Alleviating Ink-Jet Mottle and Strike-Through in Uncoated Fine Paper

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Abstract

A study examined the causes of mottle and strike-through on ink-jet printed uncoated copy paper. Mottle results from the free movement of ink on the paper surface leading to uneven ink distribution. Strike-through occurs when free ink on the surface of paper finds a defect on the surface and then funnels into and through the defect to the back side of the paper. Mottle and strike-through were quantified with a stochastic analysis method using Verity IA software. Based on the mechanism of mottle and strike-through a study was made of paper additives that would either reduce free ink or overcome surface defects. Absorbents, adsorbents, and mordents reduce mottle and strike-through. In addition, the study identified several additives that changed how paper absorbed ink-jet ink. The additives very effectively reduced the print problems. The methods of reducing mottle and strike-through can be additive as seen in recently developed surface sizing agents.

Introduction

Beautiful prints with deep and uniform images are readily obtained by ink-jet printing on specialty grades of paper. However, on uncoated copy paper or multipurpose paper, muted colors and print defects are still the norm. Ink does not always stay where it is wanted on plain paper as noted in a review by Yang [1]. Two ink-jet print issues are mottle and strike-through.

Mottle is an uneven density of solid printed areas. Strike-through is an uneven pattern of ink penetrating the paper. (It is not show-through, which is the ability to see the printing on the back-side of the paper and is related to low opacity.) Mottle and strike-through are more visible when printing with black pigmented inks than with black or color dye-based inks. Therefore, the recent move to pigmented color inks will not eliminate the problems [2].

This article discusses the causes of mottle and strike-through on black ink-jet printed uncoated paper, provides a description of one method of quantifying them, and provides examples of the key role paper additives play. In addition, this article presents a means of alleviating mottle and strike-through.

Causes of Mottle and Strike-Through

Ink-jet printing of solid black areas requires relatively large quantities of ink compared to the paper weight. An average copy paper weighs about 7.5 mg/cm^2. A survey of several ink-jet printers showed that during solid black ink printing between 1 and 6.5 mg/cm^2 of ink was applied, with variation from printer to printer and with different printer settings. However, only minimal correlation was found between strike-through and mottle and the level of ink applied. Some of the worst printing was observed in a case where only about 2.2 mg/cm^2 of ink was applied.

Prior to this study it was observed that if a paper has reasonable formation, uniform application of size press starch, and very low sizing, then no mottle or strike-through occurred. However, with increased sizing, mottle and strike-through occurred. In general, to obtain higher optical density values and good print resolution, some sizing was required. Figure 1 shows a progression of mottle as sizing was increased. At low and moderate levels of sizing, mottle occurred. The magnified image shows the details. At very high sizing levels a dark, uniform, mottle-free, printed image was obtained. A highly sized paper may have other issues, such as long ink dry times and reduced toner adhesion during electroreprographic printing. Figure 2 shows the corresponding strike-through for each print in Figure 1. Again, the magnified image shows more detail. Without sizing, no strike-through occurred but much more show-through occurred. Without an understanding of the causes of mottle and strike-through, it is difficult to balance paper properties.

