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PAPER

QUESTIONED DOCUMENTS

James A. Green,[1] *B.S.*

Reliability of Paper Brightness in Authenticating Documents

ABSTRACT: Evaluation of paper brightness in multipage documents is a practice of forensic document examiners when there is a question of a page insertion or substitution. This article demonstrates that occasional errors occur in the manufacturing process that affects the consistency of paper brightness. The inconsistency of paper brightness may therefore influence conclusions reached in authenticating documents. Reams of multipurpose paper, from 21 manufacturers, were examined. When assessing the individual pages of each package with an ultraviolet light, approximately 30% of the reams revealed differences in paper brightness. A study of the paper-manufacturing process was conducted to determine where variations originate. It is concluded that brightness differences occur when one incompatible roll of paper is mistakenly placed with others used for one production run. It was also determined that brightness variations (when present) are patterned throughout individual reams. When the authenticity of a document is in question, consideration of these findings is essential to assure an accurate assessment.

KEYWORDS: forensic, document, examination, paper, brightness, forgery, fluorescence, paper manufacturing

A forensic document examiner considers many features during the examination of a multipage document. A common allegation is a page replacement that changes the original text or the terms of the document. An examiner will make note of the printing methods used, consistency of the number of staple holes from page to page, indented writing, ink comparisons, fonts, etc. Attention is also given to the consistency or differences of paper brightness in the pages of the document in question.

Wilson Harrison (1, p. 90) in *Suspect Documents*

> The exposure to ultra-violet light is a useful test when a document consists of several pages and the substitution of one or more is suspected. The forger may be able to match the general colour and appearance of an unwatermarked sheet as viewed under ordinary conditions of lighting, but unless a very similar paper has been chosen, it is unlikely to exhibit the same fluorescence in ultra-violet light.

The observation by Mr. Harrison must be qualified. The author noted variations in the paper brightness of sheets within the same ream of common photocopier and computer printer paper, in spite of the package label indicating a specific brightness factor. The phenomenon has been reported previously, by authors Ellen (2), Fortunato (3), and Hilton (4). Shiver discussed the issue in his presentation about the pitfalls in the use of ultraviolet examination to differentiate between writing papers, given at the Southeastern Association of Forensic Document Examiners, in April 2007 in Atlanta, GA.

Materials and Methods

Each ream of paper examined contained approximately 500 sheets of 8.5″ × 11″ paper. Paper brightness was evaluated in a dark room with long-wave (365 nm) ultraviolet light source (Spectroline Mod. ENF-260C; Spectronics Corp., Westbury, NY).

The brand names and paper specifics used for the comparison process are listed in Table 1.

Results

Of the 21 products used in the study, six had variations in paper brightness within the individual reams. The results are shown in Table 2.

An example of an inconsistent paper brightness response in one product is shown in Fig. 1. The fanned pages from the domestic manufacturer revealed a pattern of every sixth page having a greater brightness than the five pages preceding or following. The pattern existed throughout the ream.

A ream from a manufacture in Indonesia had three shade gradations rotating in sequence (Fig. 2).

Discussion

A point of clarification should be made regarding terminology. When discussing the fluorescent properties of paper, two terms are commonly interchanged: paper brightness and paper whiteness. In fact, they are not the same. Paper brightness is measured at a specific wavelength (457 nanometers in a 44-nm-wide beam) in contrast to paper whiteness that is measured across the full visible light spectrum with a brightimeter—a laboratory instrument used to measure paper brightness. It emits a blue light that strikes the paper sample at a 45-degree angle. To avoid measuring reflectance (gloss), the light reflected at 90 degrees is measured. An illustration of the testing process is shown in Fig. 3 (5).

Essentially, brightness relates to a measurement in the blue region of the spectrum, ignoring the green and red wavelengths which whiteness includes. Paper, when tested, yields a brightness value relative to magnesium oxide—that is, a paper that has a measured brightness of 86 reflects 86% as much light, under the test parameters, as does the magnesium oxide (6).

The sophisticated and expensive instrumentation found in the laboratories of paper production companies is not common, or

[1]Forensic Document Examiner, PO Box 5379, Eugene, OR 97405.

