low filler level. This difference is a result of top side being calendared first and not the difference in surface filler levels. The kaolin filled sheets had highest gloss, but the impact of filler type on paper gloss appears to be stronger on gloss of top side with high filler levels. For instance, the aragonitic PCC 2 had lower gloss than the other PCCs on the top side, but more or less similar gloss on the wire side, Figure 9.

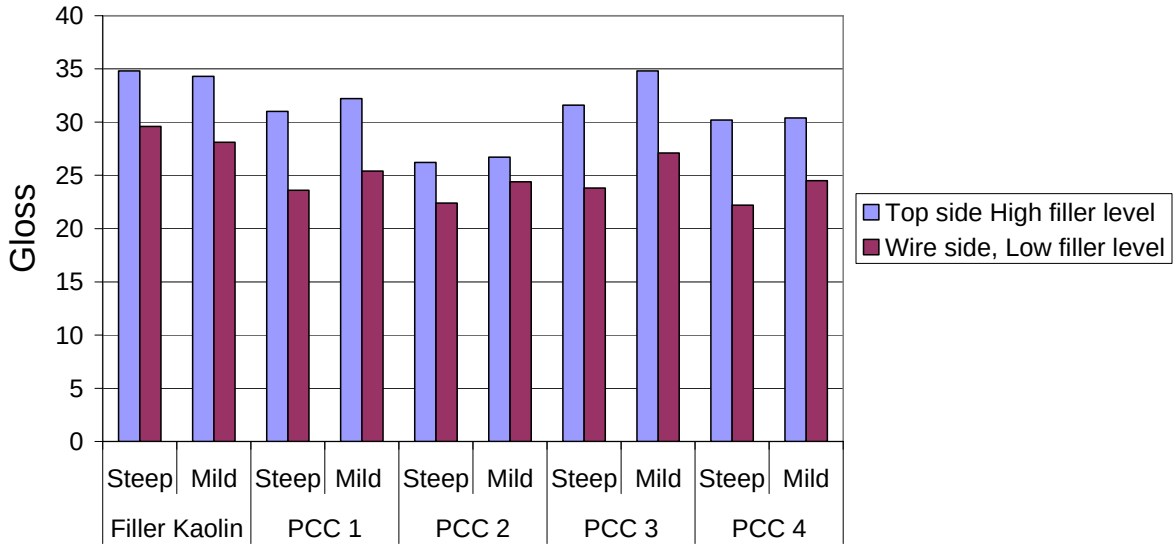


Figure 9. Gloss results with different fillers.

The optical advantage of PCC was quite obvious. The PCC filled sheets had 3-5 points higher opacity than the kaolin filled sheets with PCC 1 and PCC 2 giving highest opacity, Figure 12. There was a large brightness difference between high filler level top sides and low filler level wire sides in the PCC filled sheets, but there was a much smaller difference in the kaolin filled sheets when the two sides were compared. The differences between top and wire sides were also larger for sheets with steep filler distribution, Figure 10. This difference between kaolin and PCC performance is of course related to the difference in pigment brightness and scattering power. A high filler level on the surface is of particular advantage for paper brightness with high brightness fillers.

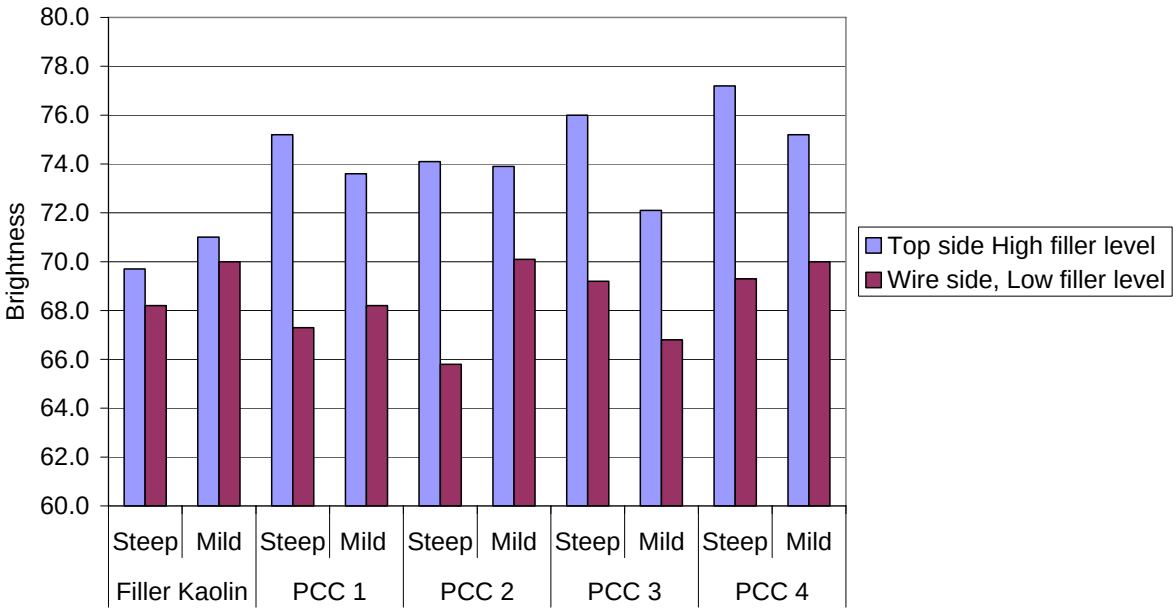


Figure 10. Sheet brightness.

A more detailed analysis of the interaction between filler type and surface filler level on paper brightness can be seen in figure 11. It can clearly be seen that increasing surface filler concentration of PCC has a much stronger effect on sheet brightness than increasing surface filler concentration of kaolin. It can also be seen that different types of PCC filler yield different brightness responses with PCC 4 giving a higher brightness than the other PCCs.

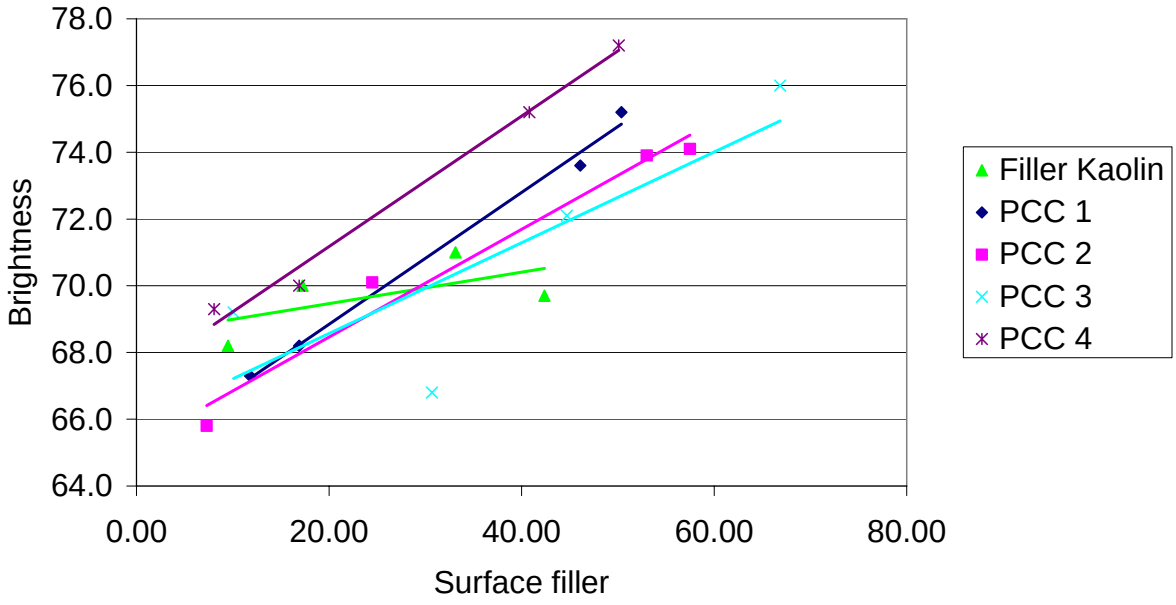


Figure 11. Sheet brightness as a function of surface filler concentration.

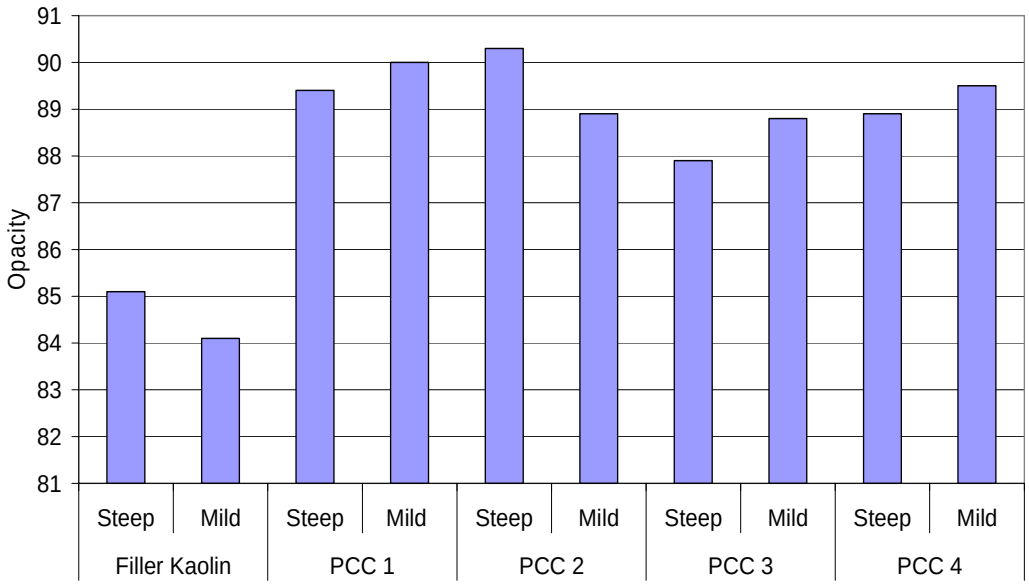


Figure 12. Opacity of all sheets

Print through performance showed a surprisingly strong interaction between filler type and surface filler concentration, Figure 13.

