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MARK IN THE PRINT DENSITY VARIATION**

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**Image analysis of an LWC paper reveals wire mark  
in the print density variations**

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**ABSTRACT** Microscopic observations were combined with image analysis to investigate the causes of apparently random "speckles" and "blotches" in a lightweight coated publication paper printed on a four-color web offset press. Observations indicated that the speckles were areas of lower print density lying over areas of greater coating thickness, and FFT analysis with an image analyzer showed that much of the higher frequency print density variation corresponded exactly to the forming fabric pattern. Thus, some of the small-scale print nonuniformities often attributed to the coating process itself are actually caused by the basesheet. We think the forming fabric pattern can be used in future image analysis studies to help investigate other coating and printing problems.

**KEYWORDS:** Image analysis, microscopy, wire mark, print defects, coating

## Introduction

New coating methods for lightweight coated publication papers have resulted in greatly improved runnability, but printers, forced by increased market demands, have complained of problems with washed-out print and increased speckle and mottle caused by nonuniform ink absorption, backtrapping, orange peel in the coating, etc. The work reported here is part of a larger effort directed at investigating the fundamental causes of these problems. This paper describes our work toward determining whether some print density variations could be ascribed to characteristics inherent in the basesheet or whether the print density variations should be attributed to other causes.

A print sample of particular interest to a cooperating company was furnished to us for this work. This sample was a portion of the blue sky in an advertisement printed on an LWC paper. Figure 1 is an enlarged view of a portion of the sample. It had been printed on a four-color web offset press (sequence B-C-M-Y); the second color down was a solid cyan, followed by a 50 percent magenta halftone with the screen angled at  $-25^\circ$  from the vertical (machine direction). The sample had a distinct speckled and mottled appearance, as well as a barely visible diagonal pattern at  $-27^\circ$  from the vertical. We define "speckle" as a very small area of low ink density, typically less than 1 mm in size, whereas "mottle" is a blotchiness in the ink density, typically 2 mm or larger.

Figure 1 here

We used both microscopic analysis and image analysis techniques in this study. Although it has been used for many years in other industries [most notably aerospace (1)], the true potential of image analysis is only recently

being utilized by the paper industry; only a few works have been published which describe practical applications (2-7). Some work has been reported on the analysis of print dot patterns in the graphic arts (8,9), but none could be found which utilized an image analyzer to study specific printing problems related to the manufacture and coating of a basesheet.

### **Microscopic examinations**

The print uniformity of the submitted sample was very uneven when print components with dimensions up to about 4 mm were considered (Fig. 1). Study with an ordinary light microscope showed the individual nonuniformities to be associated with different densities of magenta ink over the solid cyan. The magenta ink dots in the low density areas also had ill-defined borders. The magenta ink density variations had no apparent pattern except for the faint 27° diagonal lines mentioned earlier. It was not possible to determine whether the underlying cyan had similar ink density variations, but the cyan layer did exhibit some speckle and mottle in other areas of the print form where it was not printed over.

Using a novel beta radiographic technique, Parker and Attwood (10,11) showed the basesheet to have large variations in localized basis weight and/or density, primarily arising from the forming process. Recently, image analyzers have been used to more easily study these kinds of variations in the basesheet (3,4,6,7). Our own microscopy work with blade coated lightweight publication papers revealed very large variations in the basesheet and coating, along with large differences in surface appearance within a small distance. For example, the SEM micrograph labeled as Fig. 2 shows that the coating thickness of our sample varied between 4 micrometers and 20 micrometers within several hundred

micrometers, and Fig. 3 shows the remarkable variation in the surface appearance between the thick and thin coating areas. Microscopic study invariably revealed that the thick coating spots were "pools" filling in the low, thin spots of the basesheet rather than small areas of the basesheet with high coating absorbency. Our initial expectation was that the smooth (thicker) coating areas would be associated with areas of higher print density (due to greater ink holdout), but the opposite turned out to be true for a multicolored print. We felt that localized variations in coating thickness [which may also affect binder migration (12,13)] caused the print speckle in this sheet, but it was evident that a vast amount of microscopy would be required to prove whether variations in the print density always corresponded to variations in the coating thickness due to a nonuniform basesheet. We therefore resorted to image analysis to determine how much, if any, of the observed variations (and the hypothesized concomitant coating thickness variations) corresponded to the forming fabric pattern.

