

DUCT TAPE ANALYSIS AS TRACE EVIDENCE

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Duct tape, or more properly, polyethylene coated cloth tape is an all American product. It's as American as baseball, apple pie, and the fourth of July. It was invented here and all of it is still made in the U.S.A. Most duct tape is consumed in the U.S.A.

Duct tape, as we know it, is that silvery grey, thick, strong, sticky tape that will stick to virtually everything. It originated in the 1930's from a water proof medical tape developed by the Johnson & Johnson Company. With the on set of World War II, particularly in the Pacific Theatre of operations, the military adapted it to sealing and water proofing ammunition containers. They of course required an olive drab colored tape which is still made today. Following the war, the rapid surge in residential home building made this tape a natural low cost, convenient means of fabricating duct work for central heating systems. The tape was made silver grey in color — to match sheet metal, adopted its present name, and now the rest of the story is history.

Duct tape is available in virtually every retail store in America from K-mart to Food Giant to the corner drug store. Its probably a safe bet that somewhere in most American homes, automobiles and places of work, there is a roll of duct tape hidden somewhere. Duct tape is a tribute to American ingenuity for the endless number of uses that have been devised for it. Duct tape has been used for patching, sealing, and repairing almost any thing that breaks, from car bodies to broken bones. It has been to the bottom of the ocean, the top of Mt. Everest, and to the moon and back. In some cases, it has a personality all its own. It is called Duck Tape and Two Hundred mile an hour tape. I like to call it Fun Tape.

Unfortunately, however, duct tape has fallen into some sinister and macabre uses, and is now today being referred to as Crime Tape. It has been used for binding rape and murder victims, wrapping drug parcels, and holding bombs together. This paper provides a brief overview of what duct tape is made up of, and how it might be useful as evidence in identifying a suspect and linking him to the scene of the crime. This is primarily from a formulator's and manufacturer's point of view, rather than as an analytical chemist, since my expertise in that area is limited.

Let me preface my remarks with two key points as follows:

- 1 — All duct tapes are not alike even though they may appear to be the same to the casual observer.
- 2 — Everything changes. New constructions appear and old constructions disappear. Materials are constantly changing due to the intense price competition in the industry.

It is precisely because of these points, that your chances of linking a suspect to a crime scene, using duct tape as evidence, can be much more than merely coincidental. There is enough variation within the products and the process to support the notion that two reasonably matched samples could likely come from the same source.

Construction

Duct tape consists essentially of three components — a film backing, a fabric reinforcement, and the adhesive (Figure 1). There are probably two or three dozen basic models of duct tape in which the amount and

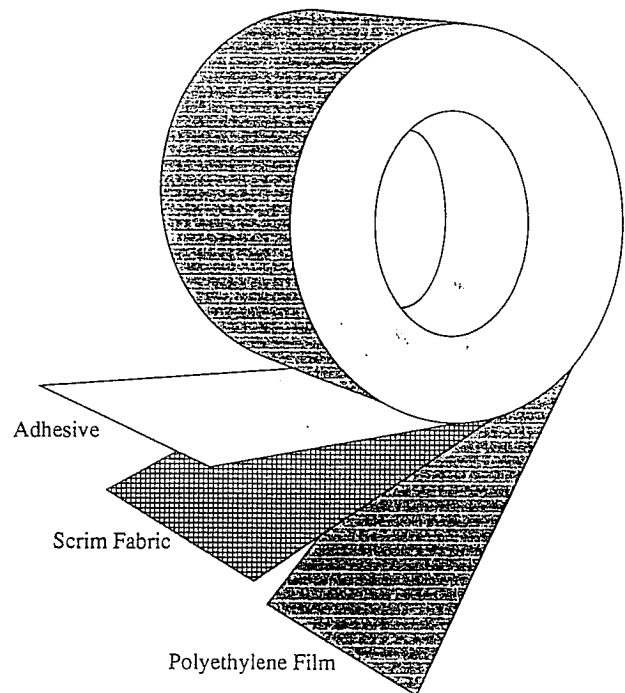


Figure 1. Illustration of duct tape.

quality of each component is varied to meet the needs of a particular end use or market. The specific grade of product can be a good clue to a suspect's profession or place of employment, since the various products are sold thru different distribution channels.