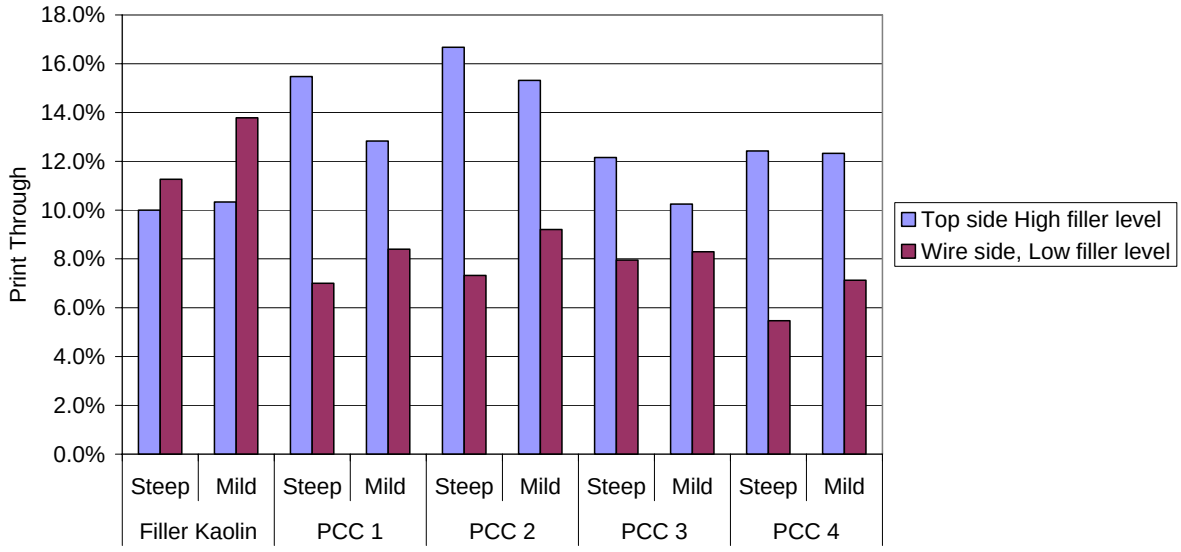


Figure 13. Print through results.

PCC filled sheets had significantly lower print through than kaolin filled sheets when printed on the low surface filler wire side and there were only relatively small differences between the different PCC filler types. Print through performance was, however, opposite when sheets were printed on the high filler side. Kaolin filled sheets had lower print through than the PCC filled sheets when printed on top side with high filler levels and there was a larger difference in print performance between sheets filled with different PCC's with PCC 1 and PCC 2 giving somewhat higher print through than PCC 3 and PCC 4

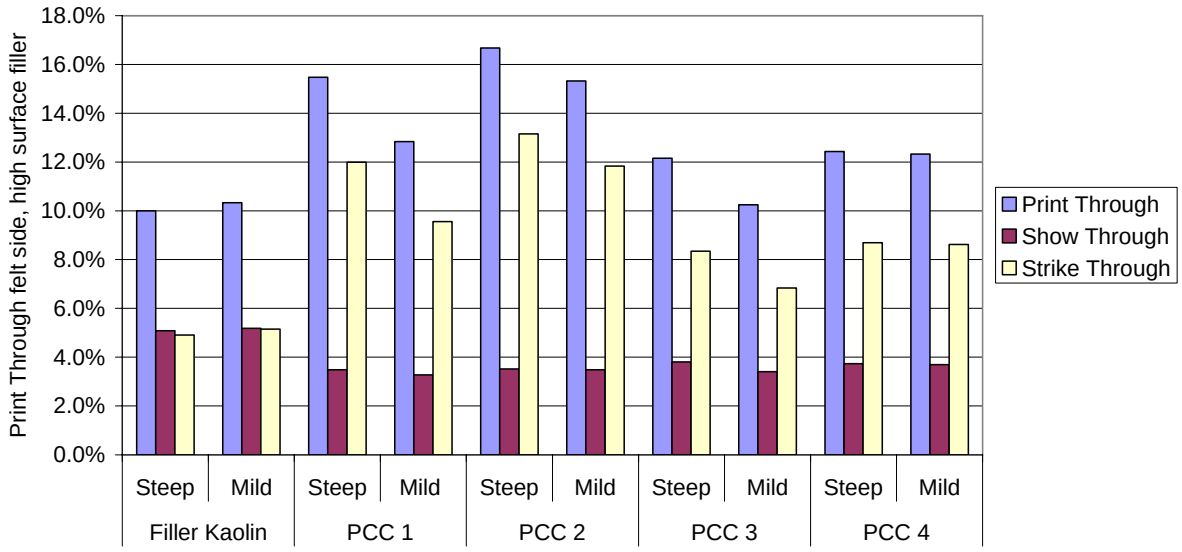


Figure 14. Print through results on samples printed on top side with high surface filler levels

Print analysis reveals that the differences in print through performance were related to ink strike through. All PCC filled sheets had high ink strike through when printed on the top side with high filler levels. In particular sheets filled with PCC types 1 and 2 had the highest ink strike through. Show through was on the other hand always lower on the PCC filled sheets because of the higher opacity.

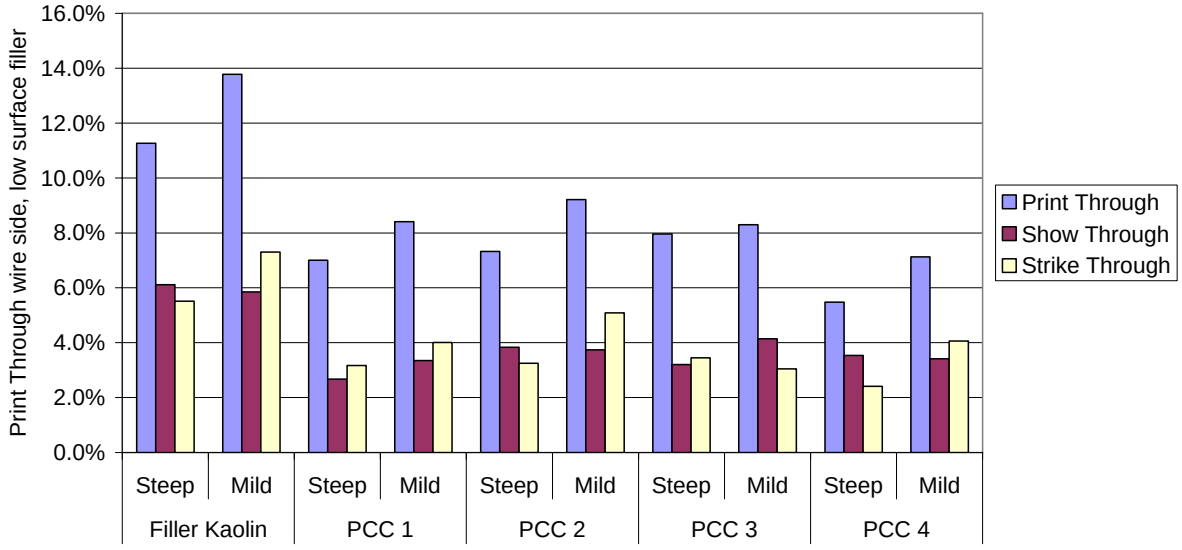


Figure 15. Print through results on samples printed on wire side with low surface filler levels

DISCUSSION

In this study we have found that the effect of filler distribution is highly related to the filler type. A high filler level near the surface is improving sheet brightness, while a low filler level is reducing sheet brightness, but the difference in brightness between filler and pulp determines how strong this

effect is. PCC filled sheets had consequently far larger brightness difference between felt and wire side that kaolin filled sheets.

Significant differences in print through performance were also observed between felt and wire side with high and low filler level. On wire side with low filler level all PCC based fillers had equal performance, with both strike and show through lower than clay reference. On felt side with high filler levels there were significant differences between sheets filled with different pigments. Conventional filler PCC's had highest strike through, while reference clay had significantly lower ink strike through. PCC pigments 3 and 4 with modified pore structures were found to have ink strike through in between the traditional PCC's and kaolin, and overall print through for these pigments were similar to the kaolin filled sheets due to the lower show through contribution from higher opacity. It should still be noted that only the effect of filler distribution has been investigated. Pulp fines distribution was not controlled in same way, and is also likely to have a strong impact on ink strike through.

Increasing surface filler thus appears to have a negative impact on ink strike through of the PCC filled sheets and it seem reasonable to assume that the increased ink strike through is caused by a more open pore structure. This is also supported by the lower ink strike through in sheets with pore modified PCCs. However, the difference in ink strike through results may not only be a result of higher ink penetration into the high filler surface. If the ink penetrates to the sheet same depth from both sides of the sheets there will still be higher ink strike through measured from the side with high filler level because the ink will have passed by a larger fraction of the opacifying filler,

CONCLUSIONS

Filler distribution in Z-direction varies quite significantly from skewed distributions, "frowning to smiling", depending on forming section and pulp. The filler distribution has a strong impact on paper and printing properties, but there can be very strong interactions between the effect of filler type and filler distribution. The effect of a higher surface filler level on printing properties can change completely with different filler. There can consequently be a risk of drawing false conclusions if the surface filler concentration is not taken into consideration.

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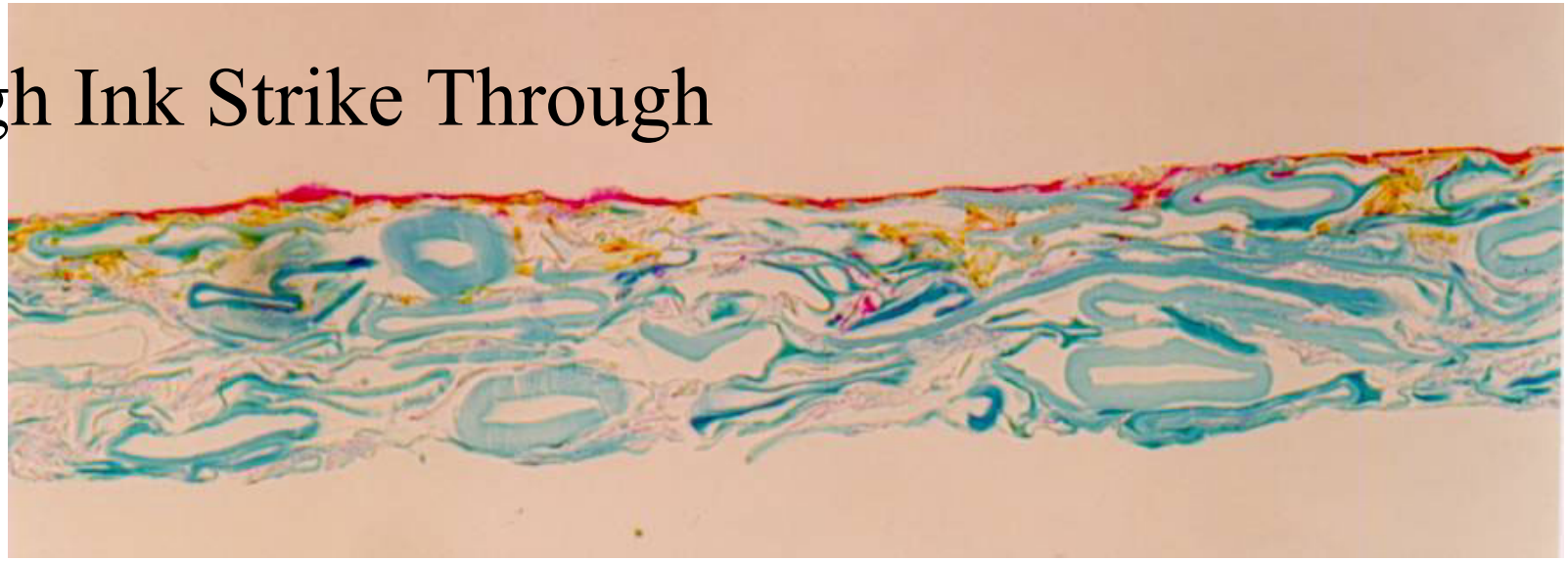
Increasing Whiteness

