SC print quality influenced by fiber length, fabric structures, and machine drainage characteristics

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NOTE: This paper presents details of an in-depth study of European and North American supercalendered (SC) printing grades. It shows that the final print quality is influenced by headbox fiber length, forming fabric fiber support spans in relation to fiber length, and machine drainage forces and turbulence on each side of the sheet. Using a unique computer print simulation technique developed by AstenJohnson Research, the study clearly shows that it is the outermost layer of the sheet that directly influences final print quality.

This study is based on the analysis of stock samples taken from the headbox, commercial sheets made using that headbox stock, and a detailed analysis of the forming fabric used on each side to form the sheet on that particular paper machine.

Each sheet was split (lamination technique), first in half, and further into a total of 14 parts. The uniformity of the outside 12.5% of each surface was then examined and compared to the remainder. The image of the outside 25% was used for the computer print simulation process.

Application: This study demonstrates the need to use an "engineered approach" to forming fabric design selection.

This study gathered information to compare North American and European supercalendered (SC) grade paper production and quality. The analyses included headbox stock, sheet, and forming fabric structures taken from commercial machines operating on a number of different types of formers in Europe and North America.

Headbox fiber length analysis

Table I shows the abbreviated results of the fiber length analysis for each headbox stock. There is a considerable range of fiber lengths used to make the same grade of paper. The extremes are 0.63 mm in Sample A North American and 0.51 mm in Sample B Scandinavia to 0.34 mm in Samples F, G, and H from North America and Europe. These stocks were prepared from many different wood species, growing in different climatic conditions, and processed by different pulping processes. They may also include recycled components.

Despite these variables, these are the lengths of the fibers approaching the forming fabrics that will filter the fiber from the water to form the sheet, under that particular paper machine's drainage forces.

Forming fabric papermaking surface

This paper concentrates only on the top surface filtration characteristics of the forming fabrics used to make these SC grade sheets. Examination of the sheets and the data provided show that only standard double layer in the 8-shed configuration and standard triple layer using the plain weave top surface were used.

To understand the relationship between the fiber lengths exiting the headbox and the drainage orifices on the forming fabric's top surface, we need to define those drainage orifices' physical dimensions. We also must define the support provided to the fibers exiting the headbox by the yarns in the fabric's woven structure. This definition has to bear in mind that the predominant orientation of the fibers exiting the headbox is in the machine direction (MD) and that all the turbulence-generating forces of blades and vacuums run in that direction.

The photographs shown in **Fig. 1** are of the two forming fabrics typically running on SC grade machines. On the left (A), is the top drainage surface of a standard double-layer 8-shed fabric, and on the right (B) a typical standard triple layer. The holes through which drainage occurs have been shaded. In the case of the double layer, there are two holes–a large one and a smaller one. Groupings of these two holes form the fabric's top drainage surface. The triple-layer's top surface is comprised of a uniformly sized one-hole pattern.

Each top surface consists of a definite, uniform, repeating pattern that can be defined and calculated in a computer program. Underneath each photograph are enlargements of the repeating pattern on each top surface. With the MD and cross-machine direction (CMD) mesh, yarn diameters and weave pattern, we could define each forming fabric's top drainage surface for all of the machines involved in the study.

A Microsoft Excel based program was developed to calculate and define the papermaking characteristics of each forming fabric surface in use (**Fig. 2**).

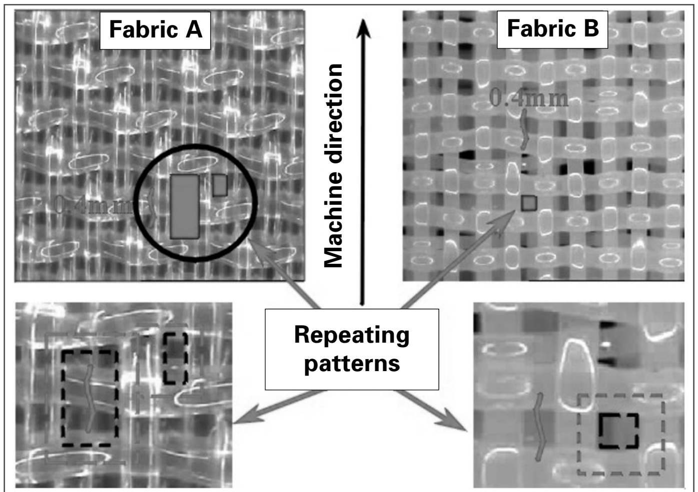
Using information entered into the computer, the program calculated the following:

- total top surface drainage area (drainage orifice)
- number of holes per square inch
- dimensions of each hole (drainage orifice)
- total MD support length per square inch
- total CMD support length per square inch
- ratio of these supports
- Beran Fiber Support Index.