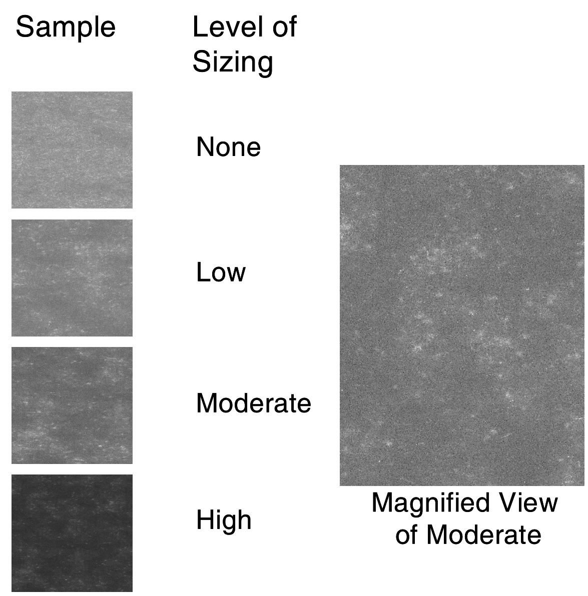

Figure 1. *Examples of Print Mottle at Various Sizing Levels*

Figure 3 shows optical micrographs of cross-sectioned printed paper samples. The sample on the top had no surface sizing applied. The ink uniformly penetrated the paper. The sample on the bottom had a moderate level of surface sizing applied. A layer of ink was observed only on the surface except in two places where the ink penetrated the paper. In Figure 4 micrographs of thin sections of similar printed papers show the path of ink through the paper. A small amount of ink penetrated almost everywhere in the unsized paper, but in the sized paper a lot of ink went through in a few places.

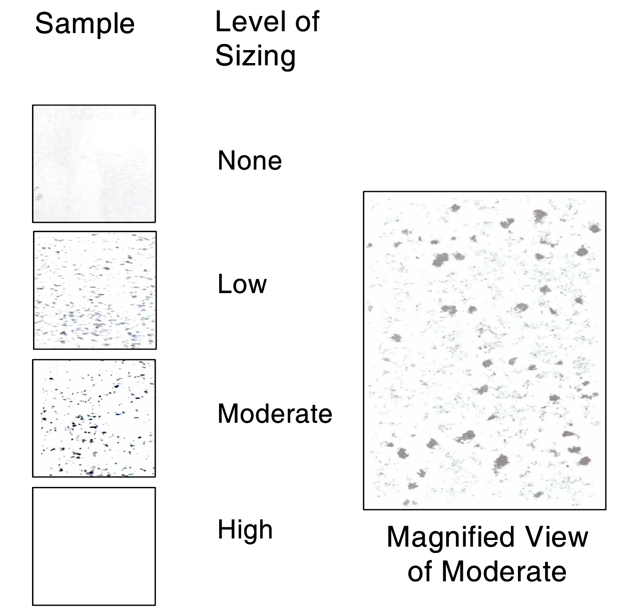

Figure 2. *Examples of Print Strike-Through at Various Sizing Levels*

Like rain on a flat, leaky roof, ink remains liquid on the surface of the paper long enough to find a place where it can penetrate into and through the paper, causing strike-through. The liquid ink funnels through in limited places. In a sized sheet there is much more free ink to penetrate a few places than there is in an unsized sheet where the ink penetrates everywhere. The penetration sites may be defects related to formation or non-uniform application of size press starch and sizing, or they may be mechanically formed. If one scores the top of a sized paper with an empty pen and then prints the paper, the ink will penetrate in the scored areas.

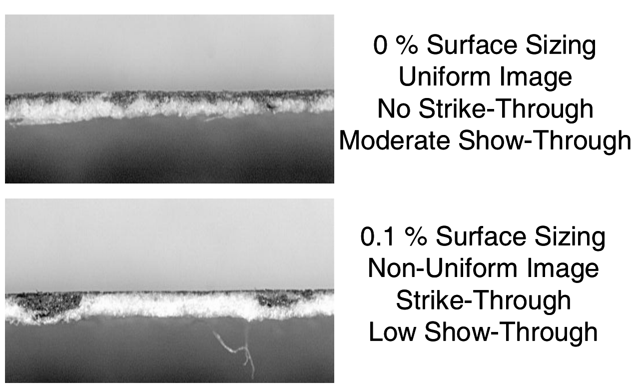

Figure 3. *Optical Micrographs of Paper Cross-Sections*

SEM micrographs and three-dimensional optical micrographs revealed that plain, uncoated paper is not uniform: the pore structure varies, the distribution of fillers from the wet-end of the paper machine is not uniform, and the size press application of starch and sizing is not uniform. Mottle can result from the varied penetration of ink and from the uneven depth of wet-ink on the paper surface. Zhmud has addressed some of the issues of the wetting of paper by ink-jet inks [3].

