GCC vs. PCC as the primary filler for uncoated and coated wood-free paper

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ABSTRACT

Calcium carbonate ($CaCO_3$) has become the dominant filler in the production of wood-free uncoated paper and coating base stock. This work compares the use of natural ground $CaCO_3$ (GCC), with its natural rhombohedral particle shape, and precipitated $CaCO_3$ (PCC), a typical filler of scalenohedral morphology (S-PCC), in a papermaking environment. Although other PCC morphologies are possible, the scalenohedral shape was chosen for comparison because it is the most common PCC particle shape for use as a paper filler. The S-PCC morphology adds significantly to paper thickness.

To demonstrate the basic differences of both types of pigment, uncoated wood-free paper (80 g/m^2 and 22% filler loading) was produced on a pilot paper machine. Only the type of filler or the ratio of fillers in the blend was changed. All other parameters where kept constant. The results showed that GCC facilitated drainage and drying of the paper web, producing a sheet with a lower size demand, a more closed structure, and higher strength.

The S-PCC applied in this comparison provided higher light scattering and higher paper bulk, producing a sheet with a distinctly more open structure. After calendering, the S-PCC filled sheet showed a slightly lower roughness (PPS, Parker Print-Surf). Despite the disparity in paper bulk between the GCC and S-PCC loaded papers, there was no difference in paper stiffness.

Commercial experience confirms the trends observed in the pilot study. The specific individual situation and the choice of pigment configuration strongly affect these tendencies. Useful compromises offer the combination of GCC and S-PCC either as a ready-to-use premixed product or with each type of pigment added individually via a dosage point into the paper machine system. Older paper production units can exhibit drying-capacity limitations, and in such situations, a combination of both pigments, GCC and S-PCC, is especially advantageous to the papermaker.

In coating base stock, GCC as a primary filler also carries the potential of a faster draining and drying sheet structure. This is particularly pronounced at higher basis weights and higher primary filler loading levels. The GCC-filled sheet usually exhibits significantly higher internal bond values vs. the S-PCC-loaded paper. This holds the potential of higher primary filler loadings at equal internal paper bond.

S-PCC produces higher base-paper bulk compared with GCC. However, this higher bulk diminishes with calendering of the coated sheet. After coating and printing in a pilot study, the choice of primary filler had no effect on surface roughness, paper and print gloss, or print quality.

Keywords:
Fillers, natural ground $CaCO_3$ GCC, precipitated $CaCO_3$ PCC, GCC/PCC blends, uncoated paper, coating base paper

INTRODUCTION

The desire for higher brightness and its strategic implementation in the marketplace has been clearly observed for several decades. Despite sporadic critical evaluation of the sense or realistic need for this brightness trend, there has been no halting influence on the market behavior.

Calcium carbonate ($CaCO_3$) fillers, which have much higher pigment brightness than kaolin, have proved to be the main cost-saving option in improving the basic paper brightness. Given this brightness asset and their worldwide availability, calcium carbonate fillers have become one of the most important pigments in the field of wood-free paper grades.

GCC AND PCC FILLERS—MORPHOLOGICAL DIFFERENCES

Natural ground calcium carbonate (GCC) filler has a rhombohedral particle shape, as seen in **Fig. 1**. The morphology of precipitated calcium carbonate (PCC), on the other hand, can be adjusted within certain technical and chemical limits. These differences can lead to significant variation in the production costs of a PCC.

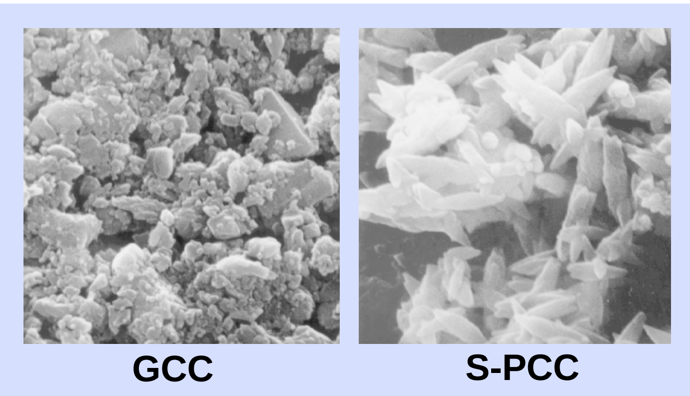

Figure 1
GCC and S-PCC fillers

The most common PCC particle shape used in the paper industry is scalenohedral. This structure is valued for its ability to increase paper bulk. Particle shapes other than the scalenohedron can be manufactured, but these structures have higher technological requirements and additional costs. To simplify presentation of the following results, scalenohedral PCC is termed S-PCC.