Figures 2 and 3 here

#### **Image analysis**

All image analysis work was performed on a Tracor Northern image analyzer at their facility in Middleton, Wisconsin. The print sample (Fig. 1) was illuminated under direct overhead tungsten lighting to minimize the effects of coating topography and ink gloss patterns. We therefore believe that the camera was essentially registering only print density variations. The camera image output was stored and manipulated in memory as a 512 by 512 pixel array with one of 256 levels of gray assigned to each pixel; the pixel resolution was limited by the camera we used rather than by the machine. The digital image was processed for uneven lighting effects, but no other enhancement techniques were employed.

Figure 4 is the resulting digitized image (magnified) as copied from the CRT screen. Note that the only obvious pattern is created by the magenta halftone dots aligned orthogonally. The general speckled and blotchy appearance of the original is also apparent, but other patterns, including the  $27^\circ$  diagonal mentioned earlier, appear to be absent.

Figure 4 here

A Fast Fourier Transform (FFT) was applied to the image array in Fig. 4, and the resulting power spectral density plot is shown in Fig. 5. Each spot of light represents a repetitive pattern found in the image. Pattern frequency is indicated by the distance from the center of the spectral density plot; lower frequency patterns are represented by dots close to the origin, while higher frequency patterns are represented by dots farther away. The angle each spot of light makes with the axes indicates the inclination which that particular pattern has in the image. Note, however, that the power spectral density plot is rotated clockwise by  $90^\circ$ ; for example, the horizontal axis in the original image is represented as a moderately bright vertical line in Fig. 5. Because quadrants are symmetrical, the patterns found in opposite quadrants are mirror images of each other.

Figure 5 here

Figure 5 shows about 20 points bright enough to stand out from the background noise. The four brightest points, orthogonally positioned, have a frequency of 5.2 cycles/mm according to the analyzer. The angles and the dot frequency agree exactly with the magenta dot pattern as seen in the digital image (Fig. 4) and also as measured under the microscope. Dimmer outer points

are also orthogonally positioned and represent weak harmonics of the fundamental magenta dot pattern. These harmonic patterns are easily visible to the image analyzer but are extremely difficult to discern with the naked eye (Fig. 4).

Several points closer to the origin are of greater interest for this study. Notice the moderately bright pair of points in the middle of the cloud of noise, about  $27^\circ$  from the horizontal in Quadrants I and III. When one of these points is tightly encircled by the cursor, only the patterns within the cursor border are displayed, masking unwanted frequencies and almost all of the noise; the image analyzer showed a frequency of 1.1 cycles/mm for this particular point. The display of the frequency/angle combination selected by the cursor is shown in Fig. 6. The diagonal pattern stands out dramatically. Note that this pattern matches the twill angle and spacing of the forming fabric after adjustment for basesheet changes in the paper machine (see Fig. 7a and 7b, also Table 1). Some type of interference pattern also appears to be superimposed on the twill pattern in Fig. 6. This pattern will be discussed later.

Figures 6 and 7 and Table 1 here

The image analyzer cursor was next used to encircle the brightest point on the vertical axis in Fig. 5. This point had a higher frequency (1.7 cycles/mm) but a lower intensity than the twill pattern. This horizontal pattern is shown superimposed over the twill pattern in Fig. 8; it agrees very well with the measured frequency of the forming fabric CD component after a small adjustment for draw along the paper machine (Table 1). It is interesting to note how the horizontal component reduces or even cancels the twill component in some areas and vice versa. Other areas have equally strong horizontal and twill components which result in diamond shapes. Superimposed over all this is the



interference pattern already mentioned. The brightest point on the horizontal axis (1.1 cycles/mm) was analyzed next. The frequency of this relatively weak point agrees very well with the measured frequency of the MD component of the forming fabric (Table 1).

Figure 8 here

Figure 9 demonstrates another interesting interactive capability of the image analyzer; it is a two-colored display of the forming fabric pattern in the digitized image (Fig. 4) after certain items have been masked for better clarity. After correcting for uneven tone density, we overlaid the frequencies from the polar spectral density plot that corresponded to the forming fabric MD and CD components. We then classified the gray levels in the resulting image into two bins and colored them for better visibility and displayed the image seen in Fig. 9. We are convinced that the discontinuities in the fabric pattern are not artifacts; we could slightly enhance or degrade their appearance in the final image, but overall, the image analyzer had limited manipulative abilities.