FILM

The film used as duct tape backing is typically a low density polyethylene blown film (Table 1). Other olefin polymers, such as linear low density polyethylene may be included to increase the strength of the film. For the standard duct tapes, the film is combined with the fabric and adhesive via a high pressure laminating process referred to as calendering.

The film may range in thickness from as little as 1.5 mils to more than 4 mils. Product cost and appearance and, to a lesser degree, functionality determine the thickness of the film that is used. Thin films show the fabric pattern most visibly, and are used in the low end commodity and retail products. Thicker films show less of the fabric pattern and may completely mask it. Those tapes are used more by craftsmen and in more demanding industrial applications.

A colorant is included in the film to provide the tape its color. Aluminum metal powder is used for the typical silver grey color. Duct tape can be made in virtually any color, though black, white, red, yellow, and olive drab are the most common. The film may be vacuum metalized to provide a bright silvery appearance.

Shuford offers twelve standard off the shelf colors, including Richard Petty blue and Daryl Waltrip orange. Custom colors are available for a 500 case minimum order (3600) rolls. We have made purple colored tape for one customer who wanted to reduce the theft of tape from his job sites.

Other additives, such as flame retardants, may be included in the film for functional purposes. The film may be printed. The state of California requires the manufacturer's name and product number on all tapes used in permanent applications in the construction industry. The film may also be embossed.

There are several products related to duct tape in which the polyethylene is applied as a molten material

Table 1. DUCT TAPE FILM BACKING

Thickness
< 2 mils — low end commodity, retail
>2 mils — craftsman, industrial
Low density polyethylene (LDPE)
Linear low density polyethylene (LLDPE)
Aluminum powder — silver/grey color

during the calendering operation rather than a preformed film. Kendall Corp. has a patent on this process and manufactures these tapes with and without fabric for pipe wrapping and asbestos removal.

The polyethylene may be applied via extrusion coating, to a high count, thin fabric. These tapes are produced primarily in Japan and Korea and usually made with rayon and a synthetic rubber adhesive.

Finally, there are dull, matte finished tapes of various colors, that are used in the motion picture and entertainment industries because they don't reflect light. These tapes are made with a polyvinylchloride plastisol coating applied to a high count cotton fabric and are called gaffers tape.

FABRIC

The fabric used in duct tape is typically a low count, woven scrim or gauze cloth (Table 2). In the past, this cloth was all cotton. Currently, polyester cotton blends are used. The polyester is less expensive and provides better strength and elasticity, yielding a fabric that is thinner and has good stability. The cotton allows the tape to be torn by hand. Blend levels range from 50/50 to 65/35.

Duct tape fabrics are described by the term yarn count, which is the number of yarn ends per inch in the warp, or machine direction, followed by the number of ends in the filling direction. Yarn counts range from the very low end 20 X 8 to the high end 54 X 28. The high count fabric would contain more than three times the amount of yard of the low count fabric.

As with the film, product cost, appearance and functionality determine the fabric that is used in a specific tape. At present, 20 count fabrics are predominant in retail grade tapes and those with counts of 30+ are used industrial tapes. A mid range 24 count fabric is found in both markets as either a high end retail tape of a cheap contractor grade tape.

