

## **The Forensic Examination and Analysis of Paper Matches**

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### **Abstract**

A brief discussion on the history and production of paper matches will be presented plus an overview of 10 key physical characteristics the analyst can determine when comparing a paper match to a book of matches. Also, a summary will be presented on the information that can be obtained by the examination and comparison of match heads and/or match stems by PLM, SEM-EDS, XRF, TLC, and MSP. In addition to these traditional techniques listed above, this presentation will discuss the value of characterizing the paper content of the match stems as well as the use of Adobe® Photoshop® in the comparison of the match stem color.

### **Introduction**

Paperbook matches are sometimes encountered at crime scenes and submitted as evidence to a forensic laboratory. Arson and bombing incidents are the most common types of cases where matches are utilized in the commission of a crime. A match collected at a crime scene may be intact or partially burned and sometimes both types may be present. Match evidence becomes extremely important when a matchbook from a

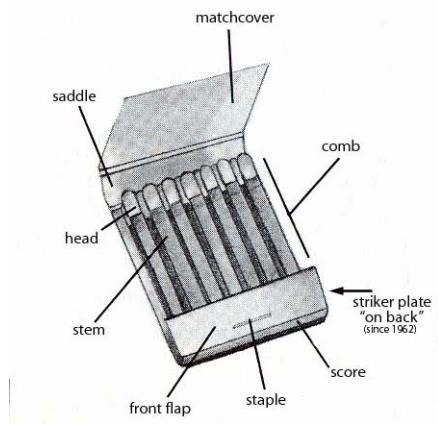
suspect is obtained and submitted to be compared with a match or matches recovered from a scene.

This paper will present a brief overview of the history of matches, how paper matches are manufactured, and the physical characteristics that one can quickly determine to provide a wealth of comparative information. Also, this paper will discuss the use of several different analytical procedures that can be employed to provide additional discriminatory information. In addition, the use of Adobe® Photoshop® to compare match stems from different books with similar colors will be addressed.

## **HISTORY**

The discovery of elemental phosphorus by German alchemist Hannig Brandt in 1669 and the invention of the first friction match by Englishman John Walker in 1827 made fire generally accessible to man. Walker's matches were simply wood splints, tipped with sulfur, potassium chlorate, and other ingredients (1). The more convenient paper "flexible" book matches were patented by Joshua Pusey, a Pennsylvania patent attorney, in 1892 who then sold the patent to the Diamond Match

Company in 1894 (2). This basic matchbook consisting of a cover folded over the cardboard matches and stapled, with one end of the cover tucked into the other remains basically unchanged today (Fig.1). Often the matchbook includes advertising on the cover, an idea sparked in 1896 by Diamond Match Company salesman Henry Traute.



**Figure 1**

## **PRODUCTION**

Matchbooks are produced from paperboard which is finished and treated with an anti-afterglow solution. The paperboard rolls are cut into long strips called combs. These combs are then dipped into a wax, dried, and then dipped into the match-head solution and dried again. The head is mainly composed of potassium chlorate (oxidizer), sulfur (fuel) and glue with some inert ingredients. The standard match book will contain two combs of 10 stems, a total of 20 matches. The advertising printing on the covers is applied prior to the friction plate (strikers). With sales targeted to the cigarette smoker, the match market reached its peak in the 1940s and 1950s but the increase in lighters in the 90's and, lately, the enforcement of smoking bans have resulted in an estimated 90% market loss (3). Thus the original "big five" manufacturers have been reduced to three major companies in North America:

- Diamond Match Co. (wooden matches)
- Bradley Industries (owns Atlas Match Co. and produces special production matches for small businesses, hotels, and restaurants)
- D. D. Bean and Sons produces matches for resale/vending market, such as grocery stores, large retail chains, military sales and convenient stores (4).

D.D. Bean and Sons currently produces approximately 80% (8 to 10 million match books a day on a four-day work week) of all matchbooks in the United States (3).

## **Physical Characteristics**

Initially, the examination and comparison of matches is made by visual inspection including utilization of a stereobinocular microscope. Early work by H. J. Funk (5) and K. C. Dixon (6) described a number of key physical features one can determine. Some

features may only provide class characteristics, whereas others may be unique and provide individual characteristics. These features are as follows:

#### Match Head

The match head color, porosity, shape and size should be noted. Even burned heads may reveal this information.