Figure 9 here

It is intriguing that the light-colored areas in Fig. 9 are the right size and shape to correspond to the "blotchiness" seen in the original print. Some CD orientation is also apparent. However, it is not possible to discover the source of the light-colored areas without further investigation (e.g., comparison with similar basesheet formation images).

#### Comments and implications

Others did not believe the wire mark was causing the print speckle, but instead felt the problem was originating in the coating process itself. However, the

image analysis work just described, coupled with our microscopy work, now makes us quite certain that the forming fabric can create periodic, high-frequency variations in the coating thickness which result in differences in ink receptivity ("speckle") in the coated sheet. The work demonstrated in Fig. 9 also makes it clear that there are many areas where the fabric pattern is overwhelmed by a blotchy pattern very similar to the mottled pattern seen in the printed sample. Unfortunately, the source of the blotchiness is not immediately obvious since it is comprised of random low frequency components which cannot yet be attributed directly to any paper machine component. (The interference pattern in Fig. 6 does not appear to correspond to the blotchy pattern in Fig. 9.) It would have been interesting to determine how well the blotch patterns correlated to basesheet formation.

Several interactions are likely occurring between the sheet and the four-color offset press to cause the print defects described earlier. We believe that a significant portion of the speckle is caused by localized coating absorptivity variations which are, in turn, associated with coating thickness variations (and possibly enhanced by local binder migration). We think the low absorptivity over the coating thick spots leads to nonuniform ink tack buildup in the exact pattern of the forming fabric. When the magenta halftone is printed, the ink dots either trap poorly over the resulting low tack areas of the underlying cyan or they are trapped back off by the following yellow blanket (13,14). The "speckled" appearance seen in the print can result from either mechanism, and the fundamental cause is localized variability in the coating absorptivity. The same mechanisms may also be occurring for the larger blotchy areas, although the work reported here did not establish that. It should also be pointed out that we think coating thickness variations probably lead to

significant print density variations only when the coating absorptivity varies along with the thickness. That is, some coating formulations may not be as sensitive to thickness variations and may, therefore, not lead to the kind of print density variations seen here. Also, other variables such as base paper destructuring (15) and drying strategy (16,17) can ultimately affect coating and print density variations.

Another intriguing aspect of this work was the possible interaction of the coating absorptivity pattern with the overlaid pattern of magenta ink dots. This is suggested by the appearance of a moiré-type pattern in Fig. 6. Although this type of image distortion is known to occur as an artifact of the FFT transformation, a moiré pattern might also have resulted from the chance overlay of one of the secondary magenta dot patterns on the coating absorptivity pattern caused by the twill in the forming fabric (we found the magenta dot frequency almost an exact multiple of the twill frequency, and the secondary screen angle almost the same as the twill angle). Since this hypothesis lacks definitive experimental evidence, we must consider the idea to be speculative; nonetheless, we think it conceivable the twill pattern led to ink dot density variations which were reinforced by a moiré pattern induced by the magenta screen angle and frequency. This result, if true, does not mean the printer must avoid screen conditions similar to the fabric twill, but it does provide further incentive for manufacturing basesheets with less noticeable forming fabric patterns and more uniform coatings.

Finally, the forming fabric pattern should be useful for future work since it provides a built-in coordinate system for image analysis studies of paper and coatings on a microscopic scale. For example, we think it should be

possible to utilize this same technique in future studies of microscale binder migration. If binder migration actually occurs, and if the amount and/or composition of the surface binder is different for thick and thin coating spots, then a map of coating binder (however obtained) should contain the same forming fabric pattern when viewed by an image analyzer. If the binder map agreed well with observed print density patterns, there would be strong evidence that microscale binder migration is an additional significant factor in print quality.

