Investigation into the Effect of Fingermark Detection Chemicals on the Analysis and Comparison of Pressure-Sensitive Tapes

Abstract

Pressure sensitive tapes such as duct tape are a common trace type sent for forensic analysis. The limited variation of tape backings and adhesives can provide valuable linkage evidence between a scene, a victim or a person of interest. Fingermarks are also often found on tapes and prioritised over tape analyses. This project aimed to investigate the effects of fingermark enhancement chemicals, namely Wet Powder^{TM}, cyanoacrylate and cyanoacrylate stained with rhodamine 6G, on various tapes and their comparison with untreated tapes. The changes in physical and optical features were observed using a Video Spectral Comparator (VSC) and microscopy. Chemical changes were analysed by Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy (ATR-FTIR). Most physical and optical properties were not heavily affected by the treatments. An increase in fluorescence was observed with specimens stained with rhodamine 6G as might be expected. Significant chemical changes were observed in the FTIR spectra produced from cyanoacrylate fuming. Polyethylene backings and rubber adhesives were heavily affected while polypropylene backings were moderately affected. Cellulose backings, polyester and polyacrylate adhesives were not significantly affected. Wet Powder^{TM} treatment proved useful for enhancing fingermarks on most adhesives while leaving behind little chemical residue that might interfere in a forensic comparison.

Introduction

Pressure-sensitive tapes are often encountered by police when investigating crimes involving kidnappings, homicides, improvised explosives, and drug packaging [1]. Typically, tape found at a crime scene will be compared to a known source such as a roll in the possession of a person of interest at the forensic laboratory. Alternatively, a request may be made to identify the manufacturer and distributor of pieces of tape if no ‘known’ sample is recovered [2]. Adhesive tapes can be analysed by a range of different analytical techniques to characterize them. Differences between physical and chemical properties of tape can then be used to distinguish between tape specimens of different origins. Furthermore, if a physical end match is possible, individualizing characteristics may be found that could associate the tape to a more specific source hence providing a conclusive connection between samples [3].

Pressure-sensitive tapes are generally composed of between three to four layers including an adhesive, priming layer and backing. An additional layer of reinforcement fabric known as scrim is included as standard for fabric tapes [1]. Generally, for forensic purposes, only the backing and adhesive sides of tape will be analysed and compared. Within these layers there is a complex combination of different components which could be used to characterize the tape down to the manufacturer or brand of tape. Tape analysis follows a sequence of physical (colour, width, optical and fluorescence microscopy, scrim count) and chemical (FTIR, XRF, SEM/EDS, Pyrolysis GCMS) examinations [2]. In combination both the physical and chemical characterization of tapes can provide a high discriminating power between different types and brands of tapes. A study performed by Maynard et al. found that through the combination of physical and chemical examination of the adhesive and backing of 58 adhesives tapes, a discriminating power of 0.99 was able to be achieved for the tapes tested [4]. Similarly, a study performed by Mehltretter et al., who conducted a trial of 82 duct tapes using a series of examinations, was able to obtain a discriminating power of 0.998 [5]. While these studies demonstrate the effectiveness of tape analysis to discriminate between types and brands of tapes, significant challenges can be introduced when tape analysis is sequenced with other forensic trace examinations.

For example, adhesive tape examinations are often sequenced with DNA and fingermark recovery, with the latter taking priority over tape analysis. Fingermark detection in particular poses a potential issue for tape analysis as it will usually require chemical enhancement in order to visualize the latent fingermarks. Common development techniques for adhesive tapes include sticky side powder, gentian violet, cyanoacrylate with the addition of a luminescent stain such as rhodamine 6G or Basic Yellow 40 [6-8]. These methods are often used in conjunction with each other to develop both the adhesive and backings of the adhesive tapes. Schiemer et al. evaluated various techniques to detect and enhance latent fingerprints on black electrical tape [7]. Cyanoacrylate and staining proved to be very reliable and was even able to successfully develop marks for both aged and fresh marks on both adhesive and backing. This study was further supported by Wilson who found that a combination dye solution of rhodamine 6G, ardrox and basic yellow when applied to cyanoacrylate gave better results than either gentian violet or powders [9]. Powder suspensions (sticky side powder) have traditionally been employed as one of the preferred methods for enhancement of the adhesive sides of tape [6]. More recently there have been a number of powder suspensions (black and white) that have been shown to be effective on both light and dark coloured tapes. Williams and Elliot developed a TiO_2 based sticky side powder, which was capable of developing both sides of the adhesive tape [8]. Further study performed by Jones et al. compared the effectiveness of a range of TiO_2 white powder suspensions, and found that differences in surface coatings and particle size resulted in differing development quality [10]. A novel study also examined the use of a liquid nitrogen cryogun to remove the adhesive from surfaces without being destructive to the fingermarks prior to development with a black powder suspension (WetWop^{TM}) [11]. Overall a number of different techniques have been shown to be very effective in developing latent fingermarks on a range of tape types on both the adhesive and backings of the tape. What has not been determined is the potential impact that fingermark detection techniques may have on the characterization of tape adhesive and backing.

This study aimed to investigate the effect of fingermark development techniques, and their potential impact on comparisons to untreated samples, on various commercially available tapes. The enhancements include commonly used techniques for this substrate: cyanoacrylate fuming, rhodamine 6G staining, and Wet Powder^{TM} suspension.

Materials and Methods

Eleven rolls of tape of various brands and types, selected at random and readily available from local suppliers in the Western Sydney area, were purchased for analysis (Table 1). Several types of duct and electrical tapes were purchased to determine if the impact of fingermark enhancement treatments varied across different brands of tape

Table 1: Tapes used in this study

Tape Number and Type	Scrim	Brand	Backing Colour	Adhesive Composition	Backing Composition
1 (Duct)	Yes	Scotch	Grey	Rubber	Polyethylene
2 (Duct)	Yes	Scotch	Transparent	Rubber	Polyethylene
3 (Duct)	Yes	Unbranded	White	Rubber	Polyethylene
4 (Duct)	Yes	3M	Black	Rubber	Polyethylene
5 (Duct)	Yes	Unbranded	Red	Rubber	Polyethylene
6 (Duct)	Yes	Nashua	Grey	Rubber	Polyethylene
7 (Electrical)	No	Performer	Silver	Polyester	PVC
8 (Electrical)	No	Unbranded	Black	Polyester	PVC
9 (Electrical)	No	Omni	Silver	Polyester	PVC
10 (Masking)	No	Performer	White	Rubber	Cellulose
11 (Packaging)	No	PPS (Pack Post Send)	Transparent	Polyacrylate	Polypropylene

Specimen Preparation

The first layer of exposed tape on the roll was cut off and discarded to remove contaminants that may have been acquired during storage. A length of each tape was cut into six 3 cm pieces with a pair of scissors. The untreated set of specimens were then placed on acetate sheets with either the backing or adhesive side facing up to allow for further examination.

On the specimens to be treated with fingermark development chemicals, a single fingermark donor placed their thumb on the centre of the backing and adhesive sides of each piece. There was no grooming of the finger prior to deposition. A larger donor pool was not used in this study since the focus was on the impact that development techniques had on the adhesive tape analysis, rather than the quality of the fingermark recovered. These were attached to A4 length strips of acetate with half of the tape exposed (Figure 1). These strips were then treated with fingermark enhancement chemicals.

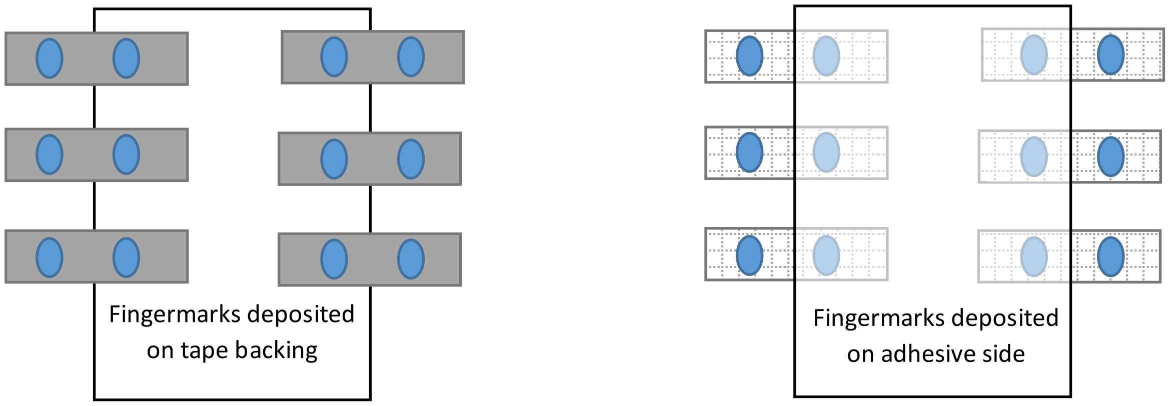

Figure 1: Schematic of fingermark deposition for the adhesive and backing of tape samples

The effects of fingermark development chemicals were observed individually as well as in combination. Therefore, twelve tapes each with six replicate pieces were prepared for each path of fingermark development chemical treatments. Chemical enhancements used were: Wet Powder^{TM} (WP), cyanoacrylate (CA), and rhodamine 6G as well the combination sets of cyanoacrylate to rhodamine 6G, (CA-R6G) and Cyanoacrylate to Wet Powder^{TM} (CA-WP). A representation of these treatments can be seen in Figure 2.

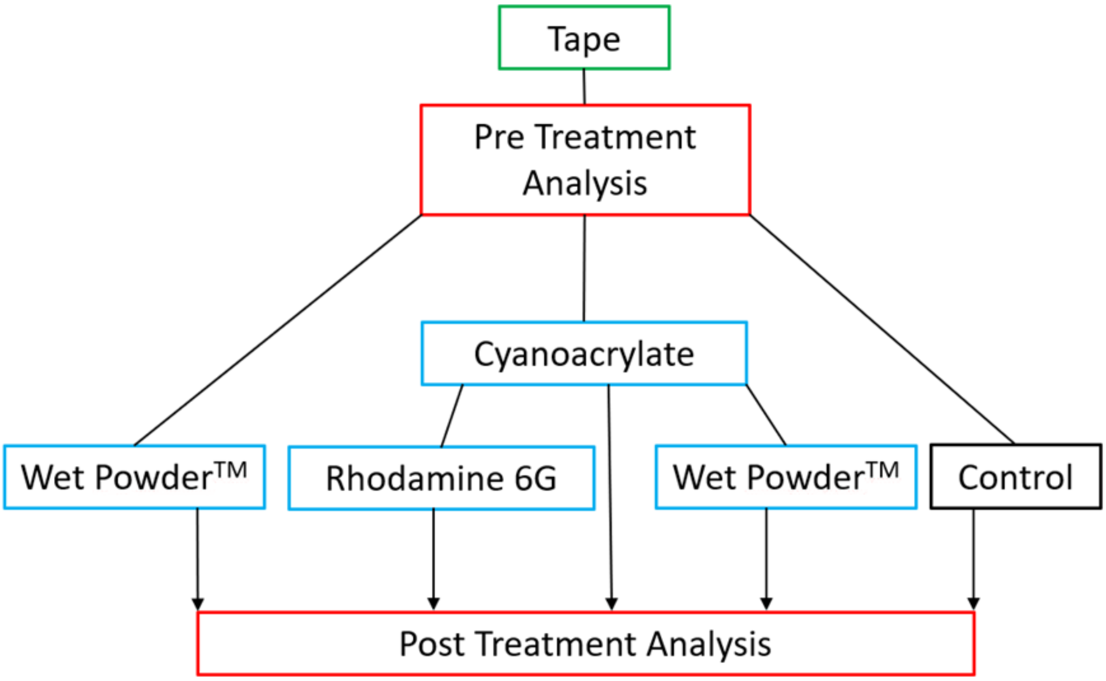

Figure 2: Workflow developed for this study

Treated tapes were left to dry by hanging overnight in the laboratory. Once the specimens were dry, they were transferred to acetate sheets with the adhesive side facing up for further analysis.

All fingermark detection techniques were applied according to the Fingermark Detection and Enhancement Manual [12]. Specimens treated with cyanoacrylate were developed using a Foster and Freeman MVC 1000D cyanoacrylate chamber. The fuming conditions for all specimens (backing and adhesives) is found in Table 2. Following the fuming, all specimens were left to cure for 24 hours before further analysis. For tapes further developed with aqueous rhodamine 6G solution, tape specimens were submerged in the rhodamine 6G working solution, prepared according to [12] for 15 seconds before being removed and allowed to dry.

Table 2: Cyanoacrylate fuming conditions

Fuming Conditions	
Mass of Cyanobloom (g)	0.5
Development Time (mins)	10
Hotplate Temperature (°C)	120
Relative Humidity (%)	80

A fingerprint brush was used to apply the Wet Powder^{TM} to completely cover the surfaces of the tape. After 10 to 15 seconds, the tapes were washed under cold running water.

Tape Analysis

Optical Examination

Physical and optical characteristics were examined using a Leica EZ4D stereomicroscope and a Foster + Freeman Video Spectral Comparator (VSC) 8000. Features observed using the steromicroscope include: backing and adhesive colour, backing and adhesive texture, the appearance of fabric reinforcements, number of tape layers and calendaring marks. The weave pattern and scrim count could also be noted where possible. The Foster + Freeman VSC 8000 was also used for general white light examination and fluorescence analysis. A Fluorescence spot filter was set to 485-610 nm. Measurements were made on the backing as well as the adhesive side. Where visible, the fluorescence of the scrim yarns was also recorded. Three fluorescence measurements were taken at random points on the tape where no fingermark development had occurred and averaged for each specimen.

ATR-FTIR

A Thermo Scientific Nicolet 6700 FTIR with a Micro ATR accessory (diamond crystal) was used over a range of 4000-400 cm^{-1}, with a resolution of 4 cm^{-1} and 64 scans. A new background measurement was made every 100 minutes. The surface of the crystal was wiped clean with ethanol between specimens. The software OMNIC 5.2a was used for visualisation and comparison of the resultant spectra. For each prepared piece of tape, three measurements were made on each surface. The location of each measurement was spaced across the sample so that the three measurements would include a better representation of the entire surface of the tape. These measurements were then averaged using the software to produce spectra that would be used for comparison and evaluation. For tapes that had been exposed to fingermark development chemicals, measurements were not performed on the developed fingermark, only on areas where no development had occurred. ATR-FTIR spectra were visualised in absorbance format.

Using the software, a library of untreated tape spectra was created. Spectra from untreated specimens were overlaid with spectra from treated specimens using a common scale which allowed for a direct visual comparison between the spectra. Differences such as peak movement, peak widening or thinning, and the appearance or disappearance of peaks were noted. Differences and similarities between the treated tapes and the untreated tapes could then be evaluated to see if the treated tapes could still be differentiated. The library search function was subsequently used for each of the treated tapes. The differences between the treated and untreated tapes could then also be reflected through the library match quality. The ability of the software to identify the correct tapes even after treatment was also assessed.

Subtraction of a standard CA spectra from CA treated specimens was attempted. The CA standard was created by applying 5 drops of Cyanobloom onto a piece of acetate sheet. After 24 hours of drying in the lab, ATR-FTIR analysis was conducted on the dried spot of Cyanobloom. This spectrum was then subtracted from CA treated specimens using the OMNIC software.

Results and Discussion

Optical Examination

In general, the effect of the fingermark detection techniques on optical characteristics was as expected. After treatment with cyanoacrylate and Wet Powder^{TM}, there were minor visible colour changes to most of the tapes (in areas that fingermarks were not present). Tapes developed with cyanoacrylate had white deposits, while Wet Powder^{TM} treated specimens had a darker colouration (Figure 3). After treatment with rhodamine 6G, there was pink colouration on all tapes and a minor increase in fluorescence. Notably, the masking and packaging tapes were significantly affected by the rhodamine 6G staining. The tapes after treatment were stained pink and had a large degree of fluorescence (Figure 4). Since the masking tape had a more porous backing than the other tapes, it absorbed the dye quickly resulting in very high fluorescence. The packing tape did not have the same porosity of the masking tape, but still showed strong fluorescence. This is likely due to the polyacrylate adhesive absorbing the dyes in a similar manner to how the dye is absorbed by the cyanoacrylate.

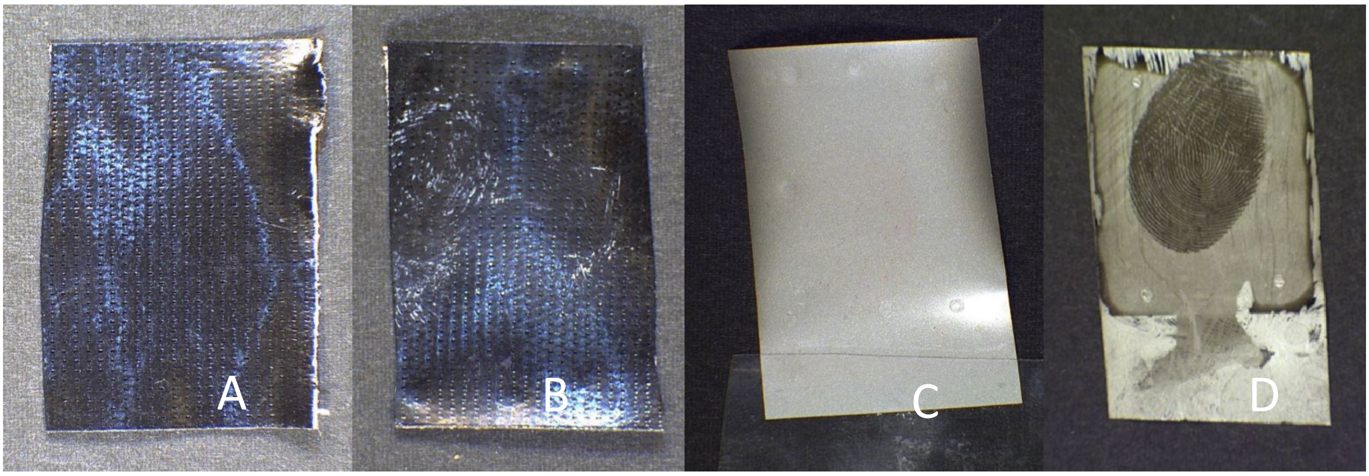

Figure 3: Optical examination images from VSC 6000 for: A - untreated backing (Tape 4), B - CA treated backing (Tape 4), C - untreated adhesive side (Tape 7), D - Wet Powder^{TM} treated adhesive (Tape 7)

There was no change to the physical properties of the tapes (scrim count, layers or width) as a result of fingermark development.

Figure 4: Masking tape (left) and packaging tape (right) post CA-R6G treatment

Analysis with FTIR

Backings made from PVC and cellulose, and adhesives made from polyacrylate and polyester, did not show marked differences after treatment with CA when compared to untreated tapes. This could be explained by these types of backings and adhesives sharing a number of IR peaks with CA. Therefore, the addition of cyanoacrylate would not significantly impact the identification of these compounds. Based on this, the electrical tapes used in this study could be considered to be compatible with cyanoacrylate development when in a sequence with a tape comparison.

The other adhesives and backings used in this study were affected by the cyanoacrylate development to different degrees. For the backings, the polyethylene backings were shown to be heavily affected with a number of new peaks appearing in the spectrum after cyanoacrylate fuming (Figure 5).

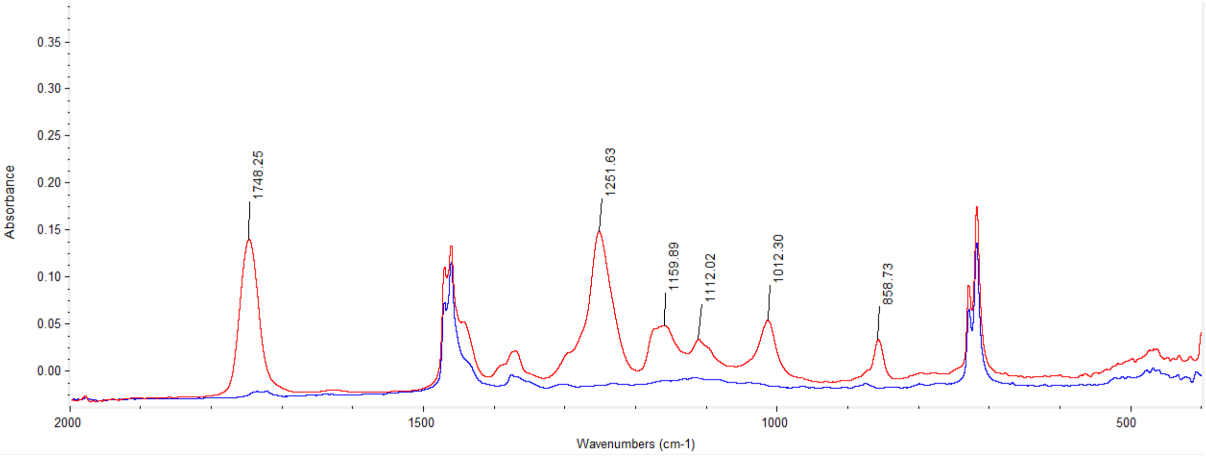

Figure 5: Overlaid FTIR spectra for Polyethylene Tape Backing, Blue: Pre-treatment, Red: Post Cyanoacrylate treatment

The additional peaks (red) present in the spectra of the CA fumed tape at 1750 cm^{-1} and 1251 cm^{-1} can be attributed to C=O stretching and C-O stretching bonds respectively. The appearance of smaller peaks at 1161 cm^{-1}, 1111 cm^{-1}, 1015 cm^{-1}, and 858 cm^{-1} could be due to further C-O, C-O-C, and C-H interactions that are not present in polyethylene spectra. These are consistent with the structure of cyanoacrylate and may lead to a misidentification of the backing type. The polypropylene backing also saw an addition of peaks at 1743 and 1252 cm^{-1} (Figure 6). While this may not result in a misidentification, it may make classification more difficult if the analyst hasn't taken into consideration fingermark treatment of the tape.

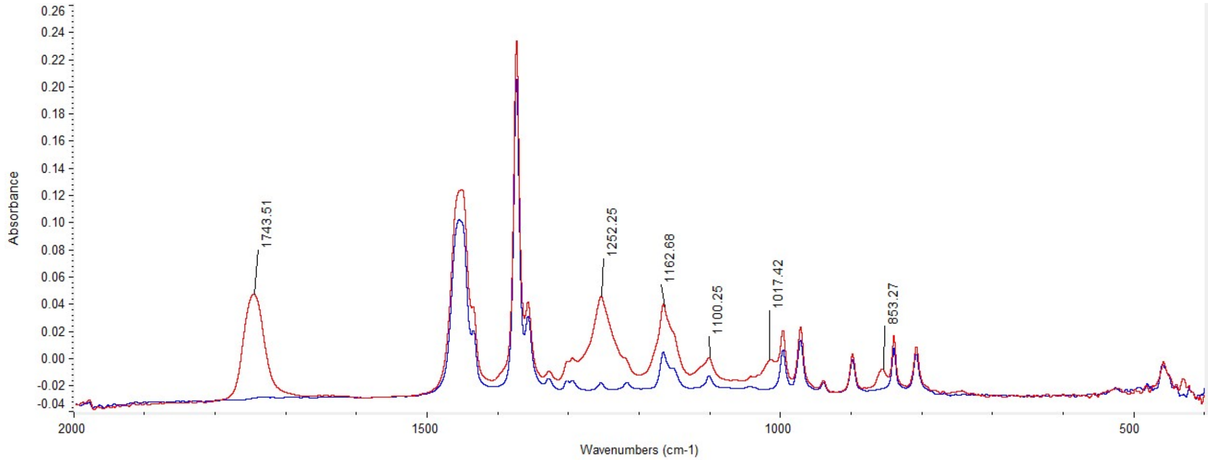

Figure 6: Overlaid FTIR spectra for Polypropylene Tape Backing, Blue: Pre-treatment, Red: Post Cyanoacrylate treatment

While traditionally cyanoacrylate may not be employed to develop fingermarks on the adhesive side of tape, the adhesive may still have some exposure to the treatment. Of the adhesives tested, the rubber adhesives were the only ones that saw a major change in the spectrum (Figure 7).

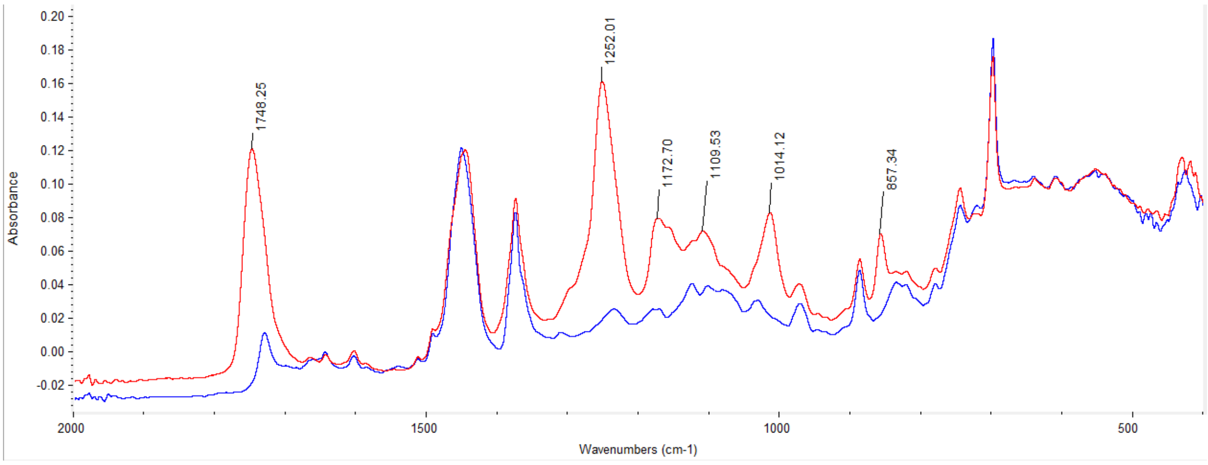

Figure 7: Overlaid FTIR spectra for Rubber Adhesive Tape, Blue: Pre-treatment, Red: Post Cyanoacrylate treatment

Similar to the backing, the additional peaks correspond to the bends and stretches that would be present in bonds within the cyanoacrylate. The rubber adhesives were commonly found ion the duct tapes as well as the tested masking tape. Given that both the backing and adhesive sides of the duct tapes were affected by the cyanoacrylate, care should be taken when analyzing these tapes by FTIR as they may lead to an incorrect classification of the adhesive or backing.

Post treatments with rhodamine 6G or Wet Powder^{TM} did not introduce any additional peaks in the spectra. For the adhesives and backings that were impacted by cyanoacrylate fuming, the additional treatments slightly decreased the intensity of the additional peaks. Both treatments required some washing (using water) which may have removed some of the residual CA and brought about a reduction in peak intensity for the CA related peaks.

Analysis using Wet Powder^{TM}

While traditionally used only on the adhesive side of the tapes, Wet Powder^{TM} was applied to both the backing and adhesive side and was found to provide suitable fingermark development without causing any interference with the FTIR analysis for any of the tapes tested. This result is not surprising as the main chemical constituents in the Wet Powder^{TM} (carbon powder, water and surfactants) are not likely to give interferences in the FTIR spectra. This result is promising as it provides fingermark examiners with a technique that can provide suitable fingermark development without interfering with the chemical analysis of the tape. The focus of this study was on the impact of fingermark chemicals on subsequent tape analysis, so before recommendations can be made to fingermark protocols, a larger study assessing the quality of developed fingermarks on tapes using Wet Powder^{TM} and cyanoacrylate should be performed.