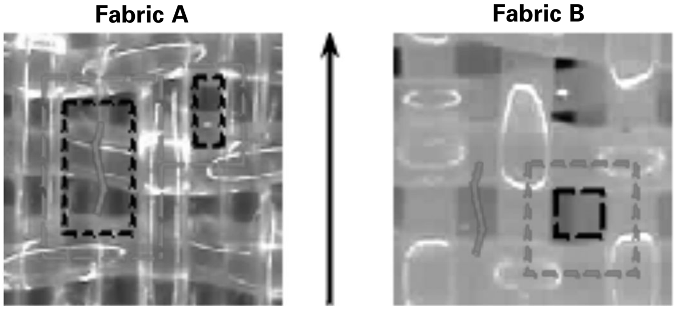
The numbers in Fig. 2 show that, despite

MILL REFERENCE	ARITHMETIC AVERAGE	LENGTH WEIGHTED AVERAGE	WEIGHT WEIGHTED AVERAGE	REPULPED PAPER
A North American	0.63 mm	1.74 mm	2.43 mm	0.67 mm
B Scandinavian	0.51 mm	1.67 mm	2.49 mm	0.62 mm
C North American	0.49 mm	1.52 mm	2.31 mm	—
D Scandinavian	0.37 mm	1.24 mm	2.37 mm	—
E European	0.36 mm	1.28 mm	2.40 mm	0.36 mm
F North American	0.34 mm	1.28 mm	2.43 mm	0.39 mm
G European	0.34 mm	1.07 mm	2.03 mm	0.46 mm
H European	0.34 mm	1.28 mm	2.43 mm	—

I. SC grade fiber length analysis.



1. Papermaking surface of two SC grade forming fabrics. (Note: fibers of 0.4 mm shown to scale on the photograph of each forming structure).



	FABRIC A	FABRIC B
Design (weave pattern)	8-shed D/L	Std. triple layer
Mesh (Total)	185 x 148	183 x 132
Papermaking surface mesh	185 x 74	93 x 53
Drainage area (%)	41.6%	31.6%
Holes/sq. inch	3422	4831
Hole #1 dimension (mm)	0.516 x 0.262	0.331 x 0.128
Hole #2 dimension (mm)	0.173 x 0.125	Only one hole
Max MD frame length (mm)	0.516	0.331
CMD support length (in/in^2)	46.3	52.8
MD support length (in/in^2)	69.4	91.4
Support ratio CMD/MD	0.67:1	0.58
Beran fiber sup. index	108	131
CFM	320	345

2. Engineering details of drainage surface characteristics.

the apparent fine mesh of the 8-shed double layer, it has a significantly greater drainage area (41.6%) than the triple layer (31.6%) and fewer drainage holes per square inch (3423 vs. 4831). One large drainage hole has MD dimensions that are longer (0.516 mm) than some of the shortest average fiber lengths of our stock analysis (0.34 mm). The other drainage hole in the double layer is very small. The triple layer, on the other hand, has equally sized drainage holes, the MD dimension of which (0.331 mm) is quite short in comparison to the average fiber length of 0.34mm. To understand the fiber support provided by the yarns used to form the drainage surface, it is helpful to review the calculated MD and CMD length per square inch. These numbers show that the double layer provides high MD support to CMD while the triple layer support is quite square. Finally, the Beran Fiber Support Index, which is calculated using the weave pattern and the MD and CMD yarn fiber support, (with a double weighting to CMD) shows that the triple layer has a much higher number than the double layer.

Cubic feet per minute (ft^3/min or cfm) is shown because many paper mill superintendents focus on that number to select forming fabrics. The cubic feet per minute numbers shown in Fig. 2 would indicate that both of these fabrics should be quite equal in drainage. However, the result, as seen by the final sheet properties, can be quite different.

When considering fiber orientation in relation to the holes in the fabric structure, remember that the majority of the fibers exiting the headbox are aligned in the MD. It is these fibers that first contact the fabric structure. It therefore follows that high CMD fiber support would be beneficial.

Using the Microsoft Excel based program, the engineering details (**Table II**) have been calculated for the two 8-shed double layers and two triple layers used to form sheets as shown in **Figs. 3A and 3B**.

Despite the high apparent mesh count of the standard 8-shed double layers, they are both very open in top surface drainage area (41.6% and 42.7%), compared to the two triple layers (31.6% and 30.6%). These drainage areas are the only passages or orifices through which drainage occurs on the top side. This considerable difference in top surface drainage area is not reflected in the cfm values, which are all in the same region of 310 to 360 ft^3/min. The standard 8-shed fabrics also have low Beran Fiber Support Index, and low number of drainage holes per square inch, with one set of holes larger than the other. The larger hole has a long MD frame length in relation to the average fiber length exiting the headbox. The triple layers, on the other hand, have a higher number of drainage holes per square inch. In fact, the intrinsic weft fabric has twice that of the double layer. Both triple layers have only one drainage hole—the MD dimension of which is short in comparison to the double layers, especially the intrinsic weft fabric which is four times shorter than the 8-shed double layer.