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TABLE 1—*A variety of multipurpose papers were selected, some with recycled components as noted, and four manufactured outside of the United States, that is, Double A (Thailand), Navigator (Portugal), Paperline (Indonesia), and UPM (China). The brand names and paper specifics used for the comparison process are as follows.*

	Brand	Paper Use	Weight	Brightness Advertised
1.	Boise Aspen 30	Multipurpose—30% recycled	20 lb	92
2.	Boise Polaris	Multipurpose	20 lb	97
3.	Domtar	MultiUse	24 lb	98
4.	Double A (5 reams)	Multipurpose	22 lb	97
5.	EconoSource	Multipurpose	20 lb	92
6.	First Choice	Multipurpose	24 lb	98
7.	GP Advantage	Multipurpose	20 lb	92
8.	GP Spectrum	Multipurpose	20 lb	92
9.	Harbor	Multipurpose—100% recycled	20 lb	''Hi Bright''
10.	HP	Multipurpose	20 lb	96
11.	Husky	Xerocopy—30% recycled	20 lb	92
12.	International Paper Hammermill	Copy Plus	20 lb	92
13.	Navigator	Multipurpose	20 lb	97
14.	Office Depot	Multipurpose	20 lb	94
15.	OfficeMax	Multipurpose—30% recycled	20 lb	92
16.	Office Works	Multipurpose	20 lb	92
17.	Paperline	Multipurpose	20 lb	''Super white''
18.	Staples	Multipurpose	20 lb	96
19.	UPM (10 reams)	Multipurpose	20 lb	97
20.	Willcopy	Multipurpose	20 lb	92
21.	Xerox Business Plus	Multipurpose	20 lb	96

necessary, in the laboratory of document examiners. The examiner does not determine the exact degree of paper brightness, only to determine whether differences in paper brightness exist between pages in a document. To accomplish this task, an ultraviolet lamp is both affordable and effective in differentiating paper brightness.

When evaluating brightness and differences among pages of a document, consideration should be given to the manner in which the document was stored. Environmental effects such as sunlight may cause changes in the optical properties of paper, which may be an indication of the sheets of paper originated from different sources (7).

The aging process may also affect the UV response, ''Intensity of fluorescence must be interpreted with caution, however, because the intensity usually decreases with the age of the paper especially when the paper is exposed to light'' (8, p. 224). The aging process alone may create legitimate and consistent change to brightness, assuming that the document was prepared at the same time and the paper was from the same source.

A review of the paper-making process serves well in demonstrating why variations in paper brightness occur, also why sheets that exhibit a different brightness are patterned within a ream. The study of the production additionally identified how many reams may be affected in a production run.

Relevant Steps in the Paper-Manufacturing Process

Hardwood and softwood trees are used for paper pulp production. While the longer fibers of softwood add strength to paper, the short fibers of hardwood serve to fill voids.

The logs are first debarked; this process is required because bark cannot be whitened. If not removed, bark would appear as small, dark slivers in the paper. The logs are then ground into small, thin chips. For production of multipurpose papers, lignin (a brown-

TABLE 2—*A variety of responses to the examination with ultraviolet light were obtained. Approximately 30% of the reams examined had a noticeable inconsistency in paper brightness. Of the 21 products used in the study, six had variations in paper brightness within the individual reams. The results are shown below.*

	Brand	Pattern of Paper Brightness when Individual Sheets were Exposed to UV Light
1.	Boise Aspen 30	One bright page, five consistent pages. Pattern repeated.
2.	Boise Polaris	One slightly brighter page, one average, one slightly brighter page, three average. Pattern repeated.
3.	Domtar	All pages had a consistent brightness.
4.	Double A (5 ream case)	One brighter page, five consistent. Pattern repeated in four of five reams. The fifth ream in the case had a consistent brightness to all pages.
5.	EconoSource	Five consistent, one less bright. Pattern repeated.
6.	First Choice	All pages had a consistent brightness.
7.	GP Advantage	All pages had a consistent brightness.
8.	GP Spectrum	Two slightly brighter pages, four darker. Pattern repeated.
9.	Harbor	All pages had a consistent brightness.
10.	HP	All pages had a consistent brightness.
11.	Husky	All pages had a consistent brightness.
12.	International Paper Hammermill	All pages had a consistent brightness.
13.	Navigator	All pages had a consistent brightness.
14.	Office Depot	Three bright pages, one less bright, one bright, one less bright. Pattern repeated.
15.	OfficeMax	All pages had a consistent brightness.
16.	Office Works	All pages had a consistent brightness.
17.	Paperline	All pages had a consistent brightness.
18.	Staples	All pages had a consistent brightness.
19.	UPM (10 ream case)	All pages had a consistent brightness in all 10 reams.
20.	Willcopy	All pages had a consistent brightness.
21.	Xerox Business Plus	All pages had a consistent brightness.