GCC AND S-PCC IN PRODUCTION OF UNCOATED WOOD-FREE PAPER—PILOT TRIALS

TRIAL CONDITIONS

Trials were performed on a pilot paper machine to compare the performance of both materials as single pigment or in blends. The emphasis of these trials was on the pigments themselves and their direct and indirect effects on the production process as well as the achievable paper quality.

The working width of the pilot paper machine was 70 cm. Machine speed was 80 m/min. The furnish was 25% pine sulfate (30°SR freeness) and 75% birch sulfate pulp (30°SR freeness). The sizing agent was AKD (alkyl ketene dimer) with a promoter at a total dosage of 0.12% (dry/dry). A good retention of the filler and the sizing agent was achieved using a microparticle retention system supported by an additional 0.5% cationic starch. Following normal production conditions, a market-available anionic OBA (optical brightening agent) was also added (0.2%, 1/3 in the wet end and 2/3 in the size press). Sheet grammage was 80 g/m^2, and the adjusted filler content in paper was set at 22%.

Table I lists the specific pigment data corresponding to the three filler grades used in this study. GCC 60/7.0 (60% < 2 µm with a specific surface area of 7.0 m^2/g) is a European standard quality from a marble resource. GCC 85/7.5 (85% < 2 µm, 7.5 m^2/g specific surface), also from a marble-based source, is designed to develop a higher paper opacity than the standard GCC 60/7.0. The S-PCC used in these trials represents a typical S-PCC filler commercially available from an on-site production unit. All three filler pigments show a high pigment brightness of approximately 95% Elrepho R-457.

	GCC 60 / 7.0	GCC 85 / 7.5	S-PCC
Specific BET, m^2/g	7.0	7.5	6.5
Sedigraph, % < 2 µm < 1 µm	 60 35	 85 60	 45 15
Avg. particle size, µm	1.5	0.8	2.1
Brightness (Elrepho, R-457), %	94.5	95.0	95.5

Table I
Pigment data

PAPERMAKING PROCESS

As shown in **Fig. 2**, the usage of 100% S-PCC displays a clearly lower dry content after the wire suction roll compared with 100% GCC. Blending GCC with S-PCC clearly improved the dryness at the couch roll, which translates to higher initial strength for the wet web.

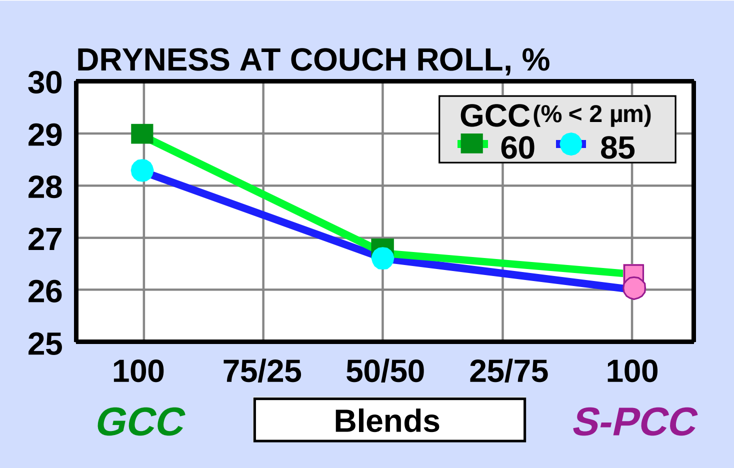

Figure 2
Drainage trends as indicated by dryness at couch roll

The dewatering trends depicted in Fig. 2 at the couch roll are confirmed by the results in **Fig. 3**, which shows dryness after the third press.

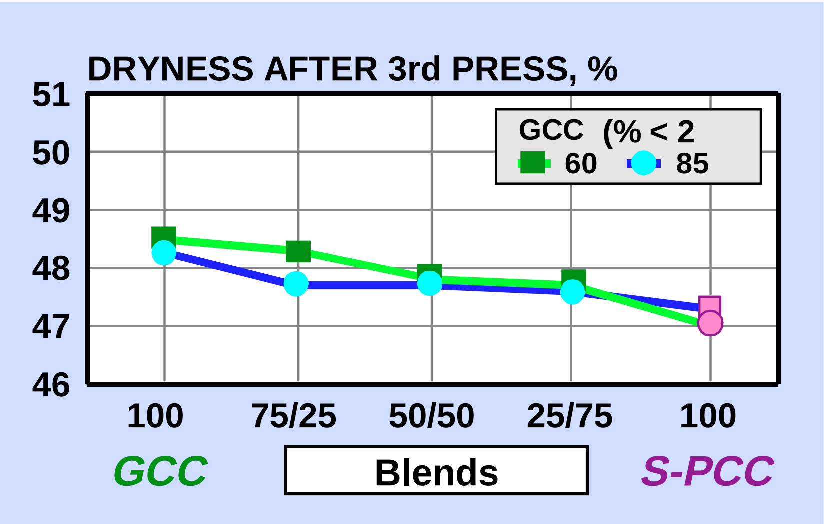

Figure 3
Drainage trends as indicated by dryness after third press

The slowdown of dewatering with S-PCC as filler can be partly explained by the pigment's voluminous structure. Paper formed with this pigment has a higher bulk mass, which requires subsequently higher drainage power.