Table 2. DUCT TAPE (SCRIM) FABRIC

Warp Yarns — machine direction (MD)
Strength of tape determined by the number of yarns, size, and type
Ease of tearing determined by polyester/cotton blend ratio
Filling Yarns — cross direction (CD)
Type and number determines the stability, appearance and bulk of the tape
Yarn Count — warp X fill - ends per inch
20 X 10 — low end commodity, retail
24 X 16 — craftsmen, painting and HVAC
38 X 24 — industrial, specification grade

The fabrics are used in their greige or unfinished state. Process aides, such as starch or polyvinyl acetate, used in weaving the fabric will be found on the warp yarns. Much of the yarn used for duct tape fabric is second quality apparel yarn which may not accept dye properly or may not resist shrinkage. Optical brighteners may be present in those yarns. In rare cases, the yarns may be treated with a flame retardant or may be dyed.

Particular yarns are used by specific tape producers. Kendall Corp. has a patent on the use of texturized filling yarns to add bulk and thickness to the tape. Shuford uses spun filament yarns to avoid that patent. Japanese and Korean tapes use rayon due to its availability. There is presently no domestic source for rayon. Acrylic yarn was used in the past, but that is also no longer available. Virtually all duct tape fabric is now woven. A knit construction that was popular in the early eighties lost out economically to the newer high speed air jet looms.

ADHESIVE

The adhesives used on duct tape are generally natural rubber compounds which contain tackifying resins that provide the "stick-um" and inert fillers that add bulk (Table 3). The natural rubber is imported from Malaysia, Indoesia, and Liberia, and is available in a variety of grades of purity and quality. Natural rubber is traded as a commodity and its price can change dramatically due to supply and demand or pure speculation. Reclaimed or reprocessed natural rubber is often used in addition to or as a replacement for virgin rubber based on price or the tape producer's manufacturing process. Synthetic polyisoprene was used several years ago when the AIDS scare led speculators to double the price of natural rubber for a short period of time. Other rubber polymers

such as styrene-butadiene, styrene-isoprene, and butyl rubber may be used, though generally as minor components, for functional or economic reasons.

Tackifying resins solvate the rubber and make it sticky. These resins are low molecular weight polymers derived from by-products of several chemical process industries. Aliphatic hydrocarbon resins are produced from the "C5" fraction that is a by-product of petroleum refining and ethylene production. The natural rosin tackifiers are produced from by-products of paper manufacturing. Some resins contain both types of monomer. Other resins contain additional monomers such as "C9" aromatics and acid functional groups.

There are several dozen varieties of tackifying resins available from more than ten different manufacturers. The resins are classified by melting point and range from 10°C to 100+°C products. Most adhesive formulations contain at least one low melt and one high melt resin. The types and amounts of resin used represent the black art of adhesive formulation. Choice depends on the rubber used, performance properties that are required, the formulator's whims, and or course, cost.

Inorganic fillers are added to the adhesive to increase bulk and allow for the thick adhesive coating that is applied on duct tape. Aluminum silicate (clay) and calcium carbonate are the most common. Choice is based on price and proximity to the source, since packaging and shipping may be more than the cost of the filler.

Other components may be present in minor amounts in duct tape adhesives for various specific purposes. Titanium dioxide is used to opaque and pigment the adhesive white in color. Consumers often perceive a white adhesive as purer and better in quality. Phenolic resins, used along with zinc oxide, provide chemical crosslinking which improves the shear strength and holding power of the adhesive. Industrial grade duct tapes are crosslinked to limit adhesive flow. Extender oils and polybutene resins plasticize the adhesive and improve quick stick properties. Antioxidants protect the adhesive from degradation during processing and extend the shelf life of the tape. Process aides reduce the time cycle required to mix a batch of adhesive. Flame retardants are required in tapes used in aircraft and some construction industries.