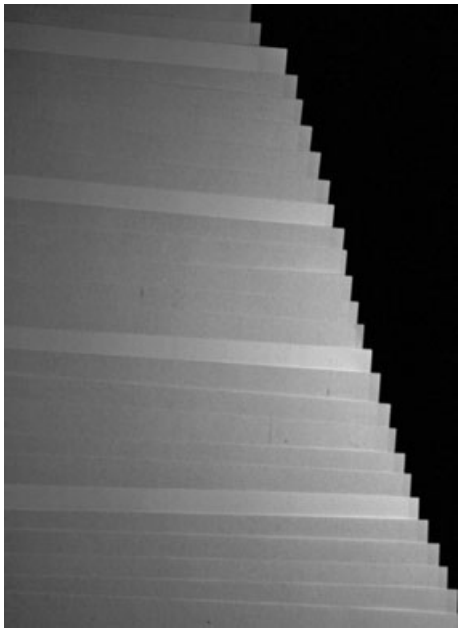

FIG. 1—*Ultraviolet light reveals an enhanced brightness in one of every six pages in this ream of paper. The brighter response was a departure from the purported paper brightness factor (92) advertised on the ream.*

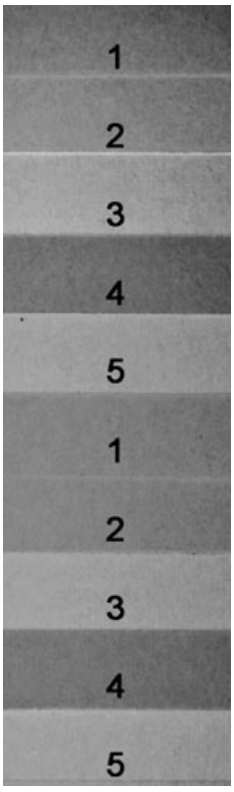

FIG. 2—*Another pattern of variation in the brightness quality was evident in this foreign paper product.*

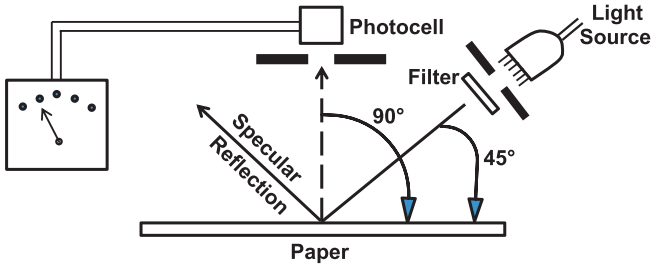

FIG. 3—*A schematic of a brightimeter. (Reprinted with permission of Charles Finley. Original source: Finley, C., Printing paper & inks, Albany, NY: Delmar Publishers, Inc., 1997:112.)*

colored compound that binds fibers together) is removed in the pulp-making process.

Lignin is removed naturally by storing the wood chips in an open environment for at least 30 days to perpetuate the oxidation of lignin as it flows to the surface. The chips are then chemically cooked to soften the wood, promoting the separation of individual fiber. Finally, a bleaching sequence is used to whiten and purify the pulp. It also adds to the sheet's cleanliness and permanence.

After the fiber separation and bleaching process, various additives are introduced to the mixture. Basically, paper consists primarily of cellulose fibers. However, many ingredients are added to give the paper its desired quality, depending upon the intended use (8). Both virgin and recycled commodity grade papers have 10% to over 40% of additives and fillers. Fillers, like precipitated calcium carbonate (a limestone derivative) and kaolin clay, are used to improve opacity, brightness, smoothness, and finish. Additionally, all paper has some moisture content.