69 Brightness	77 Brightness

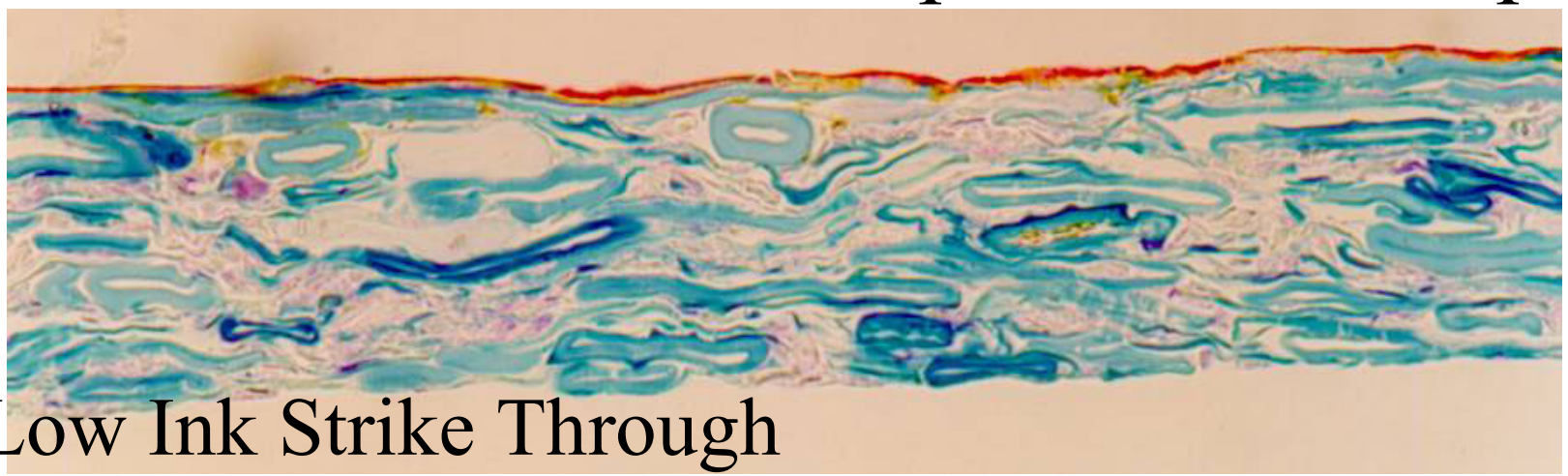




High Ink Strike Through

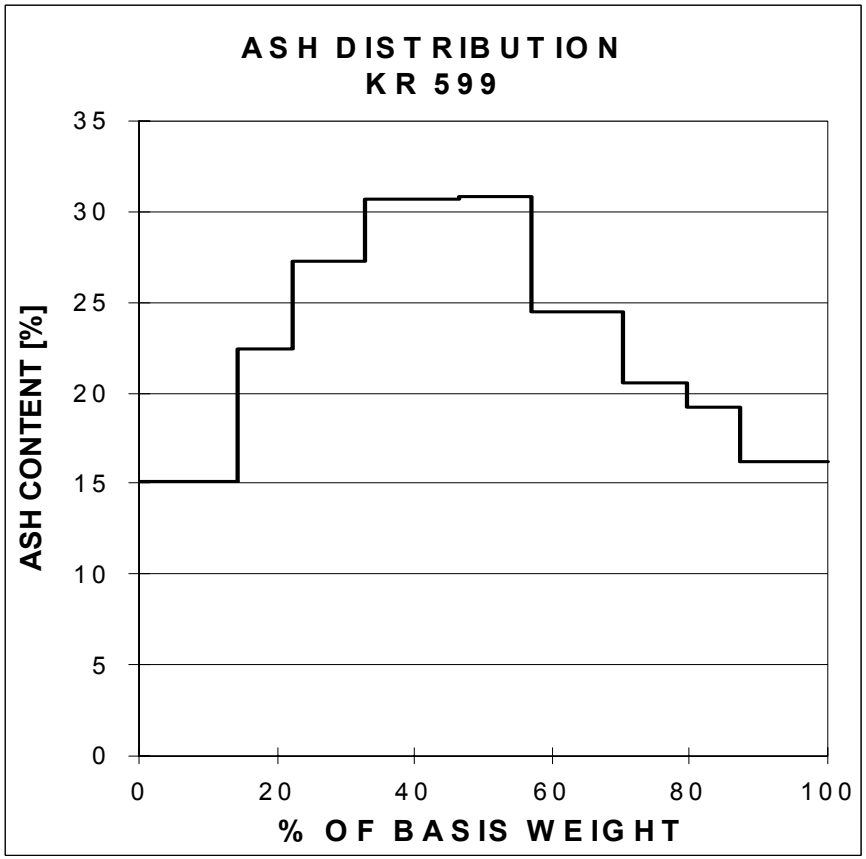


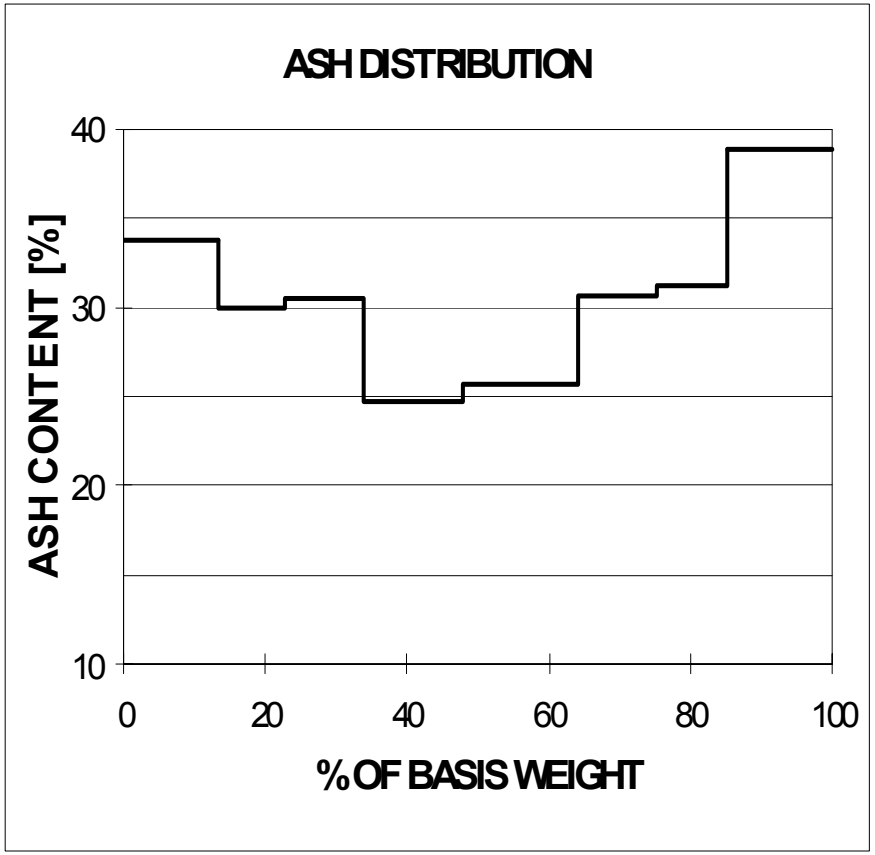
Low Ink Penetration is a Paper Surface Property