Note that both 8-sheds and the standard triple layer have a higher predominance of MD support to CMD which gives them a low CMD ratio. On the other hand, the intrinsic weft triple layer has high CMD support to MD. This feature has proven to

DESIGN/WEAVE PATTERN	STD 8-SHED	STD 8-SHED	STD TRIPLE LAYER	INTRINSIC WEFT TRIPLE LAYER
Mesh (Total)	185 x 148	183 x 160	182 x 132	146 x 200
Paper making surface mesh	185 x 74	183 x 80	91 x 53	73 x 100
Drainage area (%)	41.6%	42.7%	31.6%	30.6%
Holes/sq. inch	3422	3660	4831	7300
Hole #1 dimensions (mm)	0.516 x 0.262	0.485 x 0.266	0.33 x 0.128	0.124 x 0.218
Hole #2 dimensions (mm)	0.173 x 0.125	168 x 0.128	Only one hole	Only one hole
CMD yarn support length in/in^2	46.2	50.0	52.8	100.0
MD yarn support length in/in^2	69.4	68.6	91.4	73.0
Support ratio CMD/MD	0.67:1	0.73:1	0.58:1	1.37:1
Beran Fiber Support Index	108	112	131	182
Ft^3/min (cfm)	320	310	345	360
Thickness (inches	0.022	0.021	0.028	0.036
Wear volume (cc/sq. m.)	5.0	5.2	15.4	39.5
Fabric CD stiffness (Gurley) m/gram	3.0	2.8	4.0	15.0

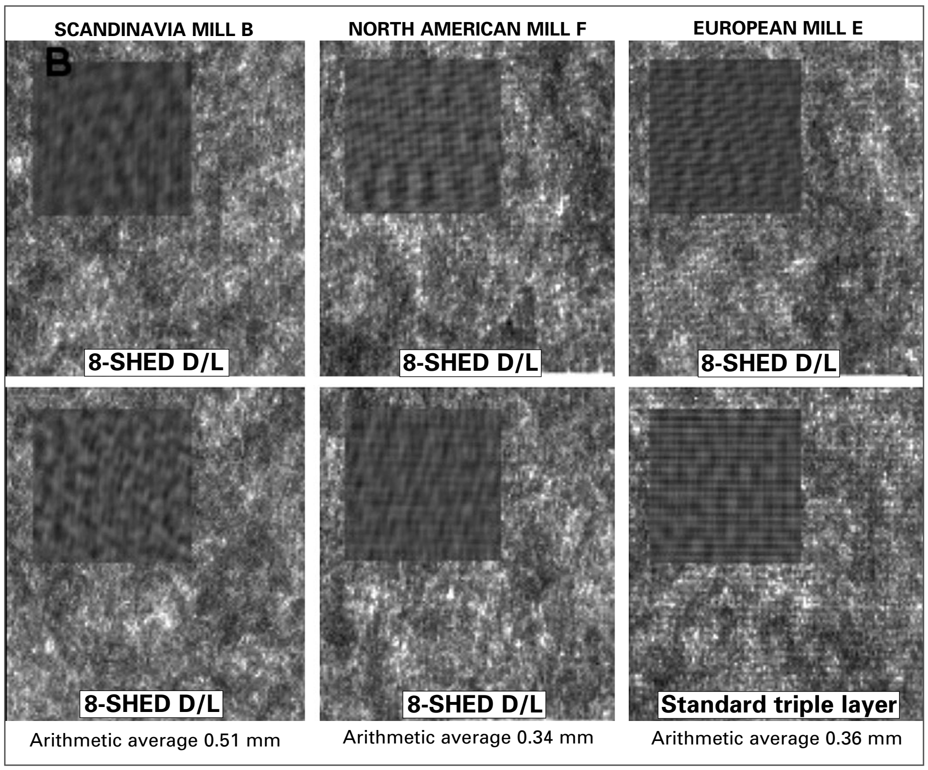
II. Engineering details of drainage surface characteristics.

be beneficial in supporting the short MD-oriented fibers.

The intrinsic weft fabric has been designed for greater wear volume to combat increasing abrasion from contaminants such as clays and titanium dioxide. Note that the volume available for wear is eight times greater than the fine double layers and over twice as much as the standard triple layer.

Fabric stiffness is becoming an important feature as machine speeds increase and basis weights go down, especially on twin-wire formers. Experience shows that the fabric's CMD stiffness can have a considerable influence on 2 sigma CMD basis weight profiles. The intrinsic weft's high stiffness is imparted by its unique weaving technique. Pairs of intrinsically woven weft yarns are used to form a strongly bonded integrated structure. As structures become thinner, as in the case of the double layers, or have slight independent binder yarns, as in the standard triple layers, the built-in CMD stiffness falls off dramatically.

The increased thickness of the intrinsic weft structure has only proven to be a problem on machines with weak or low attached CFM vacuum capacity.



3A. Split sheet images.