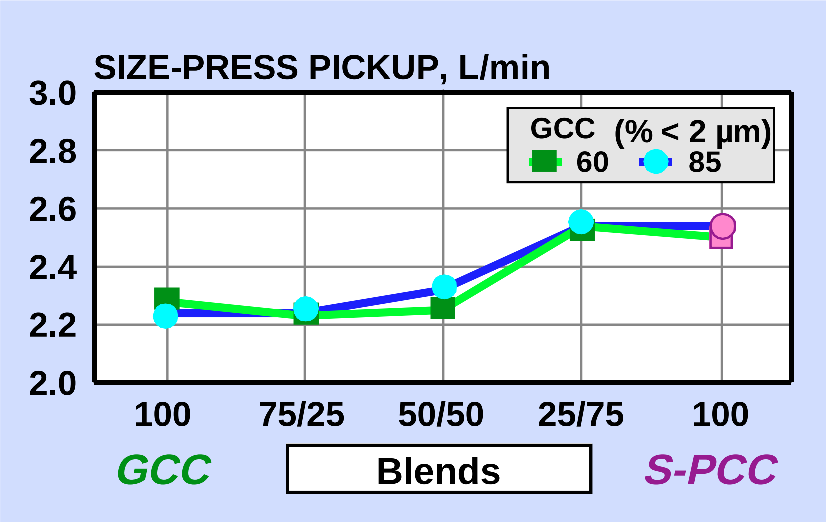

Figure 4
Size-press pickup (starch/polymer)

If a PCC with a prismatic (as opposed to a scalenohedral) structure had been used, the dewatering behavior would have been comparable with that of GCC, but such a structure would not produce such a high paper bulk. **Figure 4** shows that at high levels of S-PCC, pickup in the size press increased drastically. This phenomenon is surely due to the higher paper bulk with its open, porous paper structure. In an earlier investigation on the same pilot machine regarding an organic filler to achieve extra high paper bulk, a significantly higher pickup of starch in the size press similar to S-PCC was observed.

PAPER QUALITY

Paper produced on the pilot machine was finished by passing the sheet through a machine calender at pressures of 15 and 30 kN/m. Sheets produced using S-PCC as single filler or in a blend with GCC showed a nearly linear increase in thickness and bulk with S-PCC content, as seen in **Figs. 5 and 6**, respectively.

