Guideline for Forensic Examination of Pressure Sensitive Tapes

Scientific Working Group on Materials Analysis (SWGMAT)

1.0 Scope

This document is intended as an introductory guide for the forensic scientist in the examination and comparison of pressure sensitive tapes. Detailed analytical aspects of tape analysis will be addressed in separate documents. The methods and practices described have been peer-reviewed and are generally accepted within the forensic community.

2.0 Reference Documents

E1492-92 *Practice for Receiving, Documenting, Storing, and Retrieving in a Forensic Laboratory*

SWGMAT Trace Evidence Quality Assurance Guidelines [Online] (January 2000). Available: http://www.fbi.gov/hq/lab/fsc/backissu/jan2000/swgmat.htm

SWGMAT Trace Recovery Guidelines [Online] (October 1999). Available: http://www.fbi.gov/hq/lab/fsc/backissu/oct1999/index.htm

Pressure Sensitive Tape Council-14th edition Test Methods, Glossary of Terms

3.0 Terminology

Adhesive: A material that will hold two or more objects together solely by intimate surface contact.

Additives: Materials that are included in adhesive or backing formulations to increase overall volume, impart color, or provide other desired properties.

Backing: A thin flexible material to which adhesive is applied.

Backsizing: A layer applied to the top side of the backing. Its purpose is to coat and fill a porous surfaced backing with a material that is inert to the adhesive formulation to be used.

*Calendering:*The use of a multi-roll device to apply pressure sensitive adhesive at 100% solids to various backings by heat and pressure to produce adhesive tape.

Cellophane: Form of regenerated cellulose. A thin transparent film manufactured from wood pulp. Used as a backing material in tape products.

Celloulose acetate: A transparent film that is used for tape backings. A matte surface version is used for write-on tapes. It is more moisture-resistant than cellophane.

Creped: Paper that has small folds in it giving it high stretch and conformability. Used in masking tape (saturated paper tape).

Elastomer: A material that can be deformed, but when the forces are removed will return to its original form. Serves as the base material for PSAs.

Fill yarns: Fibers in the scrim fabric of reinforced tape that run crosswise, perpendicular to the warp direction. Also called weft yarns.

Flatback: Smooth paper backing sometimes used in masking tapes.

Migration: The movement over a period of time of an ingredient from one layer to another. This often occurs in PVC tapes where plasticizer in the PVC backing “migrates” into the adhesive.

Plasticizer: Material added to plastics to impart flexibility by creating spaces between the polymer chains and lowering the inter- and intra-chain attractive forces, allowing freer movement of the chains. Used in pressure sensitive backings (particularly PVC) as well as some adhesives to lower glass-transition temperatures and allow use at sub-ambient temperatures.

Pressure sensitive adhesive (PSA): PRESSURE SENSITIVE ADHESIVE (PSA) Consists of a polymeric base usually with appropriate plasticizers and tackifiers. It can form an adhesive bond with no physical or chemical change, and with no more than slight pressure.

Pressure sensitive tape (PST): PRESSURE SENSITIVE TAPE Consists of a flexible backing and PSA, which when applied to a surface, bonds immediately at room temperature with slight pressure. The bond can be broken (usually) without damage to the surface and without leaving a residue.

Prime coat: A coating of adhesive-like material between the tape adhesive and backing that serves as a bonding agent.

Scrim: A loosely-woven gauze-type cloth added to duct tape for reinforcement and strength.

Reinforcement: Cloth, scrim, glass filaments, or plastic filaments added to tape for stability and strength.

Release coat: A coating applied to the backing on the side opposite the adhesive that provides ease of unwind and prevents delamination or tearing.

Tack: Property of an adhesive achieved by the addition of a low molecular weight organic component that allows the elastomer to form a bond immediately with a surface under low pressure.

Tackifier: Material added to the adhesive base polymer to impart tack

Thickness: Distance from one surface of either a tape, backing, or adhesive to the other, usually expressed in mils or thousandths of an inch.

Warp yarns: Fibers in scrim fabric of reinforced tape that run lengthwise in the machine direction.

Weft yarns: See *Fill yarns*.

4.0 Summary of Guideline

4.1 The information contained in this guideline is intended to assist the examiner in characterizing and comparing evidentiary tape samples. The forensic examination of pressure sensitive tape encompasses the determination of physical construction and chemical composition of tape products. General information on product variability, construction, and composition is provided. This guideline provides an overview of techniques applied to the analysis of tape components.