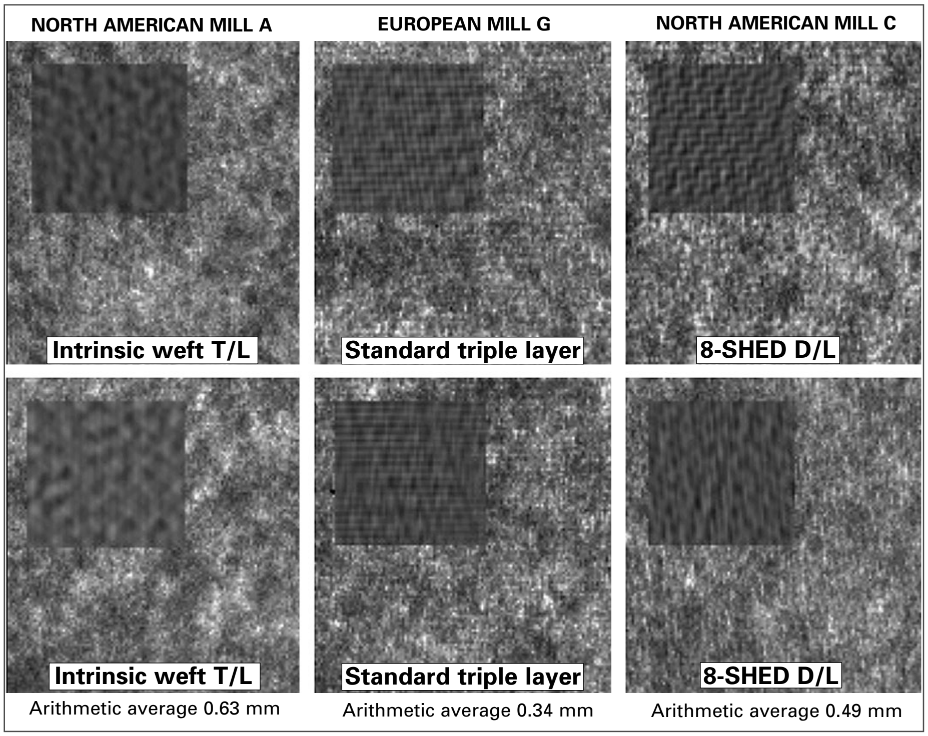
The sheet–image analysis

Figure 4 shows the results of whole and split-sheet image analyses [1]. The top two images in Fig. 4 were taken by transmitting light up through the *whole sheet* from two positions: (A) when the sheet had the side formed on the outer fabric closest to the camera and (B) when the inner fabric side was closest to the camera. These images show two different types of formation on the same sheet when viewed from different sides.

The bottom two images in Fig. 4 were also taken using transmitted light, but each image now represents the paper surface after sheet splitting, formed on each forming fabric. These images show that the surface formed on the outer fabric was more uniform and contained more fines than the sheet formed on the inner fabric side, which was open, contained numerous pinholes, and had a coarse fabric pattern. These fabric patterns have been highlighted using fast Fourier transform (FFT) techniques on the original image (top left insert image).

The bottom two images in Fig. 4 show the dramatic differences between the two sides. The differences are the micro-density variances contained on each surface of the same sheet, the patterns of which can be directly related to the forming fabric structure on which they were formed.

Experience in this area has shown that print quality for any printing process directly relates to the micro- (wire mark) and macro- (large floc) density variations on the surface on which the printing ink falls. [2]. In summary, when ink falls on a light, less dense area on the sheet surface, it will be absorbed into the sheet, directly affecting print gloss and possibly strike through. When ink falls on a heavy area, it stays on the surface, producing high gloss but also problems of set off. The ideal print surface is one that is uniformly dense. The bottom two images in Fig. 4 show that the outer side was more uniform than the inner, which, in turn, would lead to two-sidedness problems on the printing press.



3B. Split sheet images.

Split sheet image samples

Six samples were chosen for illustration which correspond to the fiber lengths shown in Table I. The images shown in Figs. 3A and 3B were taken after each sheet was split. Each image is marked as to the type of forming fabric used to make the side of the sheet. The corresponding headbox fiber length is also shown.

Figure 3A shows that the level of wire mark increased as the fiber length became shorter.This can be seen by comparing the top row of images where the fiber length of the Scandinavian sheet B at 0.51 mm compares to the North American and European sheets made with the same fabric design but with fiber lengths of 0.34 mm and 0.36 mm respectively.

Figure 3B shows that, in the case of the North American Mill A, the combination of long fiber lengths and high support provided by the intrinsic weft fabrics resulted in no wire mark. For Mill G, even the relatively coarse standard triple layer showed a heavy wire mark with short fiber lengths. Finally, Mill C showed a very heavy wire mark on the 8-shed double-layer fabrics, despite the long fiber lengths, caused by higher turbulence and high vacuum forces on the one side of the sheet to the other.

The following machine types were used to produce the sheets shown in Figs. 3A and 3B – Duoformer CFD, Duoformer CF, Duoformer TQ, Speedformer HS, and Speedformer HSSC. (The order of the sheets is not related to the order of the machine types.)

Sheet forming to fabric relationship

Superimposed on the split-sheet images, under the FFT in **Fig. 5** are images of the fabric designs used to form the sheet. Close examination shows that the micro-density difference between the patterns shown in the FFT of each surface corresponds directly with the pattern on the forming fabric's top surface.The two bottom images are enlargements of the fabric insets above.

Multiple split sheet image analysis

In this study the original split sheet was further split as follows: the 50% was split to make two at 25%, and the outside 25% was further split to make two 12.5% on each side. **Figure 6** is an example of images taken of each split.

Figure 6 demonstrates that as the sheet is split all the density variations, both macro- and micro-, are concentrated on the very outside layer of the sheet, (approximately 12.5%), and that the inside of the sheet is uniform. This finding was true on all the sheets analyzed, both uncalendered and supercalendered.