Other paper additives include dyes, starches, sizing agents, and special purpose additives. "Bright minerals" such as titanium dioxide, aluminum trihydrate, and hydrated silica are added. These chemicals are considered "natural" brighteners. An optical brightening agent (OBA) is commonly used to enhance paper brightness. The OBA may be one, or a combination, of three classes of the sulfonated stilbene derivative dye. It is the sulfonated stilbene dye that is directly related to the fluorescent property of paper.

How does an OBA contribute toward the brightness of paper? OBAs absorb UV light and re-emit the light waves as visible blue light. Under normal incandescent or fluorescent lighting, paper having a UV component appears bluer, thus brighter. All higher-quality grades of white paper have high levels of OBAs (http://www.paperonweb.com/paperpro.htm; accessed April 17, 2011).

Untreated paper pulp does not have fluorescent properties found in common multipurpose paper. In fact, many paper products, such as paper sacks, do not require additional brightening. The enhanced brightness infused in common multipurpose papers provides greater contrast for readability.

Several chemicals are used in the production process; a transition from acidic- to alkaline-based treatments was made around 1990. As a result, papers have a lower hydrogen ion concentration (higher pH), making the entire production process more environment friendly. Specifically, calcium carbonate eliminates the acidity in paper, reducing degradation, making the paper more suitable for archival use (http://www.recycleworks.org/paper/copy_paper.html; accessed April 17, 2011).

In the United States, paper manufacturers assign brightness levels consistent with the standards of the Technical Association of the Pulp and Paper Industry (TAPPI). Manufacturers outside of the United States assign brightness levels pursuant to the International Organization for Standardization (ISO).

A visual comparison of different paper brightness levels is shown in Fig. 4.

Upon completion of the pulp formulation, the pulp is piped to equipment where it begins its transformation to paper. A prepared pulp mixture is shown in Fig. 5.

The pulp slurry becomes paper through a process of dehydration, pressure, and drying. After the paper is dried to a moisture level of approximately 3% or less, a "surface size," consisting of starch and other additives, is applied to the paper. The surface size is applied to the entire paper web. Sizing provides an important quality to the paper by minimizing the absorption of liquid (ink). The added moisture from the sizing additives requires the paper to undergo a second drying process. Prior to being stored on rolls, the paper is dried with the specified moisture content per customer specifications, typically at 5%.

Later, rolls with characteristics specific to an order are used for the "sheeting" process. Depending upon the weight of paper product requested, four to six rolls of paper will be fed into a sheeter to be cut into the appropriate size. A maximum "knife cut load" is 120 pounds of paper. As a result, the paper weight basis of 20 lb. paper stock allows for six rolls to simultaneously be fed into the sheeter. It is worthy to note that paper weight basis is the weight of 500 sheets of a base ream paper size of $17'' \times 22''$ of the sheet caliper used. A maximum of five rolls may be used for 24 lb. paper and four rolls for 28 lb. paper stock.

A six-roll production is shown in Fig. 6. The layering process is shown in Fig. 7.

When and Why Variation of Paper Brightness Takes Place

It is at this point in the production process, as multiple rolls come together and are cut into the end use size, the variation of

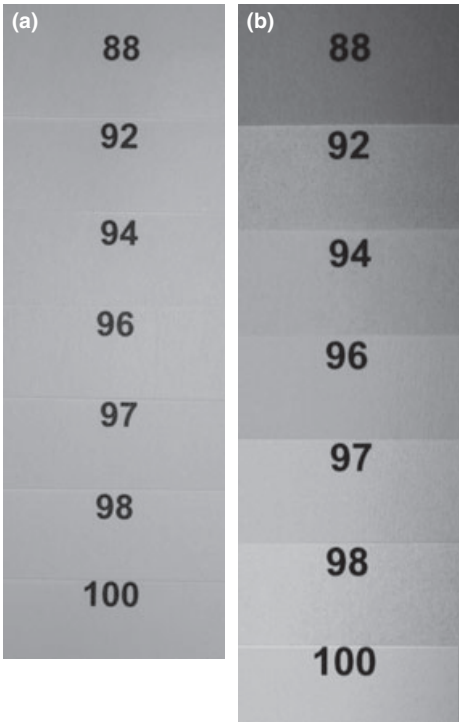

FIG. 4—*Although the papers may not differ significantly under common room lighting (a), their response under UV light (b), reveals obvious differences in paper brightness.*