4.2 Methods for the analysis of tape include examinations of physical characteristics, polarized light microscopy (PLM), Fourier transform infrared spectroscopy (FTIR), pyrolysis gas chromatography (py-GC), scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS), X-ray fluorescence spectrometry (XRF), inductively coupled plasma (ICP) techniques, and X-ray powder diffraction (XRD). These different procedures provide complementary information and should be selected and employed in an order to obtain the most discriminating information consistent with the laboratory's capabilities. It is assumed that the forensic examiner has a basic familiarity with instrumental techniques used in the methods described.

4.3 Typically, a tape examination involves the comparison of samples to determine if they could share a common origin. The goal is to determine if any significant differences exist between the samples. The evaluation of tapes for class characteristics can associate known and questioned tapes to a group but not to a single, individual source. A physical end match of two tape ends provides individualizing characteristics that associate the two tapes to one another to the exclusion of all other tapes.

4.4 Questioned tape samples may be submitted with a request to identify possible product information, manufacturing, and retailing sources. Sourcing of a questioned tape can provide valuable investigative lead information. Physical characteristics and compositional data are useful for technical inquiries to tape manufacturing companies, comparisons with various brands of tape purchased at local commercial outlets, and for searching reference databases.

5.0 Significance and Use

5.1 The analysis and comparison of tape evidence in the forensic science laboratory can provide valuable information due to the variability of tape products. However, some classes of tape exhibit more variability than others. In general, the more complex the product (e.g., duct tape), the more variable it is. The common tape classes and their components are described further in section 6.0. Studies have shown differences between randomly selected rolls of tape, but because of the ever-changing tape markets, suppliers, and economics, it is not feasible to establish the statistical probability that a given sample would have the same physical and chemical characteristics as a randomly selected tape.

5.2 While tapes within a specific class may appear similar on a macroscopic level, differences may be found on closer analysis of the physical and chemical characteristics. Differences are readily observed in tapes manufactured in different plants.

5.3 Differences may also be found between batches of tape products within the same plant, due to changes in raw materials and processing that occur over time. Also, the many components that comprise a given tape product are subject to supply-and-demand fluctuations in the market. For example, a lower bid for some minor component may lead to its substitution from one batch to the next, resulting in compositional changes that can be detected in the forensic laboratory. While it is less likely to find differences in tape rolls produced by the same production line, the probability of finding differences between batches increases with time between batches.

5.4 It may be feasible to detect physical differences between rolls of tape produced in the same batch. For example, one batch of duct tape produced in a large sheet may be slit into nominal two-inch wide (~50.8 mm) individual rolls. There are numerous cutters spaced along the width of the sheet that can result in slightly different roll widths within the same batch. Differences in the warp yarn offset from the machine edge may also be found in rolls from the same batch.

5.5 Within-roll variability has been assessed using different analytical instruments. No significant within-roll variations have been reported.

5.6 In the comparison of tape samples, much information can be obtained from macroscopic and stereomicroscopical examinations. Exclusions at this stage preclude additional analysis. When samples are found to be similar at this stage, the examiner should proceed with other examinations available and practical to adequately address the chemical, compositional, and physical properties of the tapes before rendering a conclusion. At that point if no significant differences are found, the tapes are consistent and could have come from the same source. Only in rare circumstances can a stronger statement be supported.

6.0 Tape Construction and Classes

6.1 Backings
The pressure sensitive tape backing, or film, provides a support material for the adhesive. There is a wide range of materials used for tape backings depending upon the commercial end use. These include, but are not limited to, polyethylene, polypropylene, polyvinylchloride, saturated paper, cellulose acetate, cloth, and polyester. Furthermore, fillers, colorants, plasticizers, release coats, primer coats, and preservatives may also be added to tape backings.

6.2 Adhesives
The formulation of pressure sensitive adhesives (PSA) consists of an elastomer to which tackifer resins and inorganic materials are added.

6.2.1 Elastomers
The following is a list of elastomers that are used in PSAs. PSAs may contain one elastomer or a blend of several different elastomers.