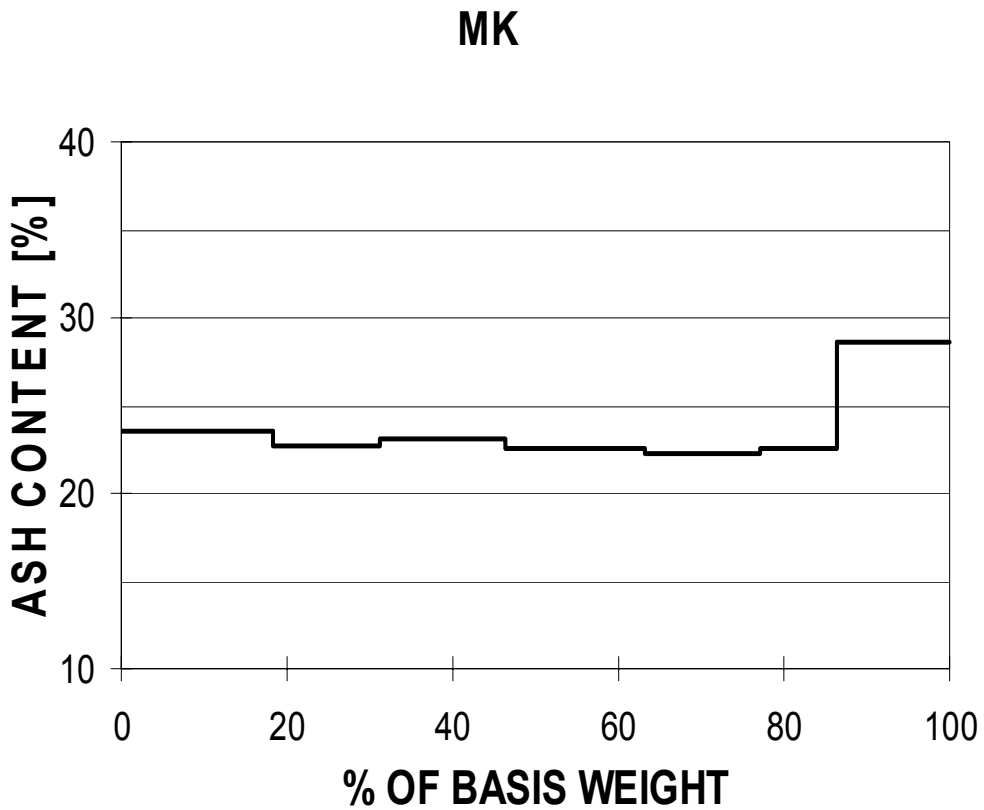
Low Ink Strike Through

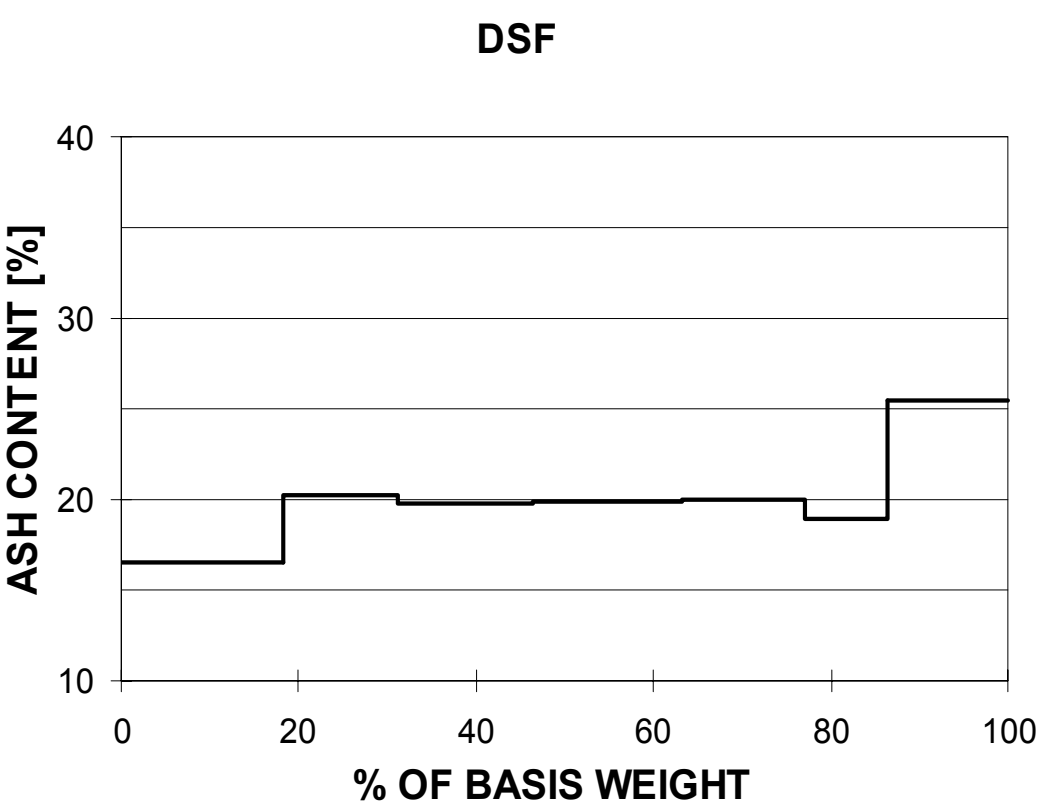
Former effect on Filler Distribution





Ash distribution in Z-direction on lab formers

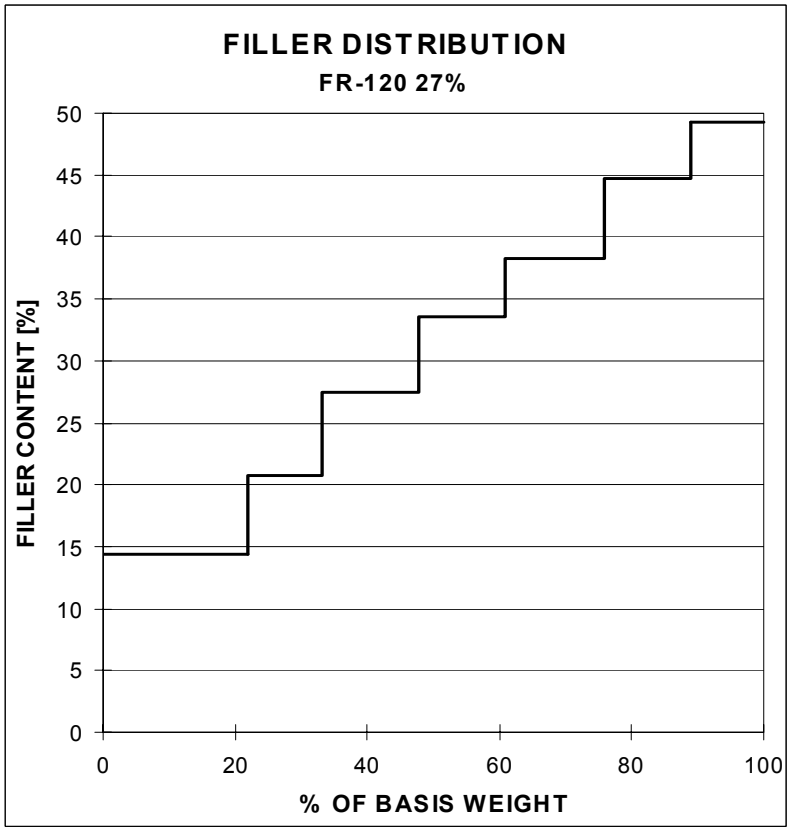




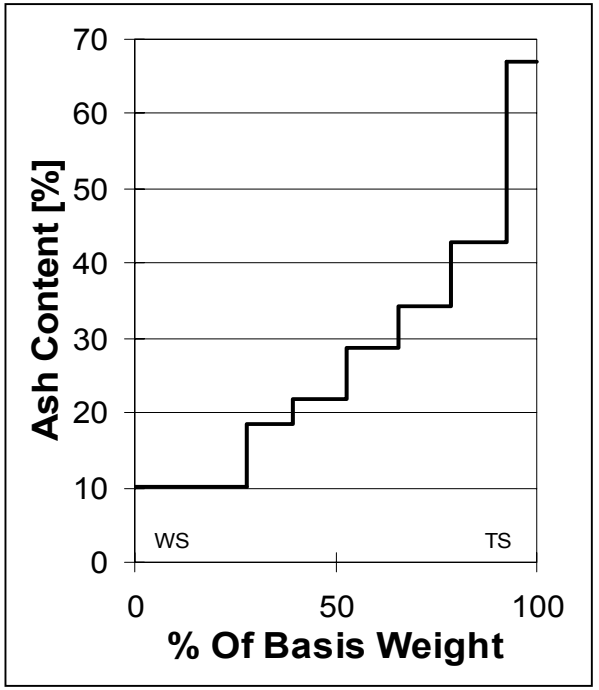
0 = felt side, 100 = wire side

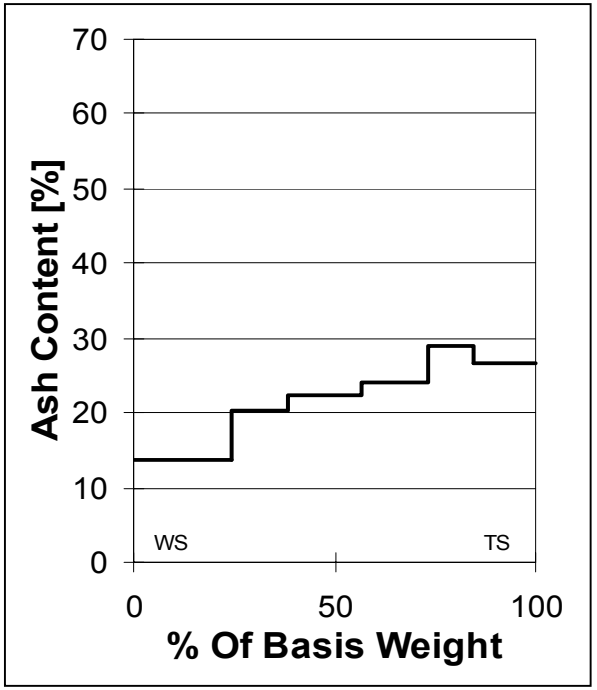
Controlling filler distribution

- Dynamic Sheet Former, Fiber Tech AB
- SC paper furnish (from a Finish SC-mill)
- 40 gsm sheets with total 25% filler
- Part of the filler was dosed prior to sheet forminging , while the rest was added to machine chest during forming
- The whole dose of retention aid was added to the pulp containing 25 % of total filler
- Calendaring
  - Steel roll temperature 80 °C
  - Pressure 80 bar
  - 2+3 nips. 3 nips for wire side of the sheet. First nip top side against steel roll, then wire side, top side, wire side, wire side



Steep and mild filler distribution





- 25% of total filler to the pulp in feeding tank
- 25% of total filler at 2, 4, and 6 minutes after the beginning of sheet making

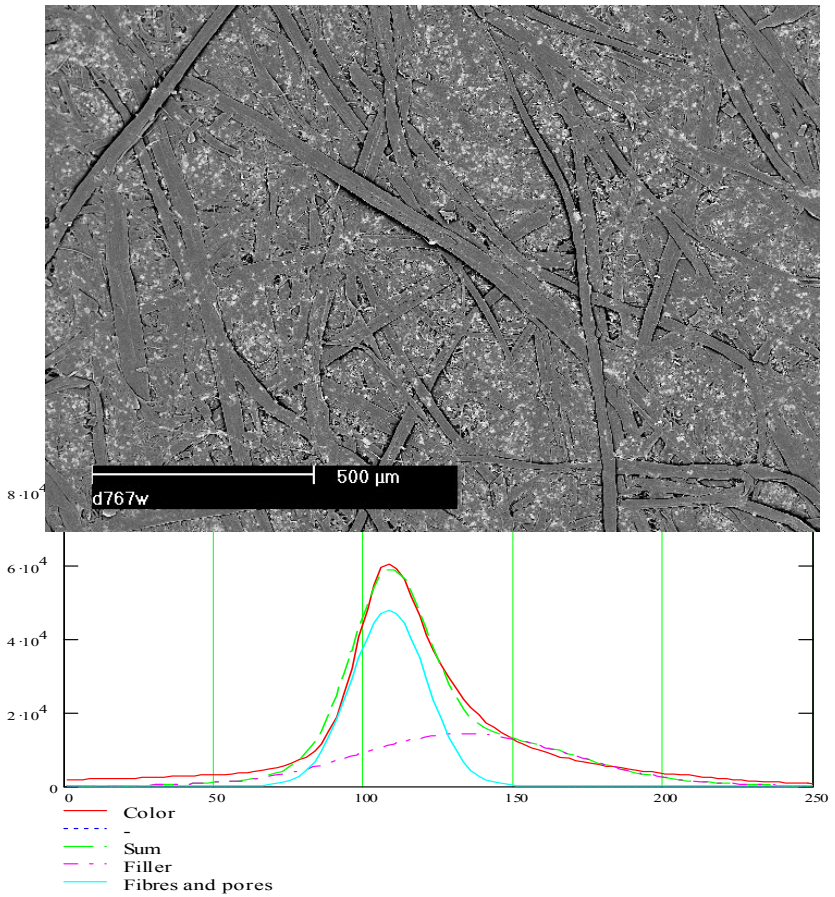
- 55 % of total filler to the pulp in feeding tank
- 15% of total filler at 2, 4, and 6 minutes after the beginning of sheet making