PROCESS

The duct tape manufacturing process will be hard for me to describe in words and difficult for you to visualize (Table 4). Traditional rubber processing equipment, such as that in the tire manufacturing industry, is utilized. The rubber is first masticated and broken down in a Banbury internal mixer using heat and high shear. The resins, fillers, and other ingredients are added to the

Table 3. DUCT TAPE ADHESIVE

RUBBER	Natural Rubber (NR) Synthetic Polyisoprene (SIR) Reclaimed, Reprocessed Rubber
RESIN	Aliphatic (C5) Hydrocarbon Natural Rosin Ester
FILLER	Clay, Kaolin, Aluminum Silicate Calcium Carbonate
OTHER COMPONENTS	SBR, SIS, Butyl Rubbers Aromatic, Terpene, Phenolic Resins Titanium Dioxide Zinc Oxide Extender Oils, Polybutene Antioxidant Process Aides Flame Retardants

Table 4. MANUFACTURING PROCESS

Rubber	Banbury Internal Mixer
Resin & Filler	Two Roll Mixing Mill
Film & Fabric	Rubber Calender
	Jumbo Roll (60 in. x 2000 yd.) Slitting
	User Roll (2 in. x 60 yd.) Packing

rubber on a two roll mixing mill. The result is a sticky, gooey mass of adhesive that looks like bread dough. The adhesive is applied to the film and fabric backings using heat and very high pressures to form the laminated tape by means of a rubber calendar. That device is basically a set of three very large squeeze rolls, machined to a precise tolerance, that control the thickness of the adhesive that is applied. Jumbo rolls of tape that are four feet or more in width and two thousands yards in length are produced at speeds of seventy yards per minute or more. The jumbo rolls are cut into user sized rolls of tape on rotary shear knife slitter rewinders. The tape is then packaged for distribution and sale.

DUCT TAPE PRODUCERS

The three major producers of duct tape (Table 5) are: Shuford Mills Inc., Tape Division, Hickory, NC, whose plant is located in Stony Point, NC; Nashua Corp., Tape Division, Nashua, NH, whose plant is located in Watervliet, NY; and Kendall Corp., Polyken Division, Westwood, MA, whose plant is located in Franklin, KY. Other producers are Tesa Tuck Industries, New Rochelle, NY, with a plant in Middleton, NY; and Anchor Continental, Columbia, SC, whose plant is in Columbia.

Table 5. DUCT TAPE PRODUCERS

Company	Market Share (%)	Million sq. yds.
Shuford Mills; Hickory, NC	35.5	52.5
Nashua; Nashua, NH	31.7	46.9
Kendall-Polyken; Westwood, MA	23.0	34.0
Others		
Tesa Tuck		
Anchor		

According to industry surveys, the big three produced over 130 million square yards of duct tape, accounting for ninety two percent of the volume made in 1989. That would amount to at least 40 million rolls of duct tape.

Producers label tape with their own brand name and with private labels for several dozen distributors and retailers. The majors produce tape for other tape manufacturing companies and also sell jumbo rolls to converters that only slit and package the tape. Unlabeled, blankcore tape, or that marked only with the roll size is made for small volume and low end resellers. Thus, though there may appear to be an infinite number of brands and producers, the industry is very concentrated, and the number of different products is really quite limited.

DISTINGUISHING CHARACTERISTICS

Each of the duct tape manufacturers product lines have common, often unique, features that are dictated by their equipment capabilities, technology base, raw material position, formulating philosophy, and marketing policies (Table 6).

Shuford Mills is fully integrated and captively produces both the film and the fabric that are used in its tape, allowing constructions to be optimized for performance and cost. The films are blends of low density and linear low density polyethylene that are 1.8 or 2.5 mils in thickness. In some products a tri-layer co-extruded film which contains high density polyethylene is used. Shuford fabrics use 100% polyester filament filling yarns along with blended polyester cotton warp yarns. The current yard counts are 20 x 10, 24 x 16, 38 x 24, and the yarn pattern is quite symmetrical and regular. Shuford adhe-

Table 6. DISTINGUISHING CHARACTERISTICS OF DUCT TAPES

SHUFORD

LD/LLDPE blends and/or coextruded 3 layer film — 1.8 and 2.5 mil thick
 100% polyester filament filling yarns
 Clay filled adhesive, aliphatic hydrocarbon resin, off white or colorless adhesive (retail)

NASHUA

Irregular weave patterns, "odd" yarn counts
 Reclaimed rubber adhesive, grey colored, rubber particles
 Modular metric width, 48mm = 2 inch

KENDALL

Thicker film backings, sometimes embossed and/or calendered
 Texturized filling yards
 Multiple rubber components, rosin ester resins, most adhesives grey or black colored

sives are clay filled and use aliphatic hydrocarbon tackifying resins. Retail grade adhesives are off-white or colorless and certain industrial adhesives are gray in color.