FIG. 5—*The vat holds a combination of wood fibers from various tree types and several additives. The pulp is constantly stirred in preparation to be pumped to the "headbox" of a twin-wire or Fourdrinier machine.*

paper brightness takes place within individual reams. The inadvertent use of a roll, or rolls, of paper with inconsistent paper brightness will be patterned throughout the ream. As noted before, the paper weight will dictate the number of rolls used. Therefore, if one roll of nonconforming paper is used, the maximum pattern found within a ream will be one in every six sheets of 20 lb. paper, one in every five sheets of 24 lb. paper, etc.

A standard roll of paper, common to the six used for a production of 20 lb. multipurpose paper, will have approximately 60,000 linear feet of paper, 86″ wide. The six rolls will collectively produce approximately 7200 reams of 8.5″ × 11″ paper. As the rolls deplete, all are replaced at the same time. Because six rolls are used for the production of 20 lb. paper, it is interesting to note that a 500-count ream of multipurpose paper will not actually contain 500 sheets. The actual count will be devisable by six. Figure 8 shows the initial 8.5″ cuts made along a web of paper.

FIG. 6—*A production run of 20 lb. multipurpose paper. The webs of paper from the six feeder rolls come together as layers at the entrance to a cutting unit.*

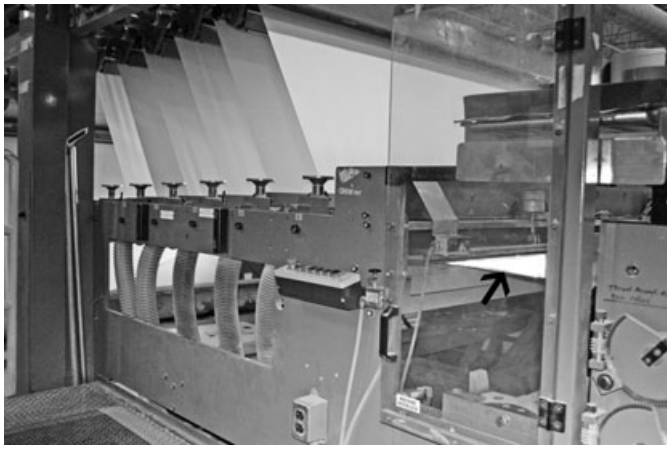

FIG. 7—*Six sheets are layered together, shown by the arrow, just prior to being cut into ten, 8.5″ wide ribbons. The ribbons of paper are then cut into 11 inch lengths, or other lengths according to customer specifications.*

FIG. 8—*Ten ribbons of 8.5″ paper are cut simultaneously, just prior to being cut into 11″ lengths. The rolls are 86″ in width, allowing a 0.5″ trim on both ends.*

Variation of paper brightness is not intentional by manufacturers. In fact, to the contrary, many steps taken to ensure quality control during the process are quite impressive. Effort is made to maintain a consistency of paper brightness within one point, plus or minus, of the targeted amount. On occasion, noncompatible rolls are inadvertently mixed with rolls matching the required specifications. However, the differences are not adverse to the printing quality of the paper or its appearance under normal lighting conditions.

Conclusions

In 1949, Ordway Hilton (4) advised, "In the light of this investigation conclusions drawn from differences in ultraviolet fluorescence of writing paper must be interpreted with caution" (p. 522). The same caution is appropriate today in the examination of multipurpose papers because of the occasional error in the manufacturing process. Finding one page with incompatible paper brightness among only a few pages in a multipage document provides less evidence by itself than one page in a document having 12 or more pages. Regardless of the size of the document, it is prudent to identify other discrepancies, such as differences in font, the printing process, etc., before asserting a page insertion or substitution did, in fact, occur.

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Additional information and reprint requests:
James A. Green, B.S.
Forensic Document Examiner
PO Box 5379
Eugene, OR 97405
E-mail: jgreen@documentexaminer.info