Pigments

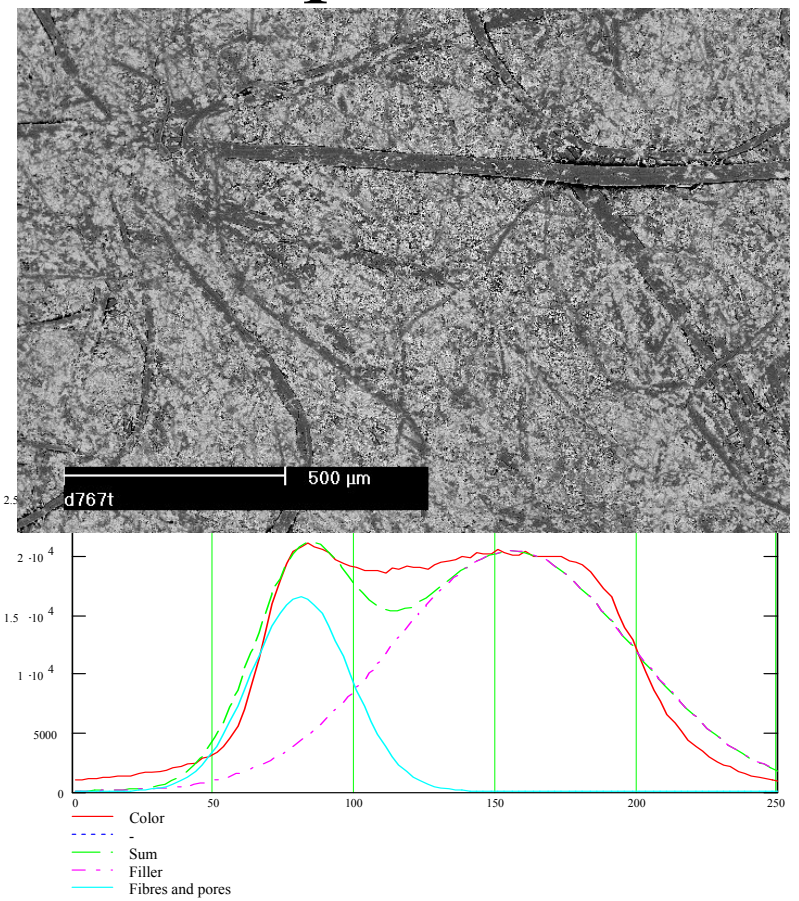
Pigment	Description	MPS	BET	R457
Filler Kaolin	Intramax			80
PCC 1	Discrete calcite	0.9 µm	8	96.2
PCC 2	Aragonitic PCC	1.99 µm	6.8	94.8
PCC 3	PCC mixture	1.2 µm	12	96
PCC 4	PCC composite	1.1 µm	14.2	96.8