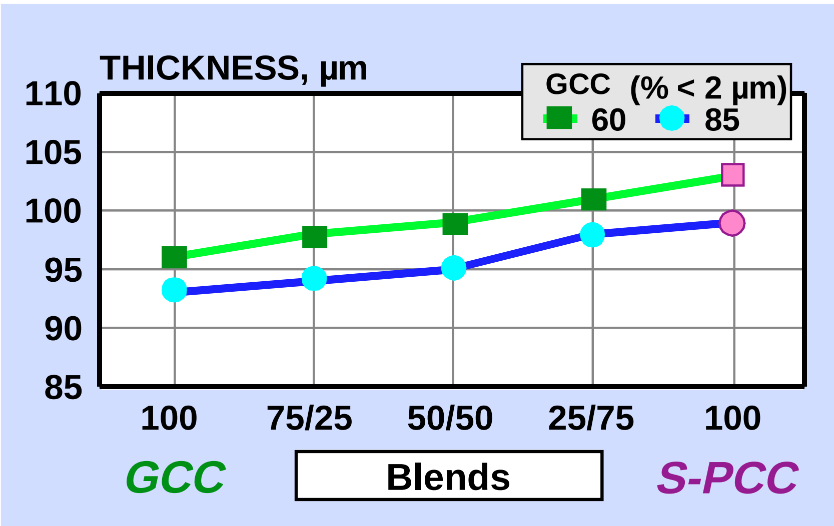

Figure 5
Thickness

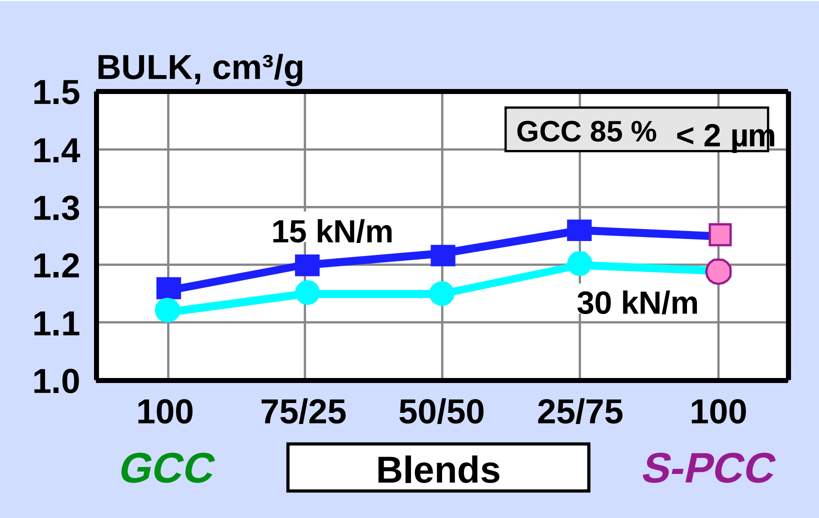

Figure 6
Bulk

S-PCC, in the form of single particles of filler, gives a higher bulk than GCC, which creates a relatively high voluminous structure through further interparticle flocculation. The resulting separation between the paper fibers increases, thereby increasing paper thickness and bulk.

However, the higher paper bulk generated by an S-PCC pigment does not automatically translate to a measurable increase of paper stiffness, as measured by resonance in **Fig. 7**. A research of market paper confirms this observation.

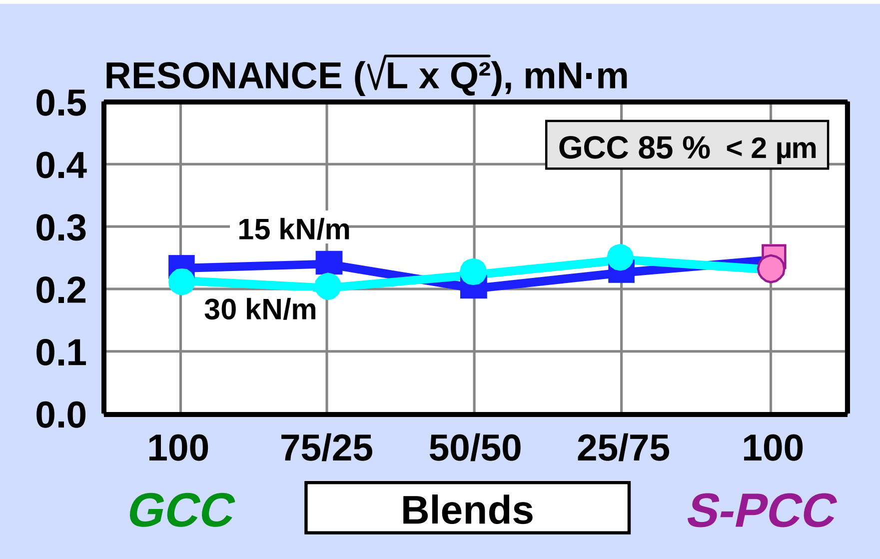

Figure 7
Stiffness

S-PCC particles increase the separation between fibers and flocs, thus reducing the occurrence of hydrogen bonds. **Figure 8** shows the reduction in sheet strength with increasing S-PCC content.

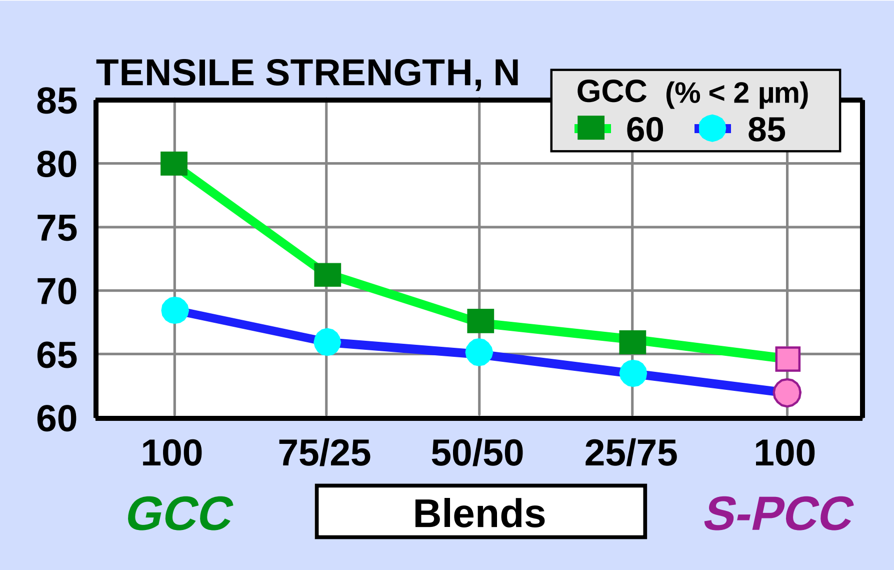

Figure 8
Tensile strength in machine direction

The difference in tensile strength between 100% S-PCC and 100% GCC 60/7.0 is dramatic. Tensile strength for GCC 85/7.5 is less than that obtained with GCC 60/7.0, which can be explained by the greater fineness of GCC 85/7.5.