#### Stem Color

Match stems are made from cardboard and may have several observable layers when viewed on edge using a stereomicroscope. A holder is described by Funk (5), embedding clips, or a small strip of doubled-sided sticky tape on a microscope slide that can be used to aid in maintaining the match on edge. The front facing surface layer of the match stem frequently has a distinctly different color as compared to the underlying match stem body due to pigmentation and/or dying. Even the front surface of brown/tan stem matches can have a slightly different appearance than the interior of the match body. The use of a simple longwave UV lamp or alternate light source (7) may also be employed during the examination of match stems which may provide additional comparative information.

#### Wax Line

The wax on the match stem can normally be seen as a slight darker discoloration on the upper portion of the match stem. The depth of the wax line on the match stems can vary between books and within a book of matches.

#### Stem Width

The width of matches usually fall into two groups; ones that have a width of approximately 3.3 mm and ones that have a width of approximately 2.7 mm. The

approximately 2.7 mm (specification is 0.0108 inches) width is a patented dimension and matches exhibiting this width are only manufactured by D. D. Bean & Sons (3).

However, it must be noted that this does not mean that the matchbook will have “D. D. Bean & Sons” markings on the match cover since D. D. Bean & Sons produces matches with this dimension for other companies and other companies produce matches other than 2.7 mm for D.D. Bean & Sons.

#### Stem Length and Thickness

The match stem length, when placed at the cardboard base of the matchbook should correspond to the length of the known unburned matches in the matchbook. If the match is burned, a portion of the head must still be present to conduct an accurate comparison. The match thickness does not vary much and cannot be related to a particular manufacturer.

#### Base Stem Cut/Indent

As far as these authors know, this feature has not been previously addressed in previous literature. Some matchbooks may be cut or have an indentation at the base of the match stem to aid in removal of the match from the matchbook. The cut/indent may be consistent on every match or vary within a book.

#### Cut Edge Abnormalities

Cut edge abnormalities appear along the vertical edge of the match body as small irregular cuts or tears. These imperfections are due to a cutting blade becoming dull over time and are another potential point of comparison to an adjacent match in a book.

#### Cross Cut and Torn Fibers

Cross cut and torn fibers may provide unique comparable features that can associate a match to a particular matchbook. Cross cut (horizontal) and torn (vertical) fibers are noted as darker colored fibers contrasted against the more lightly colored fibers. Cross cut (horizontal) and torn (vertical) fibers are recognized under low magnification utilizing a stereomicroscope. The horizontal fibers are fibers which cross individual match stems and have been cut during the manufacturing process. Vertical fibers are the contrasting fibers which run from the base into the match stem and are torn in two when the match is removed from the book. Torn fibers are less useful when attempting to make a positive association since the tearing action of the match from the cardboard base may distort any comparison. Many times the vertical fibers may not be torn in two but are completely pulled from the base or stem when the match is removed.

One can increase the contrast between the fibers in the match stems by use of stains but it should be noted that the use of stains may permanently alter the color of the match stems. One simple way to increase the contrast between fibers is to place a droplet of an 80:20 deionized water:ethanol on the match stems, allow it to set for a moment, and then wick off any excess liquid.

Dixon (6) proposed that if two fibers on the front and two fibers on the back of two matches or four fibers on the front surfaces of two matches match, that it would be sufficient criteria to assert a positive association providing, of course, the other class characteristics are the same.

### Inclusions

Foreign matter inclusions are common artifacts in match stems and many times are cut in two when adjacent stems are cut by the blade. The strength of association is

dependent upon the uniqueness or number of corresponding inclusions. To help reveal the inclusions Gerhart, et al, (8) proposed a submersion method for the comparison of match stems. A positive association can be asserted if one observes unique features for one corresponding inclusion or there are several inclusions corresponding between two matches.

### Torn End

Assuming the general class characteristics are the same, an examination to determine if there is a physical association between the questioned match and matchbook should be made. Unfortunately, a physical association is not common due to the small match stem area available for comparison.

### Analytical Techniques

Analytical techniques common to most laboratories can be used to characterize and compare matches. For this study, polarized light microscopy (PLM), paper fiber analysis, scanning electron-energy dispersive X-ray spectroscopy (SEM-EDS), X-ray fluorescence (XRF), thin layer chromatography (TLC), microspectrophotometry (MSP), and Adobe® Photoshop® were employed. The information that each technique might provide is summarized as follows:

#### PLM

Polarized light microscopy (PLM) is a well established analytical technique used to characterize and identify particulate material (9). Some of the common inert ingredients that may be present in the match head that can be quickly identified by PLM include quartz (irregular grains,  $\omega = 1.544$  and  $\epsilon = 1.553$ ), glass fragments (irregular chips,  $n \sim 1.52$ ), diatoms ( $n \sim 1.44$  with very fine structure), and wollastonite (fibrous,  $\alpha$

$\sim 1.62$ ,  $\beta \sim 1.63$ ,  $\gamma \sim 1.64$ ). Pigments and starch grains may also be noted during a PLM examination. The presence or absence of any constituent may provide quick differentiation. Also, it helps if one removes the water soluble components with warm water using micro extraction techniques. Pigments and inclusions in stems can also be characterized by PLM.