Natural rubber (polyisoprene)
Synthetic polyisoprene
Polybutadiene
Polyisobutylene
Styrene butadiene random copolymer
Styrene isoprene block copolymer (SIS)
Styrene butadiene block copolymer (SBS)
Styrene ethylene-butylene block copolymer
Ethyl or butyl acrylate
Silicones
Polychloroprene

Tackifying resins are blended with elastomers to lower the glass transition temperature, allowing freer movement of the polymer chains and thus giving PSAs their “sticky” adhesive property. The tackifying resin is typically a C-5 (5 carbon hydrocarbon component). Silicone and acrylic PSAs do not require a tackifier. More costly silicone-based adhesives may be found in adhesive formulations of tapes that are geared for high temperature or chemical resistance.

6.2.2 Additives
Inorganic materials are added to an adhesive formulation to either increase the overall volume or to impart color. Such materials include calcite, dolomite, iron oxide, kaolinite, talc, titanium dioxide (rutile or anatase), and zincite. In addition, zincite can also function as an “accelerator,” or cross-linker for a rubber-based adhesive. Other materials may be added to provide resistance to extremes in temperature and UV exposure.

6.3 Tape Classes

6.3.1 Polycoated cloth tape
Commonly referred to as duct tape, polycoated cloth tape consists of three basic components: the backing, the reinforcement fabric, and the PSA. These components in concert are what

determine a duct tape's appearance, strength, and end use. The final product will be designed for specific end usage, whether it is for general commodity use, construction, etc.

6.3.1.1 Duct tape backing
The backing, which is polyethylene, is available in various colors. Duct tapes that are silver or gray commonly contain a small amount of aluminum to impart the silver color. Other colored backings are achieved by adding colored pellets to the molten polyethylene. Inorganic materials may be added to the backing, such as talc, which improves water repellency and tear strength. The backing may consist of a single layer or multiple layers of polyethylene and can range in thickness from about 1.5 mils to 4 mils (1 mil = 0.0010 in). The backing may also exhibit characteristics imparted during the manufacturing process, such as calendering marks and striations. Additionally, lettering or designs may also be imparted on the surface or the underside of the polyethylene.

6.3.1.2 Duct tape adhesive
The PSA formulation for duct tapes consists of an elastomer to which tackifying resins and inorganic materials are added. The elastomer is typically natural rubber (polyisoprene) but could also be a mixture/blend of synthetic and/or natural elastomers. Other materials used as elastomers include styrene-butadiene copolymer and styrene-isoprene copolymer.

The tackifying resin is typically a C-5 (5 carbon hydrocarbon component) that is used to make the elastomer “sticky” or impart tack.

Inorganic materials are added to an adhesive formulation to either increase the overall volume or to impart color. In duct tape adhesives any of the following may be found: calcite, dolomite, kaolinite, talc, titanium dioxide and zincite.

6.3.1.3 Duct tape reinforcement fabric
The scrim is commonly constructed of cotton, polyester, or a blend of these two materials. Reprocessed cellulose may also be found. The scrim is generally manufactured as either plain weave or weft-insertion (having knit warp yarns and texturized fill yarns). Yarns in both the warp and fill directions can be twisted (spun), texturized, or filament. Variations of these can be seen.

6.3.1.4 Other components found in duct tape
Two additional layers that may be present within a duct tape product are a release coat and a primer coat.

6.3.2 Vinyl tape
A vinyl tape, also referred to as an electrical tape, finds use in applications that require heat resistance/retardance and insulating properties. The two main components are the backing and the PSA.

6.3.2.1 Vinyl tape backing
Polyvinyl chloride (PVC) is the most common material used to construct the backing. Plasticizers, typically phthalate or adipate compounds, are added to this material to impart flexibility to the PVC. Other plasticizers may include alkyl/aryl phosphate compounds and dialkyl tin compounds. Backings range in thicknesses of 4.5-7.5 mils and are commonly black in color, imparted by the addition of carbon black. However, a variety of colored backings are produced and available. In addition to plasticizers, inorganic materials such as lead stearate, lead carbonate, antimony oxide, kaolinite, calcite, and titanium dioxide may also be found.

6.3.2.2 Vinyl tape adhesive
The adhesive can be formulated in several ways, depending on the intended end use market, and can be either colorless or black, through the addition of carbon black. Commonly available vinyl tapes consist of acrylic-based PSA or highly cross-linked rubber-based PSA. The adhesive layer

may also exhibit plasticizers, either intentionally added by the manufacturer or as a result of migration from the backing layer.