Based on results of a lab study, sheet tensile strength decreases when the average S-PCC particle size exceeds 2 µm. However, coarser S-PCC grades—used to increase paper bulk—also have higher dusting tendencies, a well-known problem in copy-machine papers.

Paper porosity increases with increasing S-PCC content, as seen in **Fig. 9**.

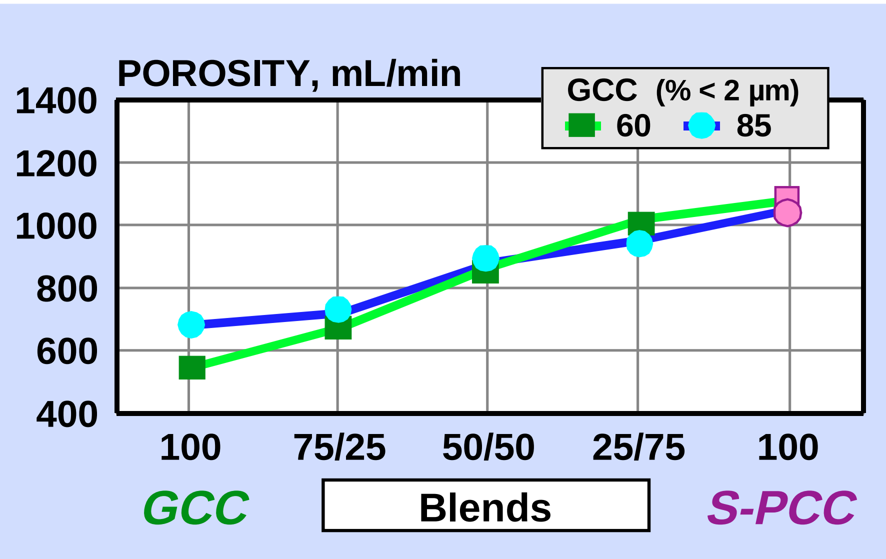

Figure 9
Porosity (Bendtsen)

Porosity can be positively influenced, i.e., the paper surface can be made more closed, through appropriate combinations/blends of S-PCC and GCC. In practice, the porosity of the paper structure is adjusted by further fiber refining, which of course incurs additional energy costs. Stronger refining also increases the hygroscopic sensitivity of the fibers and the resultant paper sheet.

The values in **Fig. 10** relate the influence of pigment on the roughness of the paper surface. Increasing the amount of S-PCC tends to lower surface roughness. Comparing 100 parts S-PCC to 100 parts GCC, the difference ranges from between 0.5 to 0.8 µm, measured with the Parker Print-Surf. However, these differences in surface roughness were not apparent on printed samples.

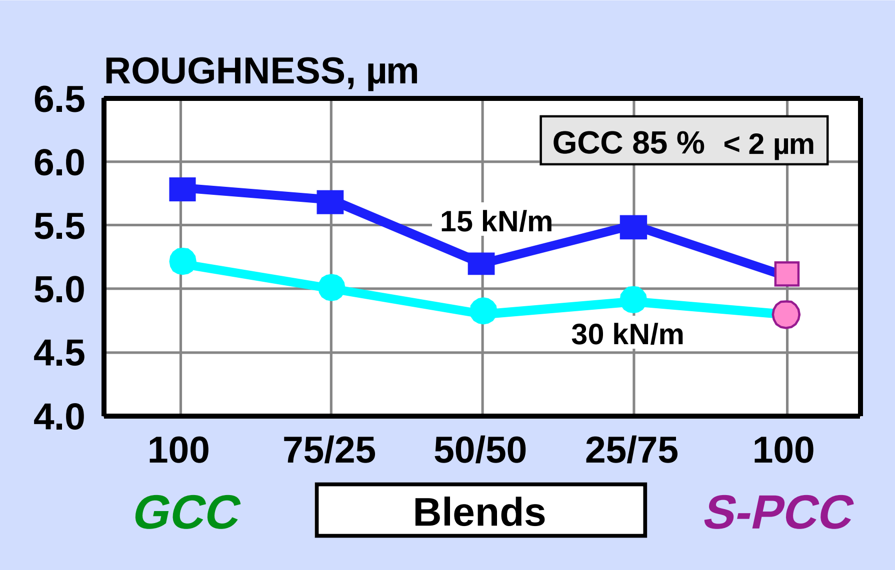

Figure 10
Roughness (PPS)

As already mentioned, all three fillers showed a similar pigment brightness of 95% with Elrepho R-457. The brightness differences measured in the manufactured base sheet are therefore minimal, as seen in **Fig. 11**.