This analytical work clearly shows that any formation tester producing a number based on information obtained by measuring the formation of the whole sheet, will give questionable results as it certainly does not indicate the final print quality on either surface. It can further be said that the outermost layer dictates the final print quality of each surface of each sheet. Additionally, the uniformity of the outside layer is controlled by the combined influences of headbox fiber length, top surface forming fabric support characteristics, and machine-induced turbulence or drainage forces acting on that particular side of the sheet.

Computer print simulation

Our industry has a major problem in that there is no test that will truly inform the mill as to final print quality on the printing press. Consequently, thousands of tons of paper are produced that could have questionable print qualities.

Our research group has developed a test that will simulate, through computer software, the final print quality. It uses the split sheet images of each side of the sheet as its base.

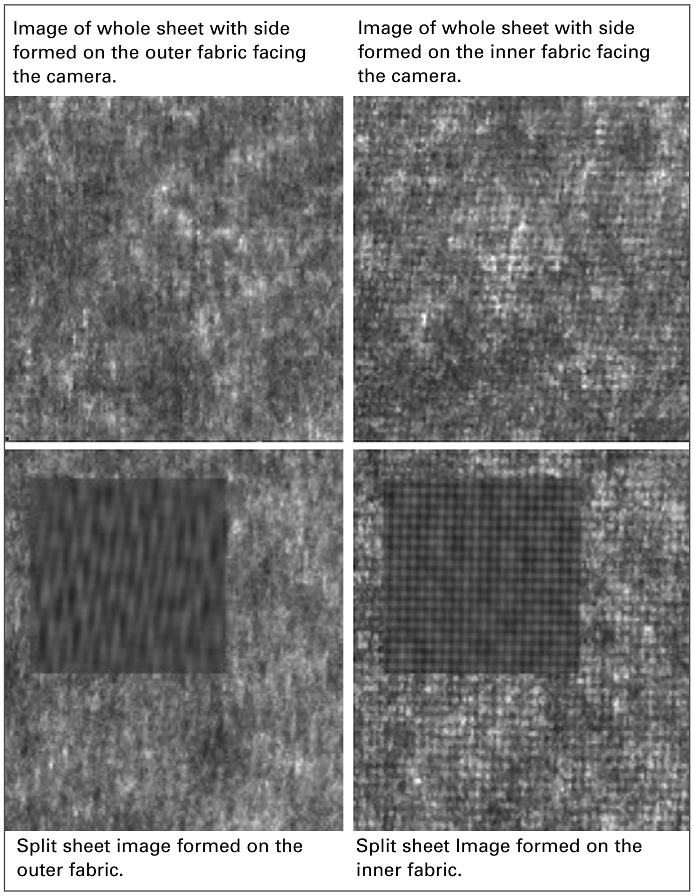
The split sheet images in Fig. 4 served as the base onto which the printing simulation was processed by the computer. **Figure 7** shows the simulated print quality that would have been achieved by these sheets. The Fig. 7 images are at 4x magnification to make them more easily understood. At this magnification, however, there is an obvious exaggeration of faults in the print quality.

Figure 8 shows the results of the computer print simulation done on the outside layers (12.5%) of the top half of the sheet as shown in Fig. 6.

From the above print simulation work, it can be seen that an almost perfect print would be the result if the outer 12.5% of the sheet could be removed!

Effect of supercalendering on final print quality

There is no doubt that soft calendering and/or supercalendering have a beneficial effect on apparent sheet uniformity. They compress the sheet and not only improve surface contact with the printing presses but also reduce the extremes of density differences.



4. Sheet image analysis.

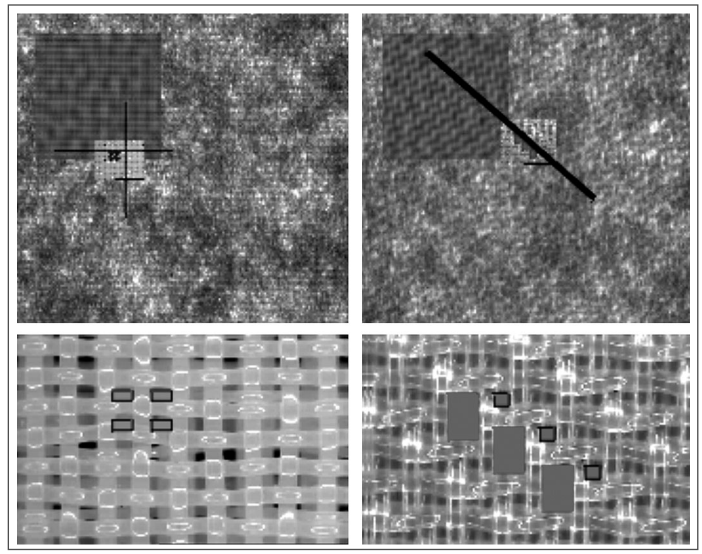
The images of the whole sheet appear to be uniform in density when viewed from both sides (**Fig. 9**). Yet when the sheet is split and each side is viewed independently, the micro-density differences caused by wire mark reappear. This situation supports the experience of having a good-looking sheet when viewing through the whole sheet and still receiving printing complaints. It returns us to the fact that print quality is directly related to the micro-density variations on the outermost 12.5% of each surface.