BS SEM of surface filler

Wire side

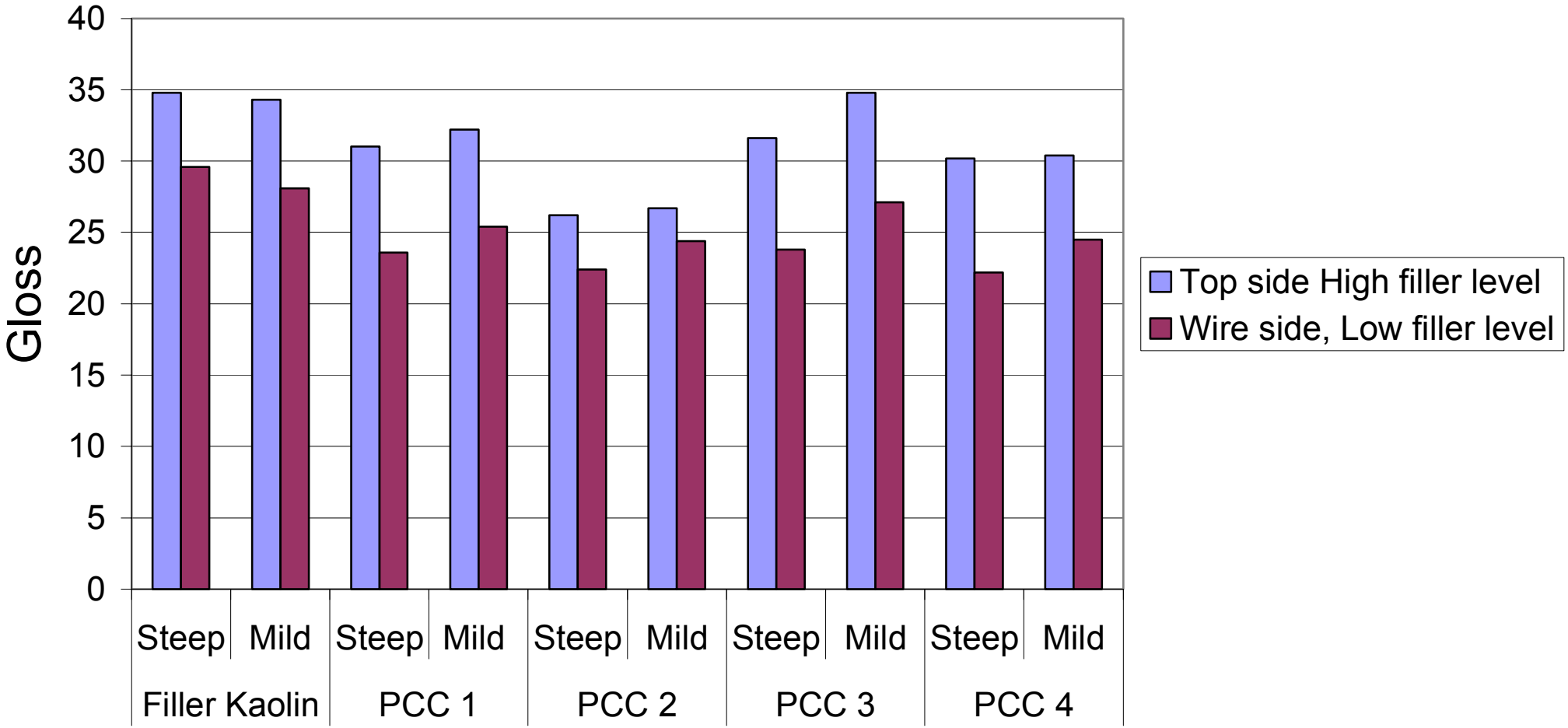


Top side

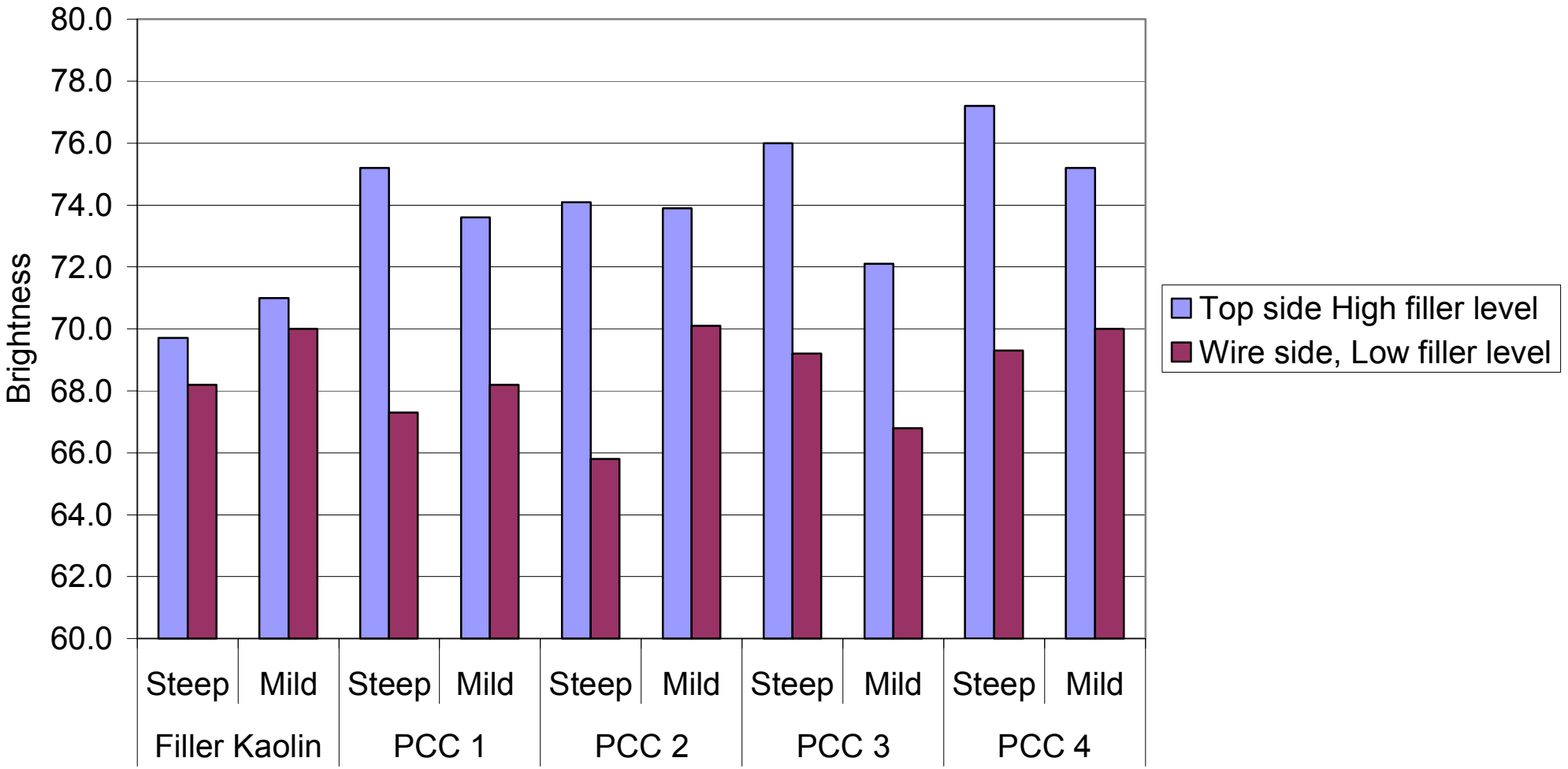


Results

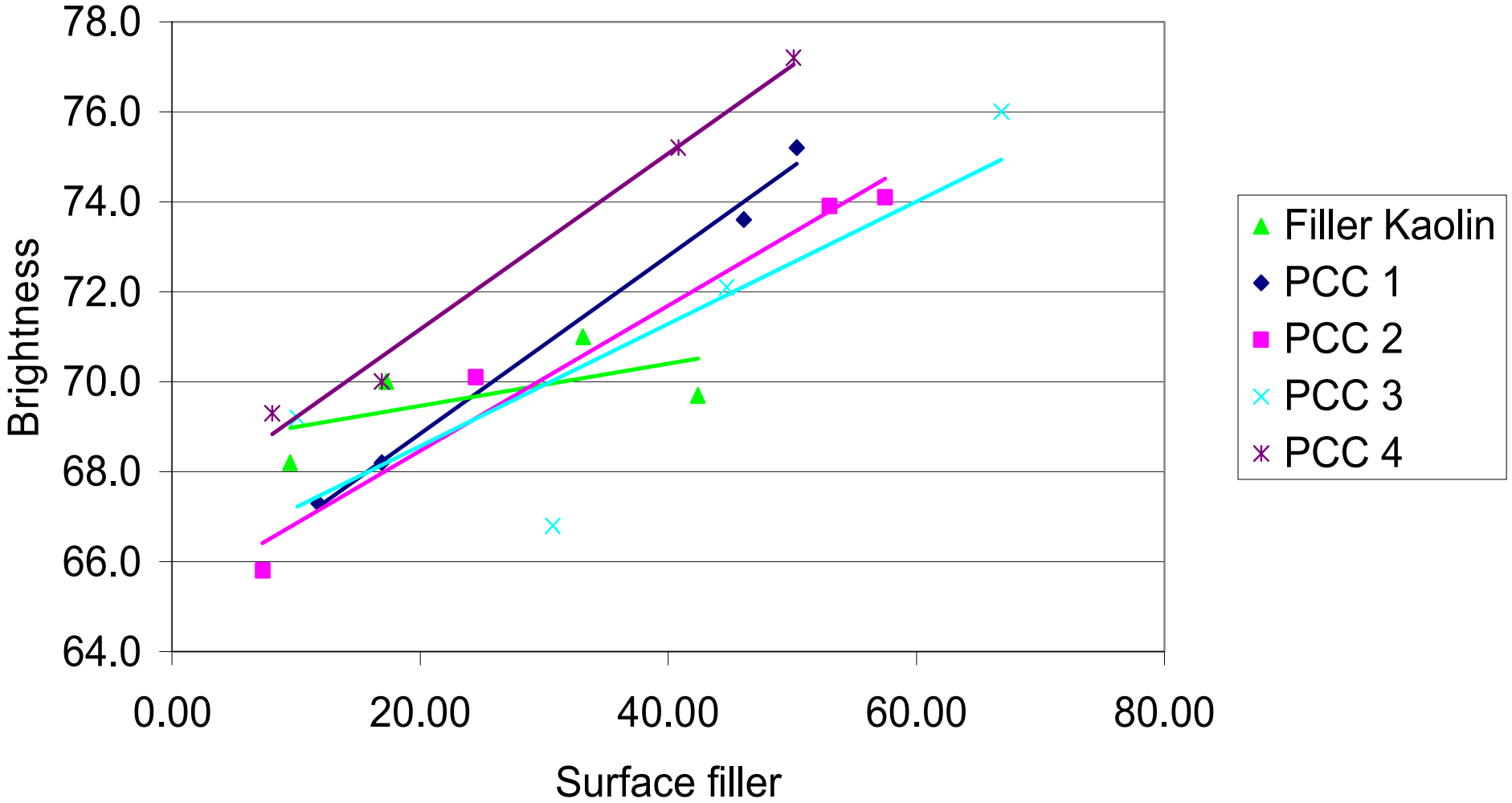
Paper Gloss


Gloss
40
35
30
25
20
15
10
5
0
Steep
Mild
Steep
Mild
Steep
Mild
Steep
Mild
Steep
Mild
Filler Kaolin
PCC 1
PCC 2
PCC 3
PCC 4
Top side High filler level
Wire side, Low filler level

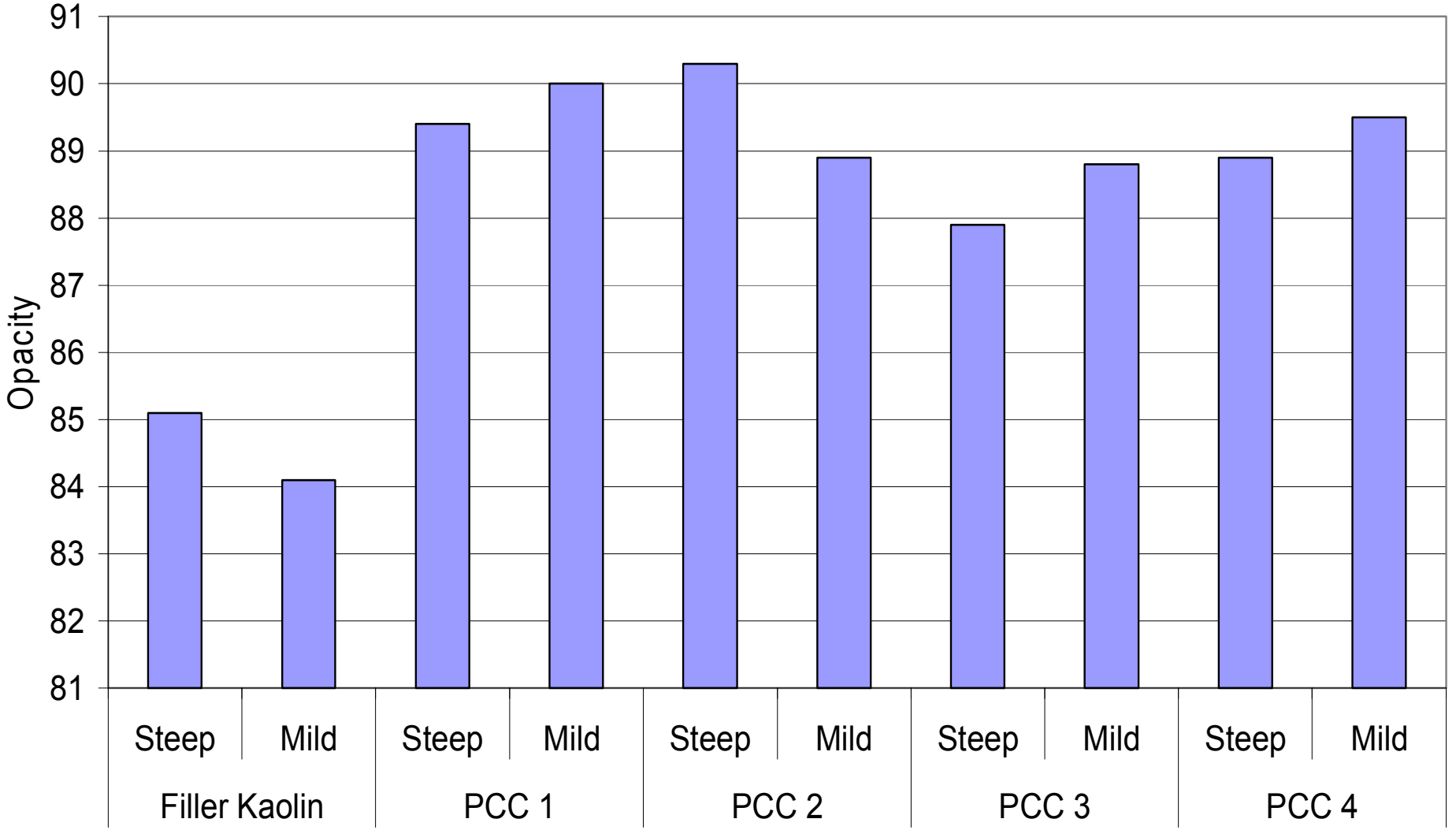
Paper Brightness



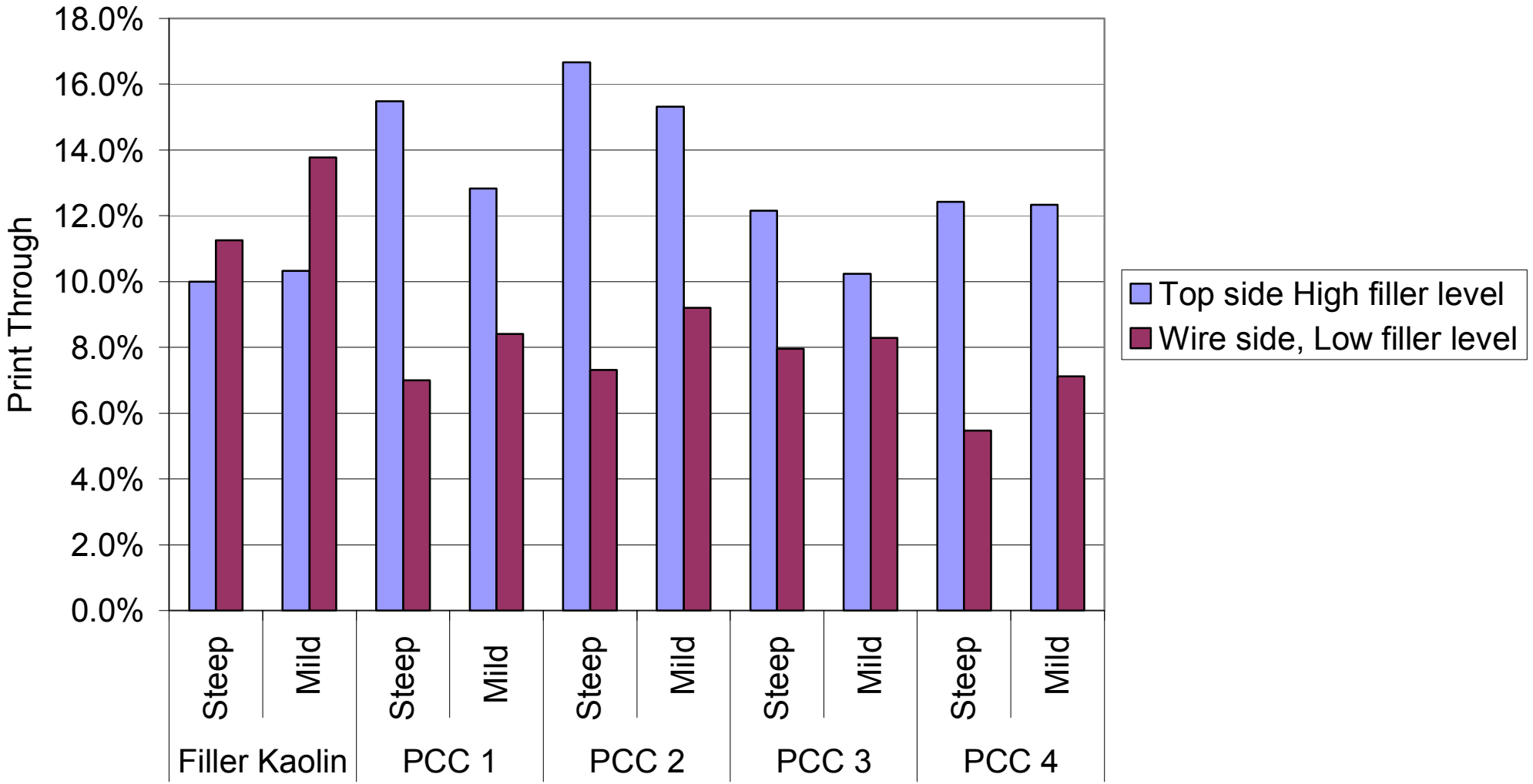
Brightness


78.0
76.0
74.0
72.0
70.0
68.0
66.0
64.0
Brightness
0.00
20.00
40.00
60.00
80.00
Surface filler
Filler Kaolin
PCC 1
PCC 2
PCC 3
PCC 4