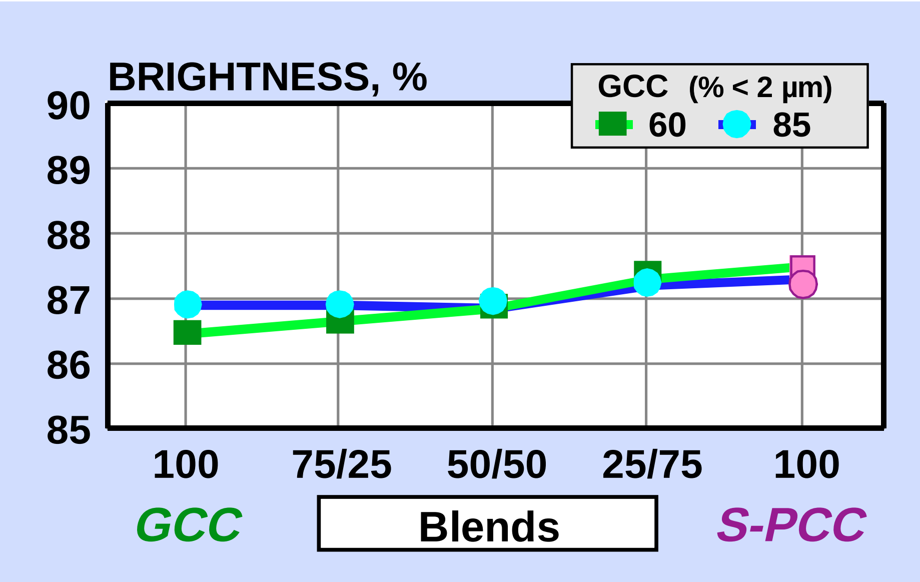

Figure 11
Brightness R-457 - UV

The very slightly higher brightness with S-PCC in comparison with GCC is mainly due to its comparatively higher light-scattering coefficient as a function of filler–fiber voids. The slightly darker fiber is better hidden.

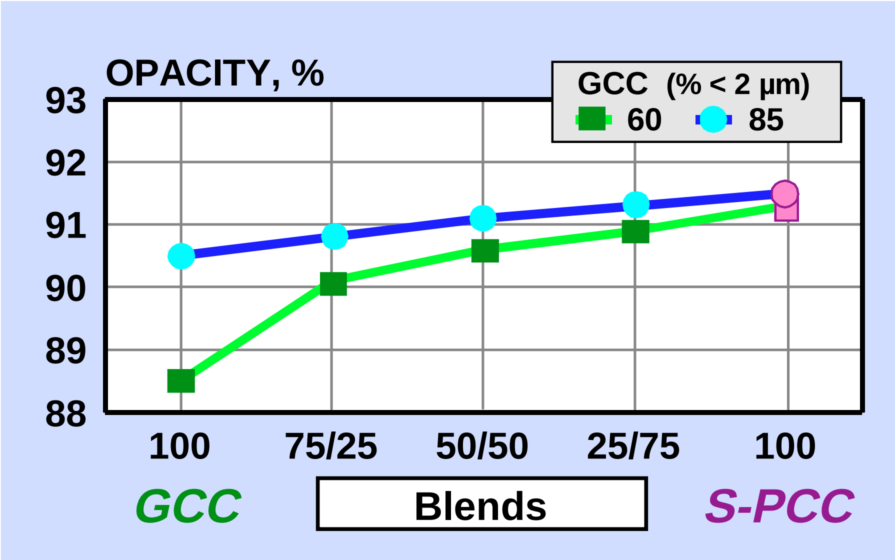

Figure 12
Opacity for 80-g/m² sheet

Figure 12 shows that the light-scattering effect (opacity) is increased by the fineness of the GCC particles.

The literature reports that the use of S-PCC pigments can lead to difficulties when sizing with AKD. This phenomenon was also noticed in these trials. The results in **Fig. 13**—at a dosage of 0.12% AKD (dry/dry)—show that sizing was insufficient even at 50% S-PCC content.