#### Fiber Analysis of Paper Stems

The cardboard from which paper matches are manufactured is sometimes referred to as sulfate board, which relates to the alkaline chemical process for separating the fibers from wood. This pulping method is also known as the kraft process. Many of the paper matches examined appear to be from old corrugated container (OCC), which is mainly composed of used unbleached kraft paperboard. Bleached kraft fiber, hardwood semichemical pulp, and grass fibers, i.e. cereal straws, reeds, and sugar cane bagasse, can also be present in OCC.

Dixon (6) suggested the potential of analyzing the fibers in the match paperboard by differential staining. In the paper industry, this type of fiber analysis on papers is a common practice (10). Herzberg and Selleger's Stains have been used for this type of testing. However, Graff "C" Stain is more commonly utilized. These stains give color reactions which serve to differentiate chemical wood pulps, such as sulfate (kraft), soda, and sulfite (acid process) along with mechanical pulps, such as groundwood and thermomechanical pulp. These colors also vary depending on whether the wood fiber is hardwood (broad leafed trees) or softwood (conifers). There are also described color reactions for non-woody fibers, such as bast, leaf stem, and grass fibers.

To differentiate between certain pulp types that are similar, other stains can be utilized such as the Green and Yorston Stain. This stain detects only unbleached sulfite fiber by displaying a pink color.

In general, a fiber analysis method is a destructive test, which reduces the paperboard to a fibrous slurry in water. The slurry is deposited on a glass microscope slide and dried down with an even distribution of fibers across the slide. The stain is then applied to the dried fibers on the slide and examined under the transmitted light microscope. The percentages can be determined by counting the fiber types in traverses across the slide. The identification of the species present is determined by the morphology of the cell types and the anatomical features on the softwood fibers or the hardwood vessel elements.

The ability to identify the species comes from experience, familiarity with TAPPI Test Method T263, wood anatomy keys, and fiber atlases. The precise species can not always be determined due to common features within a given genus. For example, one can determine that a vessel of Yellow Birch is at least a type of birch, but not that it is particularly that species.

When comparisons were performed using matches within the same matchbook, the variance of pulp type percentage was within the tolerance ranges of 2% to 5% depending on proportion.

When comparing the paperboard of match stems from different books, including those produced by the same company, enough variance was found to state that they were significantly different. This was true for every comparison tested in our study. This probably reflects the nature of the product, since the board has been made from recycled

fibers. This study suggests there is considerable variability within match book paperboard from different batches. It should be noted that there is a possibility that the same mix could be found in different batches, but that likelihood is certainly low.

#### SEM-EDS

SEM-EDS can provide bulk elemental information (11) and can also be employed to characterize and identify particulate material and can confirm the constituents identified by PLM. Quartz grains have an irregular shape containing silicon and oxygen; glass fragments are irregular chips containing mainly silicon, oxygen and calcium with minor/trace amounts of sodium, aluminum, magnesium, and iron; diatoms have very fine structure and are composed mainly of silicon and oxygen; and wollastonite is fibrous containing mainly calcium, silicon and oxygen. Also, as with PLM, the pigments and inclusions in stems can be characterized by SEM-EDS.

#### XRF

The use of x-ray fluorescence (XRF) for the elemental analysis of forensic samples has been utilized for over 20 years and found popularity partially due to its easy sample prep and non-destructive testing. Several authors have studied the elemental analysis of match heads and stems using both SEM/EDS and XRF (11) (12).

In order to determine the discriminating ability of XRF for match heads and stems, different groups of matches were evaluated with each group sharing common visual gross characteristics such as red heads with white stems. Samples were analyzed using a 40 KeV excitation energy to allow heavier elements such as strontium (Sr) and zirconium (Zr) to be detected.

Spectra of the match heads were obtained by placing the beam near the center of the head and testing several random areas to detect homogeneity of the sample. Most heads were very homogenous in nature with few minor variations.

Spectra for stem samples were obtained by analyzing the finished side of the stem and below the wax line to ensure the elemental profile reflected only that of the paper stock. Several areas were analyzed to determine homogeneity of the stems. As was the case with the heads, some variability existed within a single stem but most stems were homogeneous.