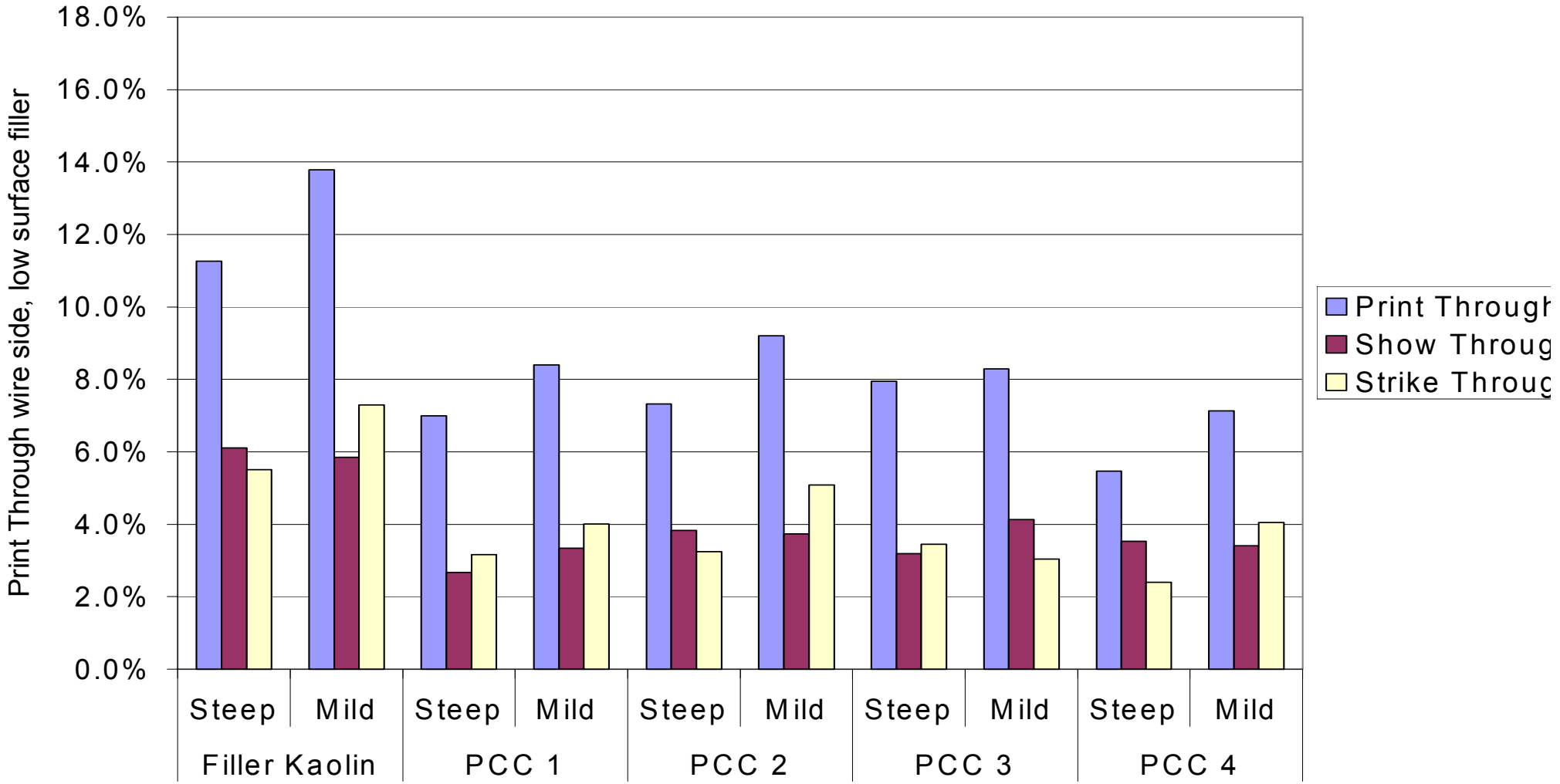
Opacity


Opacity
91
90
89
88
87
86
85
84
83
82
81
Steep
Mild
Steep
Mild
Steep
Mild
Steep
Mild
Steep
Mild
Filler Kaolin
PCC 1
PCC 2
PCC 3
PCC 4