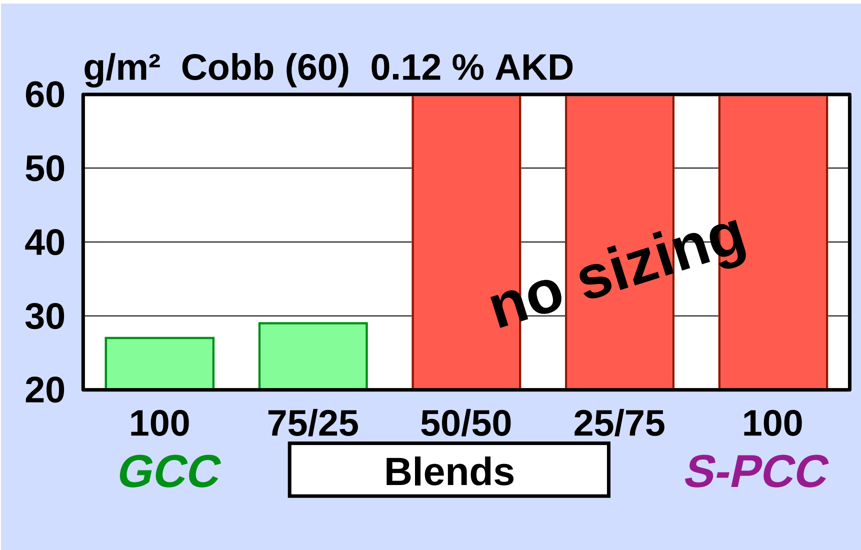

Figure 13
Sizing

In a following trial made under the same conditions, a 50% higher AKD demand was necessary to reach the desired sizing. The primary reason for such a high AKD demand is to be found in both the higher paper humidity of the sheet web when entering the predrying section as well as the remaining quantity of $Ca(OH)_2$ when using PCC.

At high temperature and high moisture levels, the reaction between AKD and water (hydrolysis) is very strong. This hydrolysis of AKD is additionally supported by the remaining traces of $Ca(OH)_2$ (alkaline).

SUMMARY OF TRIALS ON THE PILOT PAPER MACHINE

Both GCC and S-PCC fillers can increase sheet brightness. The natural rhombohedral GCC facilitates dewatering and drying of the web. On the other hand, S-PCC provides a significantly higher paper bulk. This higher paper bulk, however, does not automatically lead to additional paper stiffness. GCC fillers reduce sheet strength less than S-PCC. This gives an advantage to GCC for higher filling levels and associated reduction in fiber costs.

The specific structure of S-PCC and the steep particle size distribution curve provide this pigment with a high light-scattering coefficient for good opacity. GCC 85/7.5, with its increased fineness and steeper particle size distribution curve compared with GCC 60/7.0, also shows a higher light-scattering coefficient and provides higher paper opacity. A paper with GCC as filler shows a significantly lower paper porosity than a sheet filled with S-PCC. The paper produced with S-PCC has, after calendering, a lower surface roughness. However, no noticeable differences could be found on printed samples related to this slightly lower surface roughness.

Due to the rhombohedral particle structure and the resulting better dewatering/drainage properties, as well as improved pH stability, the demand of sizing agent in this pilot study is lower with GCC compared with S-PCC.

The combination of both pigment types in different ratios allows a fast and flexible adjustment for the required paper quality. The specific optimal pigment ratios to achieve defined quality parameters can be easily fine-tuned.

NOTES FROM THE FIELD

The tendencies noted on the pilot paper machine have been confirmed on several occasions on existing production lines. The basic differences generated by the pigment are mainly dependent on the respective technical conditions. Considering that the aim is to produce marketable paper quality, direct pigment comparison is heavily influenced by several necessary correcting measures in practice. As a matter of fact, the new huge production machines usually have sufficient drainage and drying capacities built-in. A potential bottleneck in the postdrying section is typically found in older production units.

A combination of S-PCC (higher paper thickness) with GCC is, when facing insufficient drainage and drying capacities, of great advantage. With such an alternative, the papermaker obtains both high paper bulk and high strength. The demand of AKD is kept at normal levels, and the production speed (drainage) corresponds nearly to an operation using 100% GCC.

(+ = improved)	S-PCC	GCC/S-PCC
Refining demand	o	(+)
Drainage	o	++
PM speed	o	++
Bulk	o	-
CIE whiteness	o	+
Opacity	o	-
Stiffness	o	o
Roughness	o	-
Burst	o	+

Table II
Comparison of S-PCC and GCC / S-PCC blends (commercial experience)

The benefits of blending GCC with S-PCC are summarized in **Table II**. The experience of a European paper manufacturer is typical: The mill made several trials to produce a high quality 80-g/m^2 copy paper using 100% S-PCC of different origins on a fourdrinier machine. The mill saw that dewatering became distinctly worse and consequently had to reduce PM speed by about 10%. Additionally, the open paper structure could only be closed by higher fiber refining, which required a 20% increase of energy demand. With a filler combination 50% S-PCC / 50% GCC, the customer went back to the original machine speed and could reduce also the required fiber refining. At identical smoothness levels, the paper thickness decreased only by 2 µm and the opacity by 0.5%. With this pigment formulation, an increase of paper strength of nearly 10% was observed.