The head and stem elemental profiles of matches from the same book were consistent with one another while matches from different books varied considerably. Although several samples shared either similar head or similar stem profiles, the combined head and stem profile discriminated all matches in this group. It is also important to note that five of the books have printing on the book indicating they were manufactured at the same Universal Match plant location.

Burned and unburned heads from the same match book for several match samples were analyzed to determine if a close elemental profile exists as noted from previous work. The overall elemental profile of the heads and stems did not significantly differ between burned versus unburned matches from the same book. However, unlike earlier reports (11) (12) where sulfur levels only were reported as varying in burned heads from the same book, spectra in this work showed variations in the sulfur (S), chlorine (Cl), and potassium (K) levels.

No absolute elemental profile was noted that would distinguish between heads of differing colors. It is interesting to note that significant Titanium (Ti) levels were present

in all white head matches tested other than the D.D. Bean samples. Contact with the D.D. Bean Company supports this finding with the confirmation that D.D. Bean does not use titanium oxide as a pigment in any of its match formulations. A significant Ti level was considered to be a Ti Ka peak intensity larger than the Fe Ka peak. Two of the three green head matches and one of the three blue head matches had Ti Ka intensities larger than the Fe Ka.

XRF analysis has shown to be highly effective at discriminating matches, especially when both the head and stem profiles can be obtained.

#### TLC

Thin-layer chromatography (TLC) has been used for decades as a separation technique and the possibility of discriminating colored match heads based on the TLC of their dye content has not been investigated. Since dyed match heads are common, the use of TLC to discriminate between visually similar red-colored match heads was investigated. A match head contains approximately 20 mg. of material, 0.05 to 0.3% of which is dye. Therefore, approximately one-half of an intact match head should be sufficient to perform a TLC analysis. In order to determine the applicability of TLC to discriminate colored match heads, 16 red match heads with similar shading from different match books with red heads were selected for analysis.

Water is the most effective solvent for the extraction of dyes from heads but using water also extracts potassium chlorate which interferes with the TLC analysis. A double extraction procedure was employed as follows: Acetone extraction (x2 in warm water bath) followed by a single dye extraction using methanol (warm water bath). The TLC development systems used were n-butanol/ethanol/water (4:1:1) and n-butanol/pyridine/water (3:1:3).

The TLC of match heads did not provide a high degree of individualization but did reveal a similar dye pattern for matches of similar manufacture/brand origin.

### MSP

Transmission microspectrophotometry (MSP), an indispensable method for the comparison of color, was utilized to compare colored match stems. To evaluate this method several visually similar black stem matches from hundreds of match books were selected. Although most spectra from the different stems were distinguishable, a few spectra from some of the black pigmented stems produced little or no spectral curves or slope for comparative purposes.

Reflectance MSP was also attempted for the comparison of red match heads. Reflectance MSP examination of visually similar red head matches disclosed that differences could be detected between three manufacturers that were tested.

### Adobe® Photoshop®

Although not normally considered an analytical technique, utilizing Adobe® Photoshop® shows promise for the comparison of paper matches. The matches are scanned together and the comparison of the image of the matches can be conducted using two techniques within Photoshop®; Hue/Saturation and LAB color mode. The adjustment of the hue within the Hue/Saturation window was able to distinguish between black match stems that visually looked the same but were from different matchbooks. No differences were noted when comparing matches from the same matchbook. The image viewed within LAB color mode channels that can be observed within the channels palette: L= lightness (luminance) shows how bright or dark the image is; A= the A

chromatic component/channel identifies colors in the image between green/red; and B= the B chromatic component/channel identifies colors in the image between blue/yellow. Normal image adjustments using "levels" can be performed in each channel to improve image quality. These grayscale stem images within a channel are compared to determine if the stems are consistent or inconsistent with each other. The B channel appears to reveal the most information in this preliminary study of black match stems. Using both techniques worked extremely well in differentiating black pigmented stems which were visually similar and indistinguishable when examined with transmission MSP.

### **Conclusions**

The observation of the physical characteristics as described in this paper will produce a wealth of information in paper match comparisons. The torn end of a match may be unique enough to make a positive association to a matchbook. Also, the observance of corresponding features between two matches such as cross-cut fibers or inclusions may provide a basis for a positive association. Information obtained by non-physical feature analytical techniques in a match comparison may affirm an association or eliminate the samples under comparison. Although this paper does not address the analysis/comparison of wood matches, many of the examinations and techniques described in this paper can be used.

### **Note**

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army of the Department of Defense, the Georgia Bureau of Investigation, Bureau of Alcohol, Tobacco, Firearms, and Explosives.

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