### **Summary**

Microscopic and image analyses were used to prove that the basesheet somehow contributed to higher-frequency print nonuniformities in a lightweight coated publication paper printed on a four-color web offset press. While the exact mechanisms are still under study, we found that a significant portion of the print variations in this paper were created by periodic variations in the coating thickness which, in turn, corresponded exactly to the forming fabric pattern in the basesheet. Areas of low print density were found to lie exactly over areas of greater coating thickness. We feel that one of the more exciting aspects of this work was the realization that the wire mark could be viewed in the print with an image analyzer and used as a built-in coordinate system for correlating thick coating spots with areas of low print density. Local binder migration to these areas in the coating may or may not prove to be an additional factor in the highly variable surface absorptivity observed here, but this work once again demonstrates the importance of creating a uniform basesheet and coating if the best offset print quality is to be obtained.

## Acknowledgments

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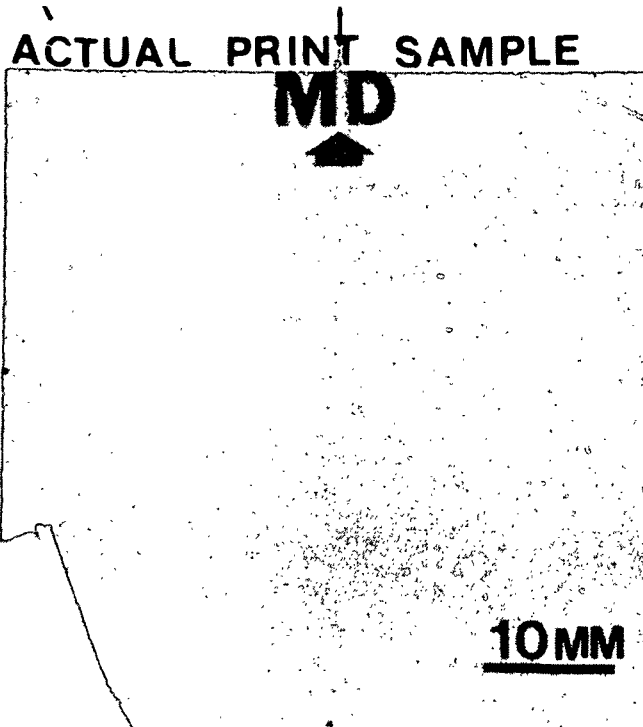
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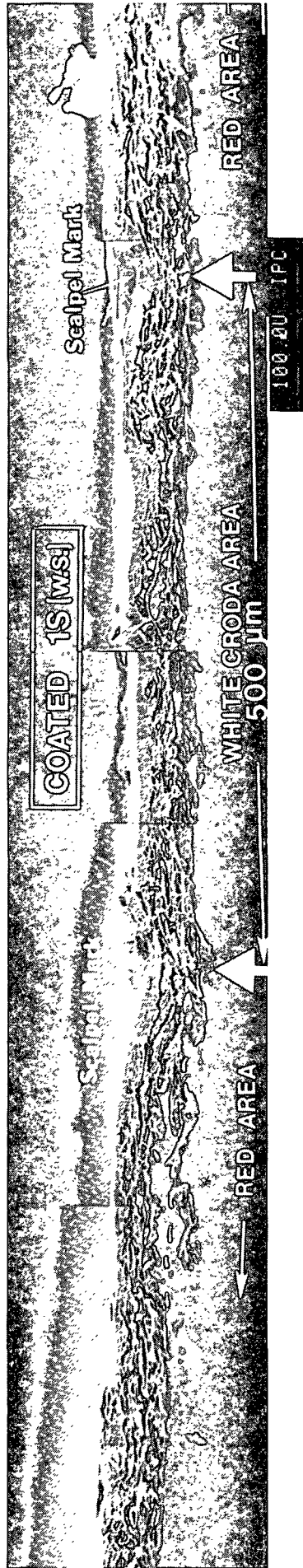
1. Comparison of frequencies.