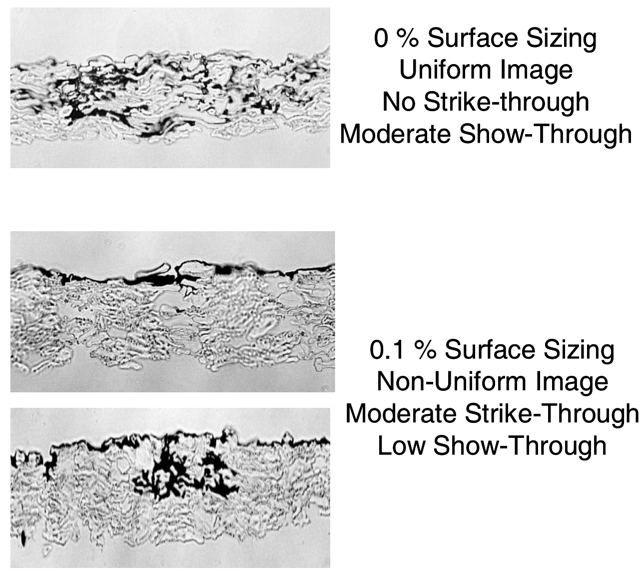

Figure 4. *Optical Micrographs of Paper Thin-Sections*

Quantification of Mottle and Strike-Through

Numerous methods of measuring mottle and strike-through exist [4]. For this study images were scanned with a dual bulb scanner at 600 dpi resolution and analyzed with Verity IA software [5]. The Verity IA software is a stochastic method that is easy to use and if used properly leads to values that are very representative of what the eye detects. The software stores luminance values for each pixel, with the number of pixels being determined by the image resolution. The user selects target sizes of interest based on the features, or in the current work, the types of mottle and strike-through being examined. The software analyzes every group of four adjacent target squares within an area of interest selected on a print. For the current work three inch by three inch sections of solid black printed areas were evaluated for the mottle results. The software determines three values. The first value is the standard deviation of the mean luminance of all of the squares, which is a common measure of print variations. It gives the distribution of light and dark areas. However, two samples can have the same values and be very different. The second value is the mean of the differences in luminance between adjacent target squares. This value provides a measure of the sharpness of transitions. The eye is very sensitive to sharp changes. The third value is the standard deviation of the differences in luminance between adjacent squares. This value is sensitive to particular features such as marks and lines. For example, one can easily pick up the effect of a finger print or some other defect on an image. The three values are multiplied together to give a mottle number. For measuring strike-through the same analysis can be used on the back side of a printed image.

For this study three target sizes were analyzed: 0.34 mm, 1.4 mm, and 10.8 mm. These target sizes correspond to features that may be seen up close, at reading distance, and from several yards away. The Verity IA analysis was tested with numerous test patterns and found to be extremely accurate and reproducible. Only the data of the 1.4 mm target size is presented in this article.

Variations of Mottle and Strike-Through

Ten commercial uncoated copy papers were printed with a Hewlett Packard Desk Jet 6122 printer using "plain paper" and "normal" print settings and then analyzed for mottle and strike-through. Large differences were observed between paper samples. The worst paper sample had a mottle number of 19.4 and the best a value of 0.4. The best samples also had the least strike-through. However, the sample with the worst mottle was in the middle of the group for extent of strike-through. Mottle and strike-through did not correlate. The results demonstrated that paper characteristics greatly affect print quality. But, which paper characteristics?

Water resistance of each sample was measured by the Hercules Sizing Test (HST) and by the Cobb test. The Cobb test was also run with a 95/5 by weight mixture of water and isopropanol (IPA). The contact angle of ink-jet ink to the paper was measured. The HST values ranged from 24 to 314 seconds and water/IPA Cobb values ranged from 102.2 to 17.2 g/m^2. Contact angles were determined for water and for black ink-jet ink with each paper. The ink contact angles varied from 58.9 to 92.5 degrees. No good correlation was observed between the HST, Cobb, or contact angle results with either the mottle or strike-through.