Figure 10 shows the results of a print simulation on both sides of the whole sheet, as shown in the top two images of Fig. 9 taken of each side of the sheet. Compare these to the print simulations in **Fig. 11** done on the split sheet images. The images shown in Fig. 11 are more realistic and relate more closely to the experience seen on a commercial printing press.

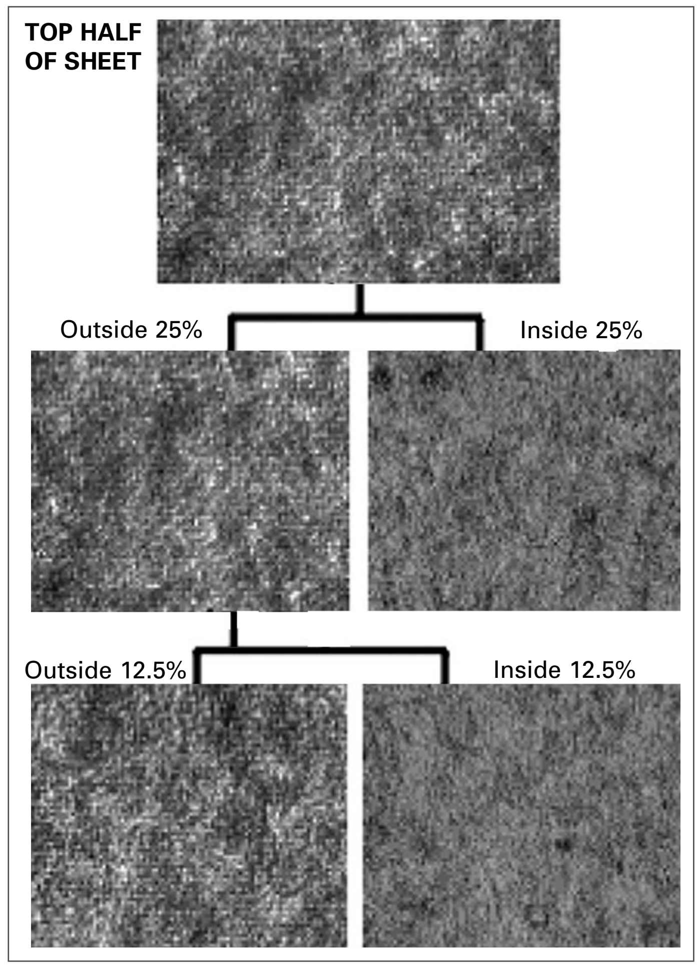
CONCLUSIONS

The following conclusions result from this study:

- The degree of micro-density variation (wiremark) can be directly related to headbox fiber length and the MD distance between CMD fiber support provided by the CMD yarns on the top surface of the forming fabric structure.
- Machines with long headbox fiber length had low wire mark, even with the long MD holes on the standard 8-shed double-layer fabric. However, machines using short fiber lengths had high wire mark when using standard 8-shed double layers, even when high CMD counts (160) were used. Many of these machines also resorted to using the shorter MD frame lengths provided by the plain weave top surface triple layer structures.