Nashua tape typically has odd yard counts (19 x 20, 23 x 12) with very irregular weave patterns. Due to equipment limitations, their adhesives are believed to be made entirely from reclaimed rubber. All are gray in color and often show small particles of undissolved rubber. Nashua is the only producer to slit duct tape in the so called modular metric sizes. A two inch wide roll of Nashua tape will actually measure 48mm rather 50.6mm.

Kendall, formerly a division of the Colgate-Palmolive Corp., has the most sophisticated technology, and perhaps the most complex products. Their film backings are thicker and sometimes embossed. Texturized filling yards are used to give the tape greater thickness. Their adhesives often contain multiple rubber components and several types of resin. Most Kendall adhesives are gray or black in color.

ANALYSIS OF DUCT TAPE

With all of this in mind, what then should one look for in a piece of duct tape found at the scene of a crime? (Table 7) Simple appearance and basic physical measurements can reveal quite a bit. The color of the adhesive and the weave pattern of the yarn may indicate the probable manufacturer of the tape. For example, if the adhesive is off-white in color and the yarn pattern is symmetrical and regular, there is a good chance that the tape produced by Shuford for the retail marketplace. Measurement of the yard count (that is), the number of yarn ends per inch in both directions, and the total thickness of the tape can reveal the relative quality. Thin tape with a low yarn count is typical of low end, mass market, retail products. Thicker tapes with higher yarn counts are more likely to be sold through professional and industrial outlets. The adhesive can be removed from the backing with toluene solvent or gasoline to allow measurement of the film thickness and adhesive weight applied per unit area.

High powered microscopy can be very useful in finger printing the fabric. It can reveal the fiber type and blend. Pyrolysis can be used to determine the total inorganic content of the tape and the amount of filler in the adhesive. Analysis of the adhesive is more difficult and will require some type of sophisticated instrumentation. Infrared spectroscopy can finger print the organic compounds. Flame ionization photometry and X-ray diffraction can identify the inorganic components.

Table 7. DUCT TAPE ANALYSIS

APPEARANCE	
Color of adhesive and film backing	
Texture and yarn pattern	
PHYSICAL MEASUREMENT	
Yarn count	
Total thickness	
Film backing thickness	
Adhesive weight per unit area	
MICROSCOPY	
Fiber cross section	
BULK ANALYSIS	
Adhesive percent ash	
INSTRUMENTAL METHODS	
Infra-red spectroscopy	
Flame ionization	
X-ray diffraction	

Duct tape found at a crime scene can usually be removed using patience and some heat from a hot air blower such as a hair dryer to soften and cause the adhesive to flow. Alternately, a freon spray can be used to embrittle the adhesive and cause it to lose its adhesion. Tape samples are most easily preserved by winding the tape on its own backing as it was in the original roll of tape.

Though all duct tape may appear to be the same to a casual observer, that is really not the case. It may be a key piece of evidence for linking a suspect to a crime scene, or for a search warrant of a possible suspect's home or car. Often, it may be stolen by the criminal from his place of employment and may reveal his trade or profession. Probably, not much thought is given to the tape that is used, and thus little may be done to conceal any tape that remains. Duct tape has played an important role in several criminal cases that I know of, and I answer regular calls from various law enforcement agencies on a regular basis. Unfortunately, our great "All American" invention has fallen into perverse uses that were never intended.

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