Tests were run to measure the absorption of water and water/isoproanol mixtures into the commercial papers. Neither test correlated with mottle or strike-through. Although the commercial samples were all the same basis weight and were all copy papers there were undefined characteristics that made them better or worse for ink-jet print quality.

One variable between papers was examined closely. A copy paper was made without surface treatment and was then subsequently treated on a laboratory size press with seven different starches. Each starch was applied at 3.75% of the paper weight and the final sizing of the papers, with one exception, was between 306 and 341 seconds by the HST. The one odd sample had an HST value of 185 seconds but exhibited average mottle and strike-through results. Table 1 lists the results.

TABLE 1 Strike-Through and Mottle of Starch Treated Papers

Starch	Starch Type	Mottle	Stk-Thr	HST (sec)
1	Oxidized	2.36	113	306
2	Cationic	1.84	148	332
3	Cationic	1.64	63	328
4	Cationic	1.23	12.4	185
5	Ethylated	1.66	75.4	336
6	Ethylated	0.57	1.78	341
7	Hydrophobic	3.26	63.2	338

The first thing the experiment proved was that dramatic changes in mottle and strike-through are possible from chemical changes. A correlation was sought between the starch properties and the printing results. However, no correlation was found between mottle or strike-through and the absorption or solubility characteristics of the starches.

A correlation was also sought between the paper properties and the print results. There was some correlation of strike-through with the HST values and water contact angles of the treated papers. A better correlation was observed with the contact angles of the ink. Contact angles were measured continually up to 10 seconds. Contact angles measured at 10 seconds gave a better correlation than contact angles measured at one second. The strike-through results are shown in Figure 5. An increase and then a decrease of strike-through versus contact angle occurred.

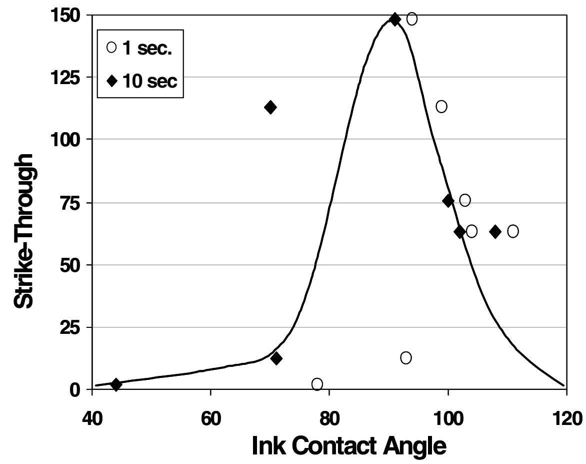

***Figure 5**. Strike-Through vs. 1 Second and 10 Second In Contact Angles*

In the early experiments, as shown in Figures 1 and 2, there was a trend of increasing and then decreasing mottle and strike-through, as sizing increased. A more careful study was made of the effects of varying surface and internal sizing levels. Paper samples, modeling commercial copy paper, were prepared on a pilot paper machine with alkyl succinic anhydride (ASA) as the internal size. The levels in the papers varied from 0.036% to 0.10%. Alkenyl ketene dimer (AeKD) was used as the surface size and was varied between 0 and 0.15%. Either more internal or more surface size increased the sizing as measured by the HST. With no surface sizing, mottle was low when a low level of ASA was used. Mottle increased as the internal size level increased and then mottle decreased as the internal size level continued to increase. When internal sizing was held at a low level and AeKD was added, the same trend occurred. Mottle was low when a low level of surface size was used. Mottle increased as the surface size level increased and then mottle decreased as the surface size level continued to increase. The more internal size used the less surface size was needed before the increase and decrease were observed. The same was true of strike-through. With high internal size levels, where mottle and strike-through were already low, the addition of surface size further decreased the print problems. A complex relationship exists between sizing additives and mottle and strike-through

Alleviating Mottle and Strike-Through

Given the mechanism of mottle and strike-through presented above, two characteristics of printed paper are important for alleviating mottle and strike-through. The first characteristic is the amount of free ink on the paper surface and the second characteristic is the presence of defects or paths through which the ink can flow into and through the sheet. High sizing levels can apparently overcome the second issue based on the results observed. The first characteristic, the amount of free ink, is a function of the absorption or adsorption of the ink and time.