	From fabric measurements	Adjusted for basesheet changes	Measured from printed sample	Measured by image analysis
CD component	1.79	1.71	1.69	1.67
MD component	3.23	3.10	2.94	NA
Twill component	1.08	1.10	1.10	1.10
Twill angle	29°	27°	27°	27°

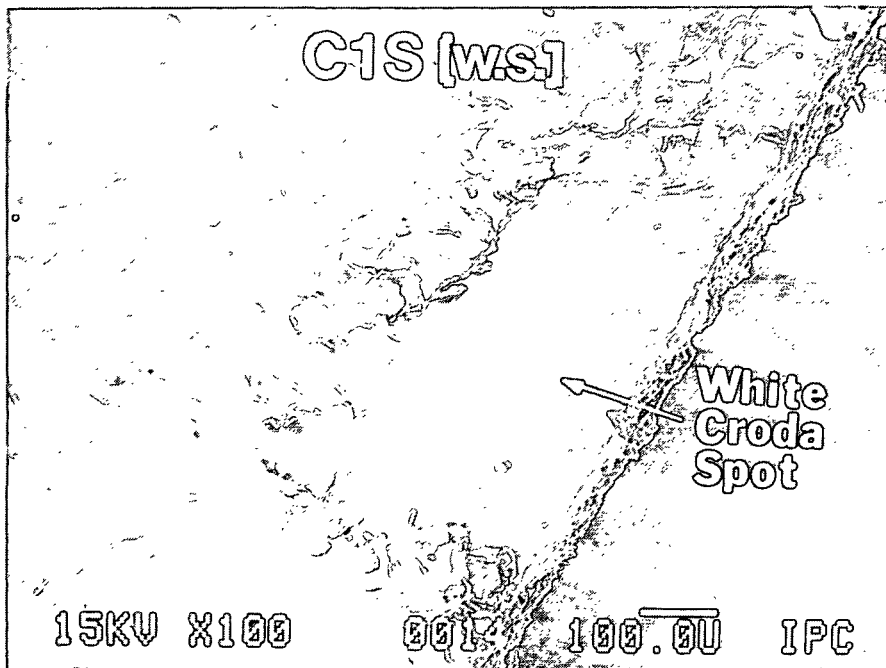


1. Somewhat enlarged photo of LWC print from the problem area.

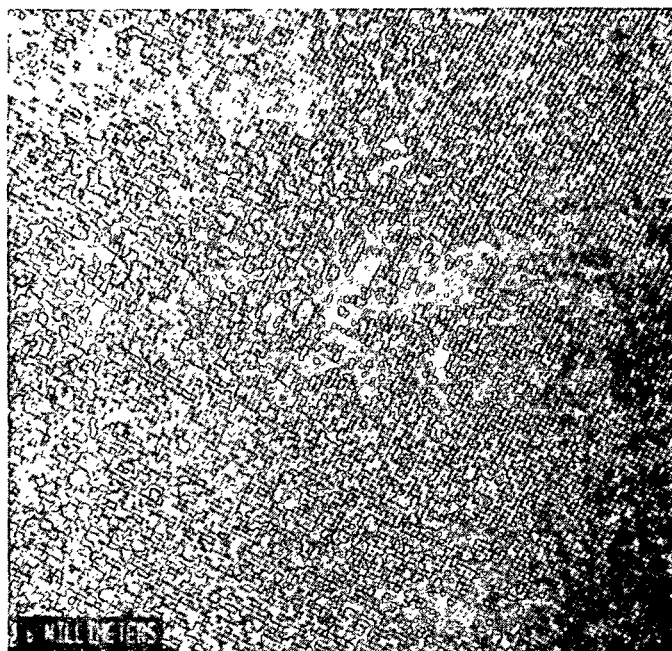




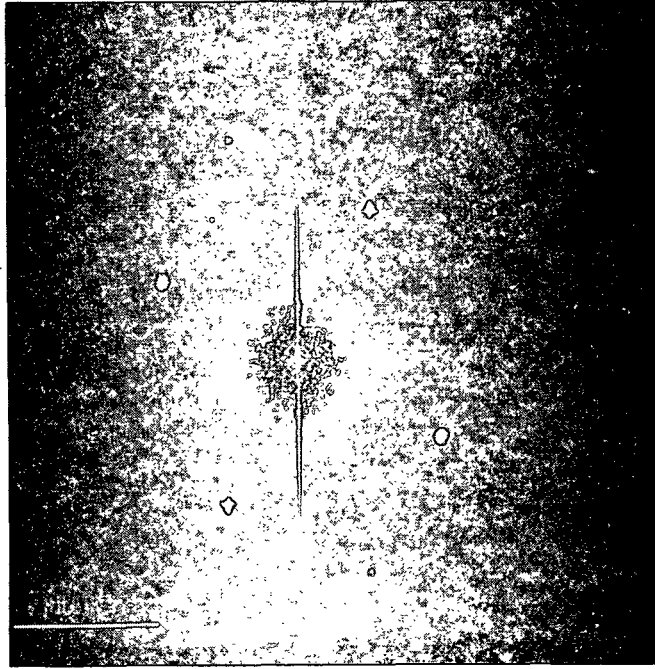
2. SEM composite cross-section of LWC showing coating and basesheet thickness variations. Dashed line locates corner of basesheet. Coating rubbed with Croda ink.