6.3.2.3 Other components found in vinyl tapes
As with duct tape, two additional layers, a release coat and a primer layer, may be used in vinyl tapes.

6.3.3 Polypropylene packaging tape
Polypropylene packaging tape has been designed as a general-purpose tape used to seal packages. The two main components are the polypropylene backing and the adhesive.

6.3.3.1 Polypropylene packaging tape backing
Packaging tape backings are typically clear but also can be found in various shades of tan or brown. The polypropylene, which is in the isotactic form, can be subdivided into two distinct types based upon their tear resistant properties: monoaxially oriented polypropylene (MOPP) and biaxially oriented polypropylene (BOPP). A monoaxially oriented backing is formed into a thin film by stretching the polypropylene material as it is slowly cooled in one direction only (length-wise) prior to introducing it into the tape manufacturing process. A biaxially oriented backing is manufactured by stretching the film in two directions (length-wise and width-wise). There is a distinct end-use or consumer difference between a MOPP and a BOPP tape: a MOPP tape is marketed as a "hand-tearable" tape, and BOPP tapes require a cutting tool such as a dispenser. Total tape thicknesses are on the order of 1.5-2.0 mil. The thickness of the film alone typically varies from 0.9 to 1.0 mil but can range from 0.8 - 2.0 mil.

6.3.3.2 Polypropylene packaging tape adhesive
Packaging tape adhesives are typically clear but are available in shades of tan or brown. Generally, when the backing is colored, the adhesive will be clear and vice versa. While clear adhesives contain no inorganic material, the colored adhesive may contain inorganic material such as iron oxide and titanium dioxide. Adhesive formulations typically are isoprene-based, styrene-isoprene copolymer-based (SIS), or acrylic-based.

6.3.3.3 Other components found in polypropylene packaging tape
Two additional layers that may be present within a packaging tape product are a release coat and a primer coat.

6.3.4 Saturated paper tape
"Masking tape" consists of a paper backing, a saturant, and an adhesive. This type of tape is used as a masking material for paint applications and other general-purpose applications.

6.3.4.1 Saturated paper tape backing
The backing of a paper tape is either flatback or creped paper, which has been saturated with carboxylated butadiene styrene, acrylonitrile butadiene, or a similar material. The purpose of a saturant is to fill porous material and boost the strength of the backing. The paper alone typically exhibits weak internal and external strengths, and the saturant fills the voids between the paper fibers adding strength to the product and minimizing absorption of paint products.

6.3.4.2 Saturated paper tape adhesive
The adhesive for saturated paper tapes typically is an isoprene-based PSA or a styrene-butadiene block copolymer, either of which may contain inorganic filler. Acrylic-based adhesives have been used as well, but for outdoor or "clean release" formulations. These adhesives for saturated tapes are formulated with less tack since strong adhesion to a surface is less desirable in masking applications. As with most tapes, if the product is designed to endure exposure to high heat or chemical reagents, the formulation will be cross-linked to provide the needed strength.

6.3.4.3 Other components found within saturated paper tape
The backsize layer is applied to the side of the backing opposite of where the adhesive will be applied. The main purpose of this layer is to coat and fill the porous surface of the backing with a material that is inert to the adhesive formulation to be used. There are a variety of materials that can be used for this purpose, such as acrylic and polyvinyl acetate, and the material used will depend upon the adhesive formulation. In conjunction with the adhesive formulation, a primer coat may be present.

6.3.5 Other tapes
The previous sections have discussed the more common types of tapes encountered within forensic casework. There are numerous other types of tape that may also be found less frequently. These types include, but are not limited to, filament/strapping tape, cloth/ medical tape, and office tape.

6.3.5.1 Filament/strapping tape
Filament tapes are similar to packaging tapes in construction with the addition of reinforcement material. The backing for this type of tape is typically constructed of oriented polypropylene (low cost) or polyester (high cost). The reinforcement filaments can be glass, polyamide fibers, or polyester fibers running in the machine direction. Adhesives found on such tape products can be colored, dependent upon inorganic material content, or colorless. The elastomer can be either isoprene or styrene-isoprene block copolymer.