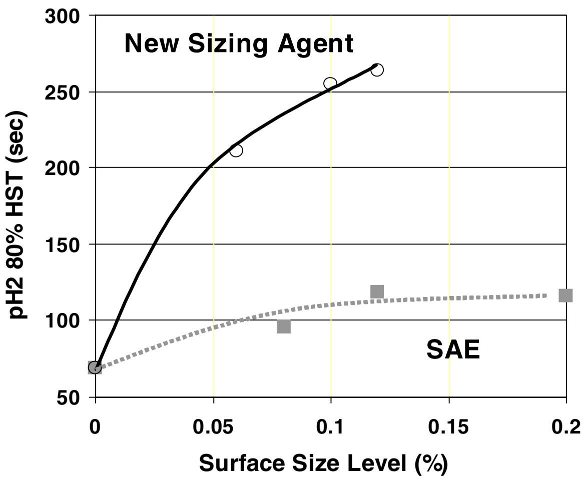

***Figure 6**. Surface Size Efficiency over Base Sheet with 0.046% ASA*

The addition of absorbent materials to the surface of a paper along with a size press starch reduced mottle and strike-through. For example, the additives methylhydroxypropyl cellulose, methylhydroxyethyl cellulose, and hydrophobically modified hydroxy ethyl cellulose were added to paper at a level of 0.025%. Each additive reduced the level of mottle to one forth the starting value. Strike-through was reduced to one-half to one-forth the starting value.

The addition of ground calcium carbonate (GCC) to the surface of the paper at a level of 0.15% had little effect. However, addition at a level of 0.5% reduced mottle from about 2.5 to 1.5. Not much change in strike-through occurred. Both adsorbents and fillers are used at much higher levels in coated ink-jet papers [6, 7].

Most copy paper contains 0.25% sodium chloride (NaCl). It is added to reduce static, which can plague the feeding of individual paper sheets from the top of a stack of paper. NaCl can also act as a desiccant. The addition of 0.5% extra NaCl reduced mottle and strike-through by 50% or more. The addition of GCC and NaCl was found to be additive.

The amount of free ink can also be decreased by use of a mordant such as calcium chloride. Strike-through was reduced in proportion to the level of mordant added. Mottle did not always decrease because the calcium chloride also increased the optical density of a printed area, thereby making the contrast between light and dark areas of mottle patterns more apparent. The overall effectiveness and balance of properties with the addition of calcium chloride was improved by the co-addition of a surface sizing agent, see Hercules Incorporated patent [8].

Based on the mottle and strike-through mechanism, tests were performed on additives that change how paper absorbs ink. The additives were found to be extremely effective. The best additive reduced mottle from 10.5 to 0.5 with just 0.008% in the surface treated paper. The additive also reduced strike-through from 15 to 2.

Some approaches to reducing mottle and strike-through may be combined and in addition can be used with highly effective sizing agents. Hercules has done so in some of their new products, which increase paper sizing very efficiently; give good, sharp ink-jet printing; and do not cause excessively long drying times of ink-jet printed images. Figures 6, 7, and 8 compare a new surface sizing agent to a commonly used styrene acrylic emulsion (SAE) product. At equal levels, the new surface sizing agent achieves far superior sizing, mottle, strike-through, and print optical density results.