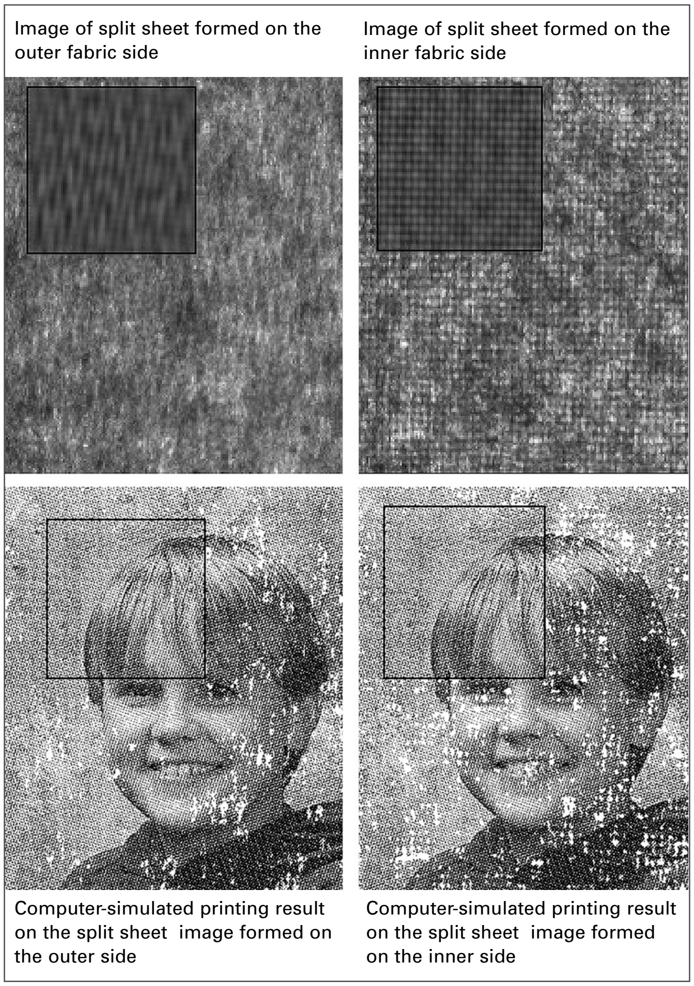


5. Fiber length–sheet micro-density differences–to forming fabric top surface topography.

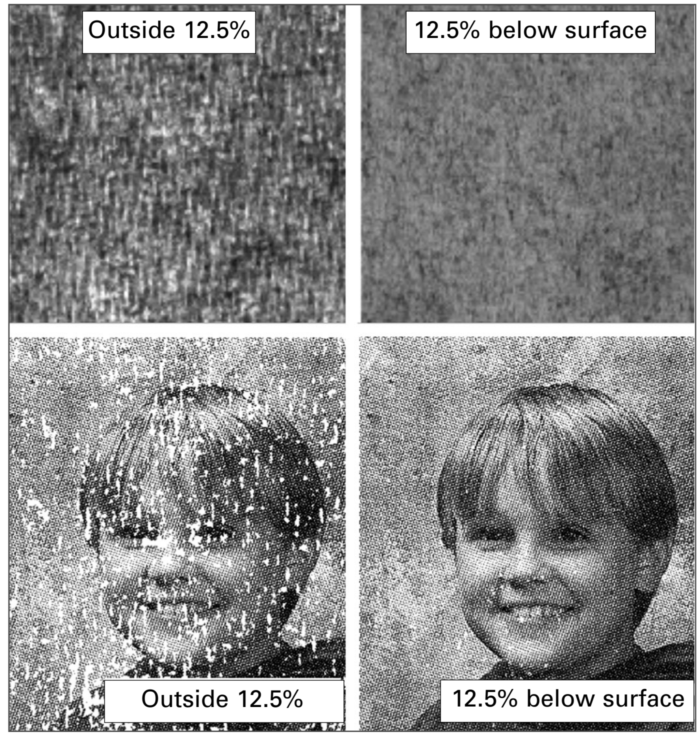


6. Multiple split sheet image analysis of top half of sheet; bottom half was similarly split.

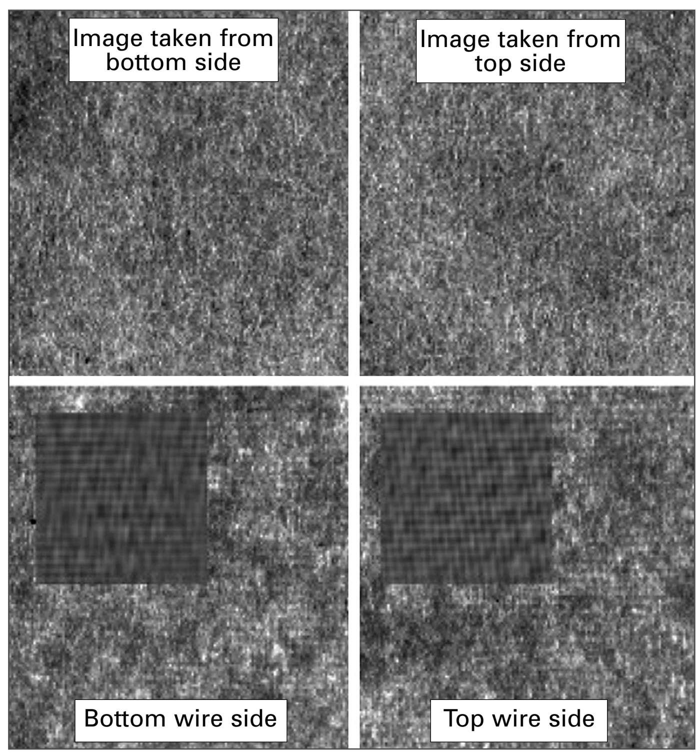
- Multiple split evaluations of all sheets, both off machine and supercalendered showed that the greater majority of both the micro (wiremark)- and macro (flocs)-density variations were to be found in the outside layers (approximately 12.5%) on each side of the sheet. The center portion (approximately 75%) of the sheet was almost perfect in its uniformity. It therefore follows that the final print and sheet



7. Print simulation.



8. Print simulation on outside layers of the sheet.



9. Whole and split sheet image comparisons.

quality is extremely dependent on the fiber lengths and the MD span between CMD supports of the forming fabric's top surface used on each side of the sheet. It is also dependent on the turbulent and drainage forces acting through the fabric and into the sheet.

- Finally, split sheet analysis showed that, although the look-through of a supercalendered full sheet looks uniform and acceptable, the original micro-density differences formed into the sheet during the forming process become evident after splitting the two separate sides. These surface micro-density differences that directly affect final print quality. **TJ**

LITERATURE CITED

1. Chaplin, D., "Image analysis: a powerful tool to pinpoint defects and gauge print quality," *Preprints of the 83rd Annual Meeting, Technical Section, CPPA*, Montreal, Quebec, Canada, 1997, A221-A223.

2. Danby, R., "Print quality advancement through cooperation," *CPPA/TAPPI International Printing and Graphic (Papermakers) Arts Conference Proceedings,* 1994, Halifax.