In Europe, huge amounts of copy paper with filler loads up to 28% are produced and absorbed by the market. An analysis of this paper shows a successful implementation of 100% GCC.

GCC AND S-PCC AS PRIMARY FILLER IN WOOD-FREE COATING BASE PAPER

The major properties required for a wood-free coating base paper are sufficient tensile strength, good internal bond (Scott bond), and stable water absorption and wetting properties at high dimensional stability. High brightness and acceptable opacity are simply a must, with a closed surface being considered of great advantage. Pigment content, including primary and secondary filler, is at a level of about 12–20%, depending on the grammage.

In a specific trial on the pilot paper machine, an 80-g/m^2 coating base paper was produced. As primary filler, 8% and 12% GCC and S-PCC, respectively, were compared. As a result of the addition of coated broke, the amount of secondary pigment in the coating base paper was 8%. Using a compromise between double coating and single coating practice, a single coat of 15 g/m^2 per side of coating color was applied with bent blade. The coated paper was afterwards calendered and offset printed. The results of this trial are summarized in **Fig. 14**.

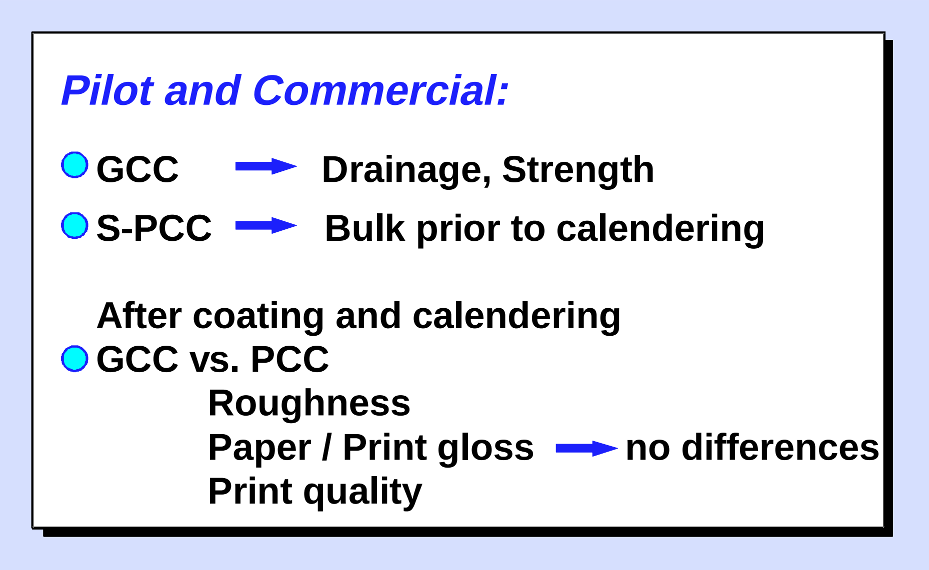

Figure 14
Comparison of GCC and S-PCC in coating base paper

Again, the GCC-filled web showed better drainage properties. Moreover, the internal bond (Scott bond) was significantly higher with a standard GCC. As expected, the coating base paper produced with S-PCC as primary filler showed higher bulk, a property that was no longer visible after calendering of the coated paper.

After coating and calendering, no significant differences regarding roughness, paper and print gloss, or printability could be detected. What was influenced, however, were the optical properties of the coated paper by those of the coating base paper (being generated by the filler).

In practice, using GCC as primary filler is of particular advantage in papers of higher grammage. The reason behind this is mainly the better dewatering and drainage properties and, as already mentioned, the higher Scott bond with this filler. Higher and better drainage also provides the option of increasing production speed. Finally, the higher Scott bond with standard GCC will allow a higher filler loading. High filling levels positively influence opacity and brightness of the paper.

At the same filler content, a paper with S-PCC as primary filler will, due to the higher light-scattering coefficient of the pigment, have a higher opacity than a sheet with a standard GCC. The difference is mainly dependent on the added amount of primary filler. A GCC 85/7.5 filler will lead to similar paper opacity as when using less fine S-PCC grades. The combination of standard GCC and S-PCC as primary filler in wood-free coating base paper is not unknown in the United States. A close look at the pigments from the coated broke together with S-PCC primary filler are already representing the combination GCC/clay/S-PCC.

Conclusion

Both the pilot and commercial examples illustrate the important attributes of GCC and S-PCC. They are very different in performance and therefore provide a wide range of options for producing papers with various end-use demands. GCC provides strength and higher loading potential, easier drainage and drying, low size demand, and higher sheet density. PCC provides higher opacity at lower filler loadings and lower density (higher bulk). Thus papermakers can choose the attributes necessary for a particular grade. Both type of pigments provide high brightness at a low cost.