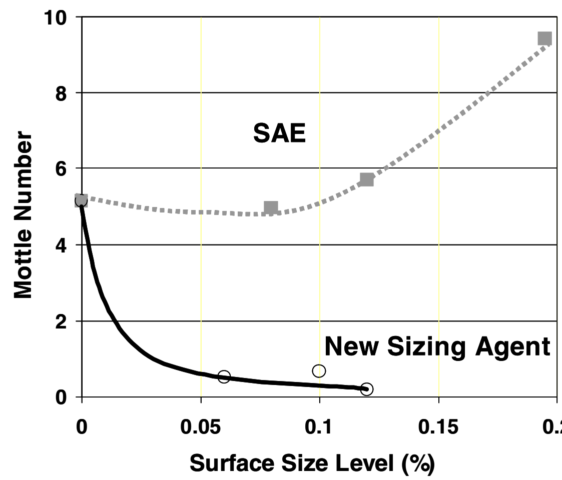

***Figure 7.** Mottle. New Sizing Agent vs. SAE over Base Sheet with 0.046% ASA*

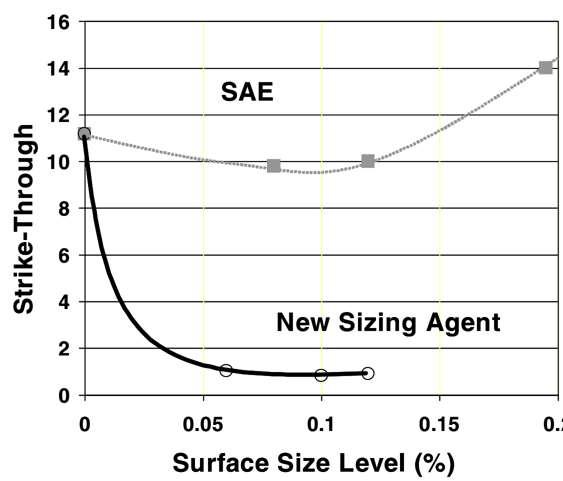

***Figure 8.** Strike-Through: New Sizing Agent vs. SAE over Base Sheet with 0.046% ASA*

Conclusions

Mottle results from the free movement of ink on the paper surface leading to uneven ink distribution. Strike-through occurs when free ink on the surface of paper finds a defect on the surface and then funnels into and through the defect to the back side of the paper. Paper additives ranging from starch to fillers and the level of ink-hold out imparted by sizing agents can cause variations of mottle and strike-through. Ink adsorbents and absorbents reduced the level of free ink and thus the print problems. Likewise, mordents were effective. Several additives were identified that changed how paper absorbs ink-jet ink and they very effectively reduced the print problems. The methods of reducing mottle and strike-through can be additive as seen in recently developed surface sizing products.

References

[1] Li Yang, INK-PAPER INTERACTION A study in ink-jet color reproduction, Thesis, Department of Science and Technology Linkoping University, Sweden, (2003).
[2] H. Wilhelm, "A 15-Year History of Digital Printing Technology and Print Permanence in the Evolution of Digital Fine Art Photography – From 1991 to 2006", Proc. NIP22 pg 308 (2006).
[3] Boris Zhmud, "Dynamic Aspects of Ink-Paper Interaction in Relation to Inkjet Printing", Pira International Conf.: Ink on Paper, Brussels (2003).
[4] Wilco de Groot, Print Mottle Measurement and Analysis, Proc Centre of Competence Paper and Board (2004).
[5] R.R. Rosenberger, "Stochastic Frequency Distribution Analysis as Applied to Mottle Measurement", Copyright Verity IA, Appleton, WI (2001).
[6] Prakash B. Malla and Siva Devisetti, "Novel Kaolin Pigment for High Solids Ink Jet Coating", PITA Coating Conference (2005).
[7] Erik Swanholm, Printability and Ink-Coating Interactions in Inkjet Printing, Thesis, Karlstad University (2007).
[8] US Patent 6207258B1, Hercules Incorporated.

Author Biography

Daniel F. Varnell received his doctorate in polymer science from Pennsylvania State University in 1982. He is a Research Fellow at Hercules Incorporated in Wilmington, Delaware. His research projects have included graphite fibers, photoresists, solder masks, new laminate materials, and internal and surface sizing agents for paper. He is credited with several U.S. Patents and commercial products.