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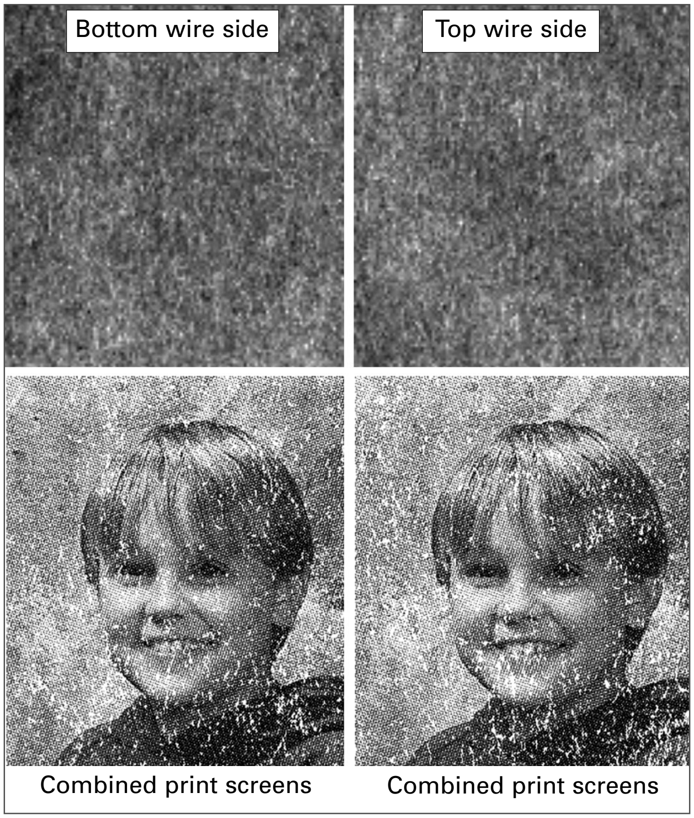
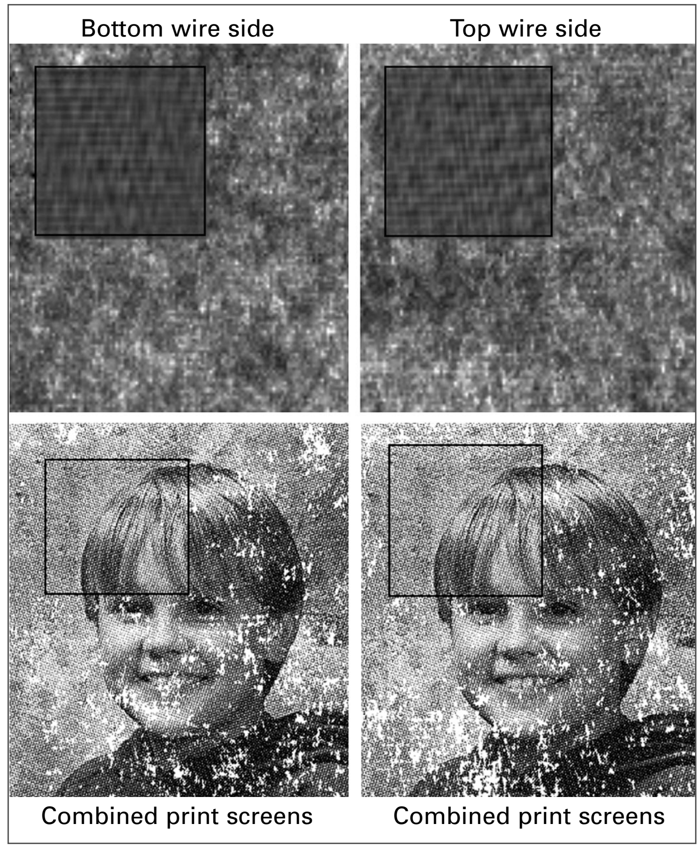


10. Print simulation on whole supercalendered sheet.



11. Print simulation on split supercalendered sheet.

INSIGHTS FROM THE AUTHORS

I chose this topic for research because, during travels in both Europe and North America, I was continually being told that what applies in Europe does not apply in North America and vice versa. My plan was to develop an understanding of these conflicting positions.

This work complements my previous research, which had concentrated on developing and understanding the relationship between fiber lengths, forming fabric surface filtering characteristics, the resultant sheet density differences, and the final print quality.

The most difficult part was obtaining stock, sheet, and fabric samples from the different regions in Europe and North America. I overcame this by enlisting the help of our European partner, Heimbach.

I discovered that there was an element of truth in every case, when taken in isolation at each mill, depending on the country, climatic conditions, wood species, pulping process, and paper machine characteristics. The data offered a sound, logical explanation for the statements made in isolation. However, when used to look at the larger picture on each side of the Atlantic, the facts showed that on machines using longer fibered stock, a coarser fabric structure worked well; as the fiber length decreased, the need to use finer forming fabric structures increased. The data fit the facts in the same manner in both Europe and North America.

Mills will benefit from this work in that they can now use the logical engineered approach to review their own history and then project for future paper machine, forming fabric, and sheet property changes.

The next step is to develop a method to produce a "Print Quality Index" based on the micro-density differences of the sheet formation images. This will allow us, as forming fabric suppliers, to evaluate new forming fabric structures for their impact on final print quality as they are developed. It will also allow us to evaluate our customer's sheet properties as the sheet is produced, rather than waiting for the printer to give them his visual evaluation.

— Roger Danby

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