6.3.5.2 Cloth tape
Cloth tapes are most frequently used for medical and athletic purposes. Common cloth materials include natural and synthetic woven fabrics (e.g., cotton, polyester). Traditionally, adhesives were natural rubber-based, but in recent history have been largely replaced by acrylic copolymers and other synthetic elastomers.

6.3.5.3 Office tape
Office or stationery tape is comprised of a backing and a PSA. The most common tape backings include cellulose acetate, cellophane, and polypropylene and can range in appearance from clear glossy or matte to a translucent yellow. The PSA can be isoprene-based, acrylic-based, or styrene-isoprene copolymer-based. As mentioned in the previous tape discussions, a release coat and a primer layer may also be present.

7.0 Sample Handling

7.1 Due to concerns with the handling of tape as physical evidence, each laboratory must develop appropriate procedures concerning sample size, collection, packaging, preservation, and order of examinations.

7.2 Different forensic disciplines may be called upon to examine the same item of evidence. The order in which the examinations will be conducted needs to be resolved on a case-by-case basis. The order of examinations should be selected and conducted so as to preserve the most transient evidence and provide the greatest discrimination and most valuable information. Examiners must be aware or make the submitting agency aware of the effects that some disciplines' processing and examinations may have upon other specific examination requests. If another discipline is chosen before the tape examination, obtaining an unadulterated representative sample should be considered.

7.3 When the amount of a tape specimen present for comparison purposes is adequate in size—as deemed by the examiner—bulk or lot sampling is the sampling method of choice. Considerations involved with bulk sampling should include where the sample is taken, how much sample is taken, and if the sample is considered representative of the whole. The examiner must be able to explain how the samples were taken and why the sampling technique was used.

Nondestructive methods should be exhausted before subjecting the sample to any destructive tests.

7.4 Techniques to untangle tape specimens should be chosen with care to minimize alterations in the chemical or physical properties. Methods include mechanical separation using warm air, liquid nitrogen, or appropriate solvents.

7.5 The item of evidence should be preserved in a manner that does not interfere with future testing.

7.6 Tape samples submitted as evidence may be degraded by environmental exposure or subjected to physical damage. The strength of an association between a damaged piece of tape and a more pristine sample might be weakened depending upon the degree of damage. In some cases, the damaged tape may be unsuitable for comparison purposes.

8.0 Methods

This section provides an overview of suggested flow of analytical techniques to be utilized for the analysis of tape. The selection of methods is at the discretion of each examiner on a case-by-case basis and will vary depending upon sample size or condition, availability of laboratory instrumentation, and examiner training. Subsequent SWGMAT documents will address these methods in more detail specific to tape analysis.

8.1 Physical Characteristics
Macroscopic and stereomicroscopical observations (e.g., color, thickness, width, and reinforcement construction) provide initial and discriminating information for tape comparisons. Physical end matches can provide individualizing associations.

8.2 Polarized Light Microscopy
Characterization of inorganic materials and other tape additives are accomplished with the use of PLM. PLM is a useful adjunct to FTIR and elemental analysis. Optical properties of oriented polymers such as polypropylene (MOPP and BOPP) and polyester can also be determined. PLM is also used to evaluate and differentiate the reinforcement fibers of tapes (e.g., duct tape and strapping tape).

8.3 Fourier transform infrared spectroscopy
Organic and some inorganic constituents may be evaluated with the use of infrared spectroscopy. These components include the backing polymer, adhesive elastomer, plasticizers, additives, and reinforcement fibers. The use of a bench ATR (attenuated total reflectance) accessory is particularly useful for surface analysis of a larger area of the adhesive and backing.

8.4 Elemental techniques
Common analytical techniques that can be utilized for the characterization of the inorganic constituents of tapes include scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS), x-ray fluorescence spectroscopy (XRF), inductively coupled plasma (ICP) techniques and X-ray powder diffractometry (XRD). SEM/EDS, XRF and ICP provide elemental profiles of analyzed specimens while XRD provides crystalline structure information. Additionally, SEM has imaging capabilities to evaluate surface topography of tape backings.

8.5 Pyrolysis gas chromatography
Organic constituents may be further characterized by py-GC. This technique separates the formulation into it individual organic components. This is particularly useful when inorganic fillers in the tape obscure the FTIR interpretation. Py-GC can be coupled with mass spectrometry to obtain molecular information.

9.0 References

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