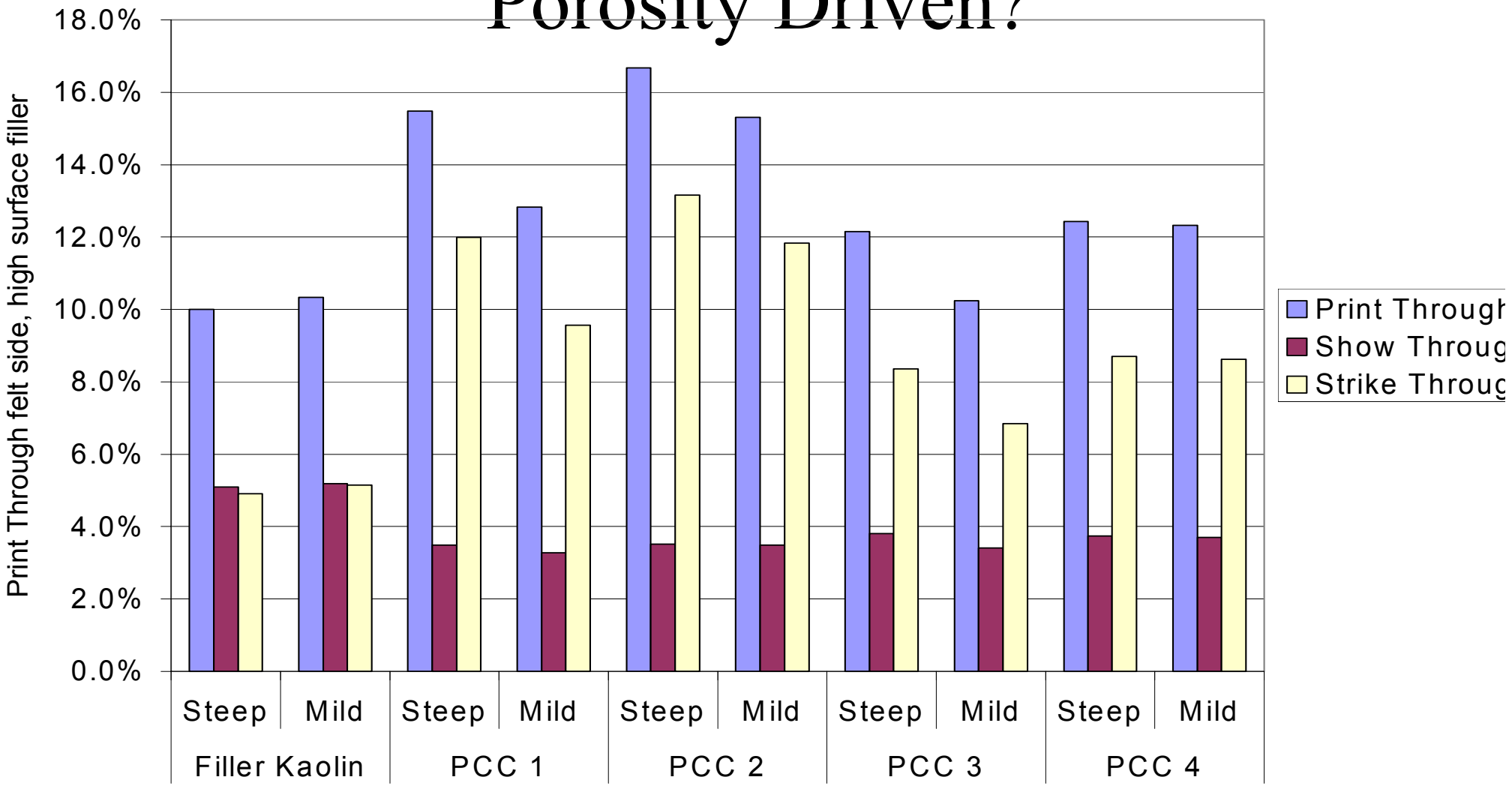
Print Through



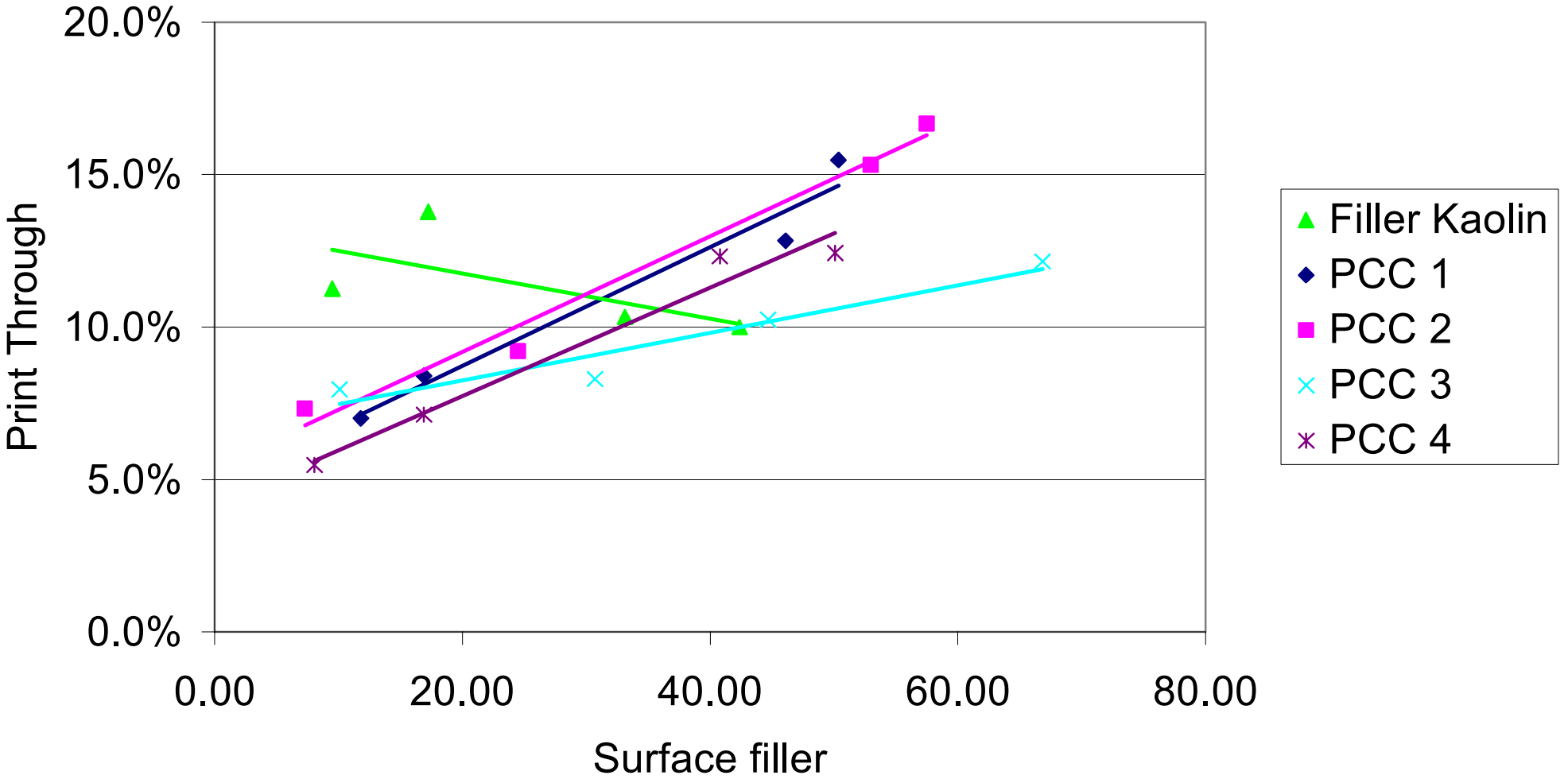
Printing Through on Surface with Low Filler



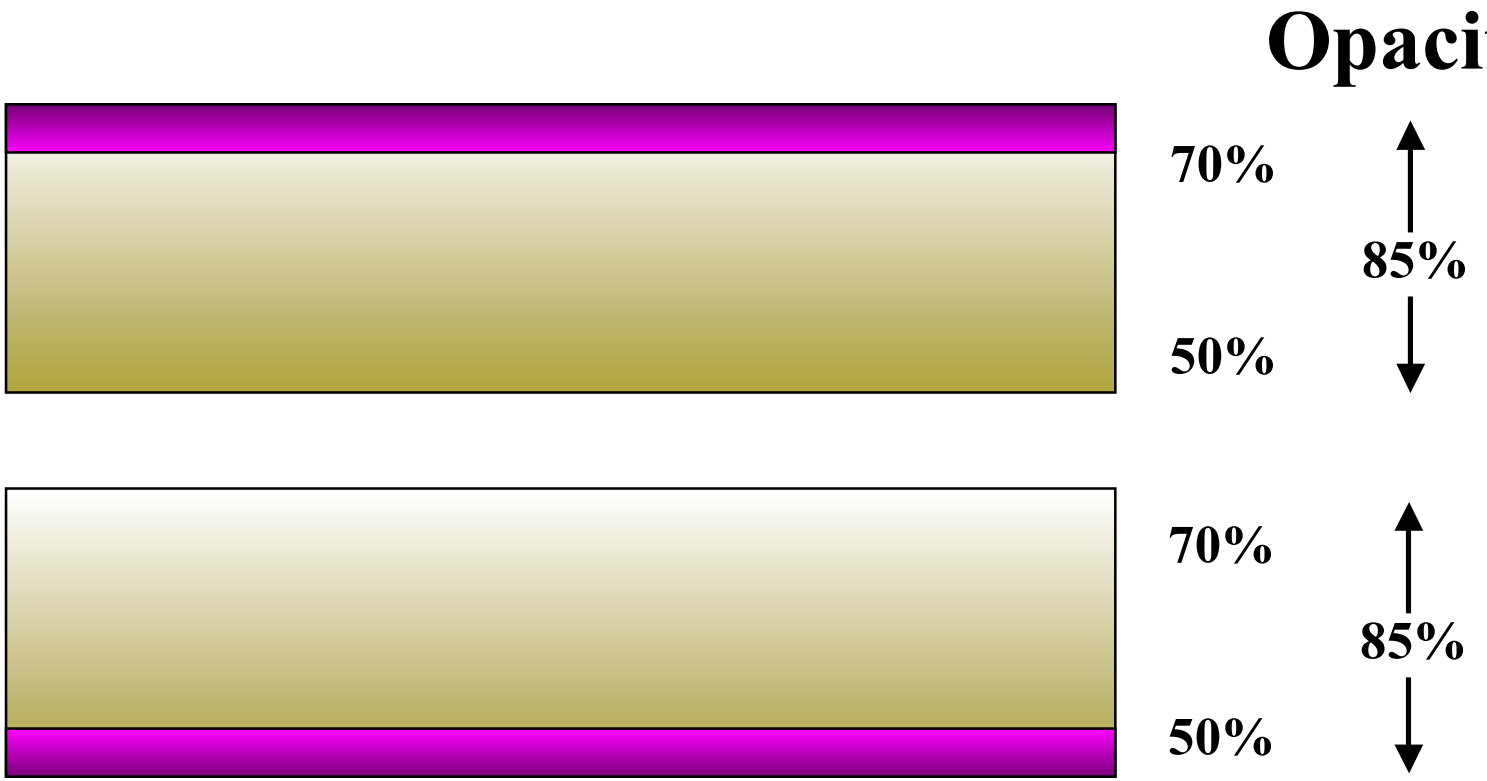
Print Through on Surface with High Filler Porosity Driven?



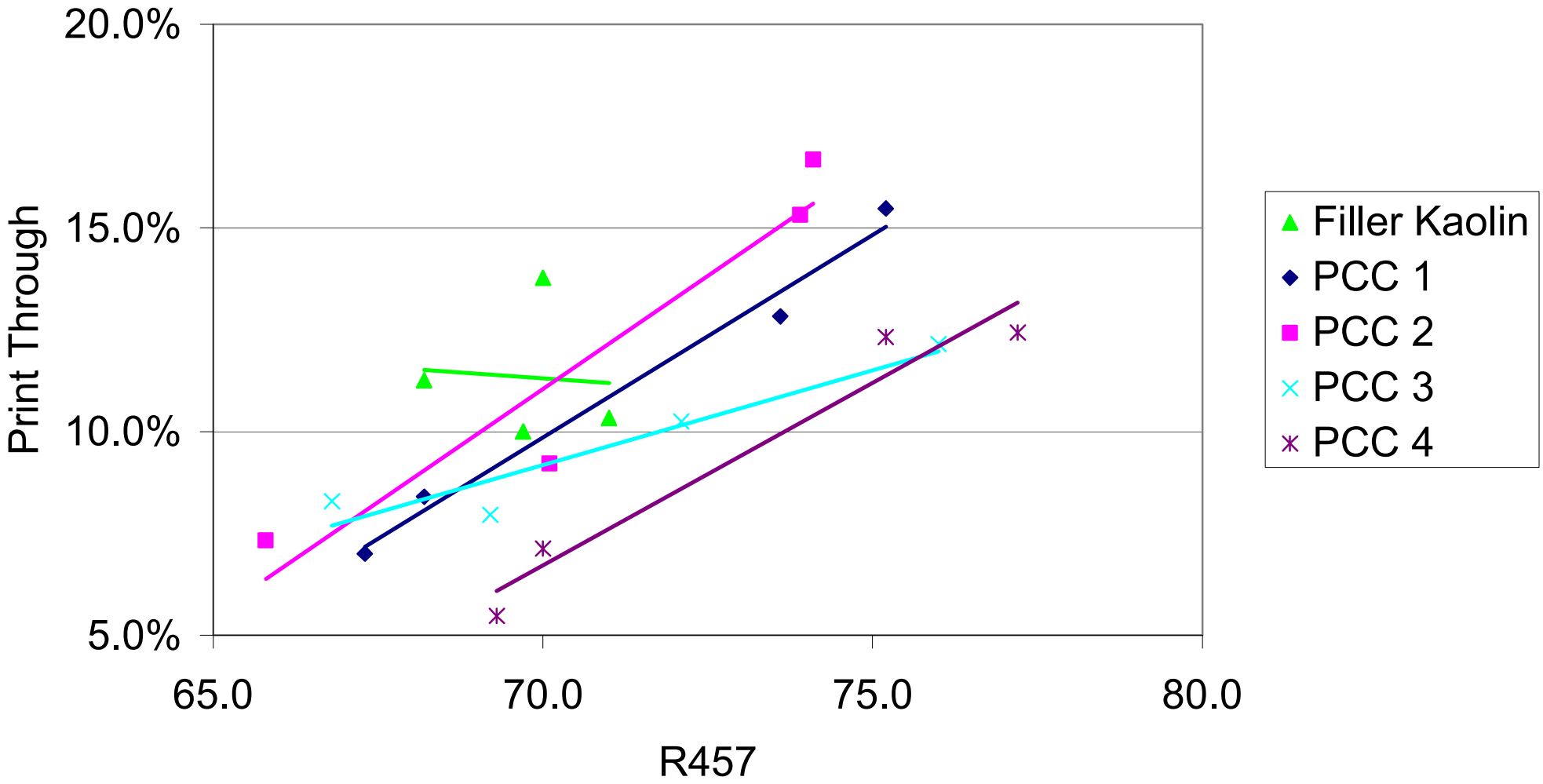
Print through vs Surface Filler



Secondary effect of Ash Distribution on Ink Strike Through



Print Through versus Brightness



Conclusions

- Filler distribution in Z-direction varies quite significantly depending on forming section and pulp. Filler distribution can be “frowning”, “smiling” or skewed.

- Our experiments have demonstrated a strong impact of filler distribution on paper and printing properties, and we found very strong interactions between filler type and filler distribution.

  The effect of a higher surface filler level on printing properties may thus change completely with different filler.

- There can consequently be a risk of drawing false conclusions if the surface filler concentration is not taken into consideration.