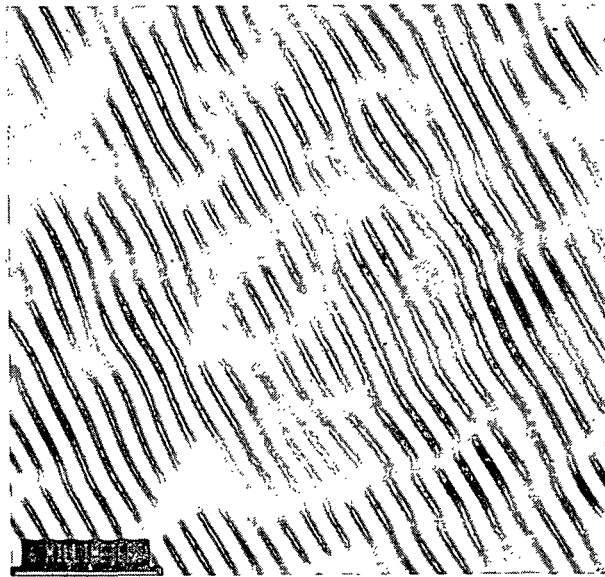
3. SEM view showing surfaces of thick and thin coating areas.



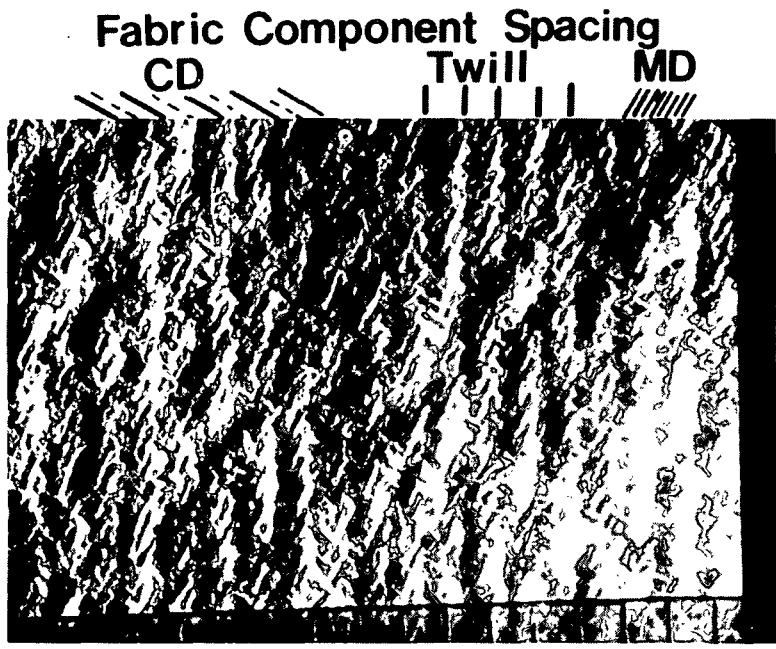
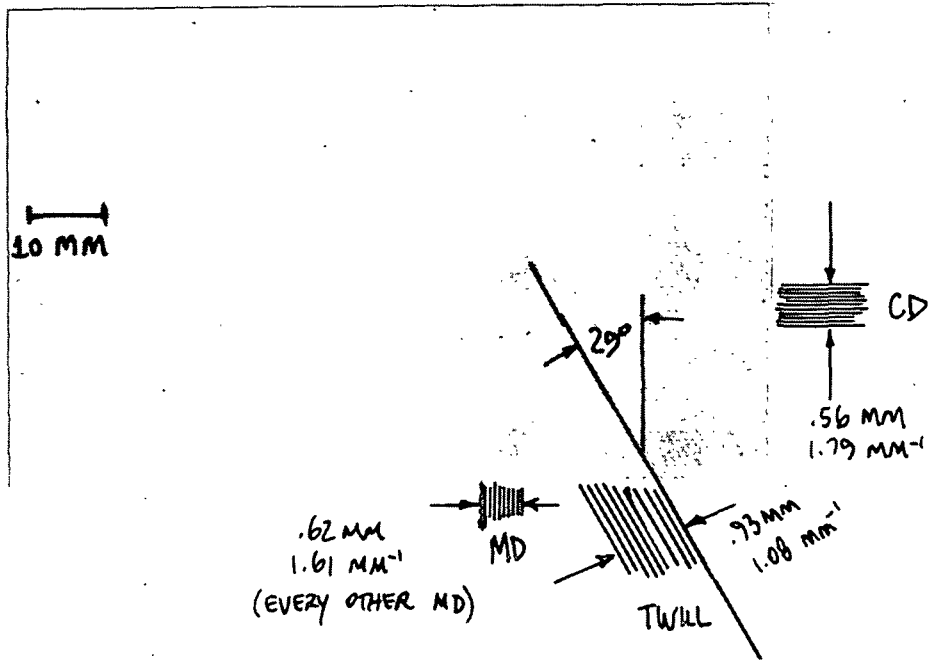
4. Digitized image of actual sample; displayed on the CRT (3x); ax. 50  $\mu\text{m}$ /pixel effective resolution.



5. Power spectral density plot of the digitized image in Fig. 4.

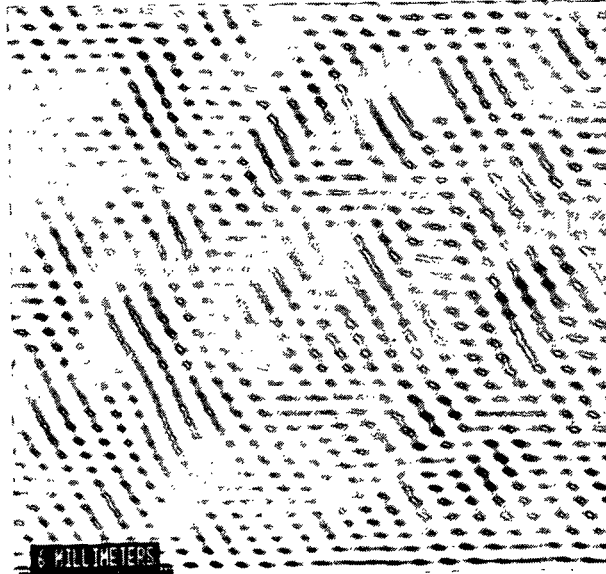


6. Image analyzer display showing the twill component inherent in the print sample shown in Fig. 1 and 4.

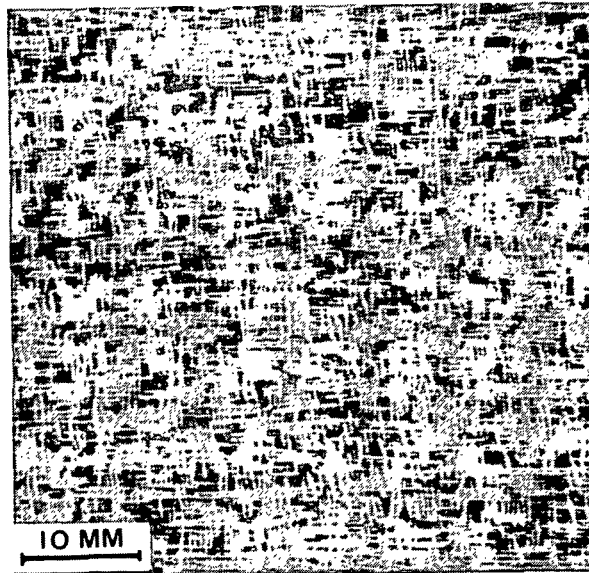


**6x**

7. (a) Photo of forming fabric used to make the basesheet for the LWC paper used in this study.
- (b) Low angle incident light photograph of basesheet (wire side) made on the fabric shown in Fig. 7(a).



8. Image analyzer display showing the twill and CD components in the printed sample.



9. Two-color display of the MD and CD fabric components superimposed to show the blotchy ink density patterns; ax. 100  $\mu\text{m}$ /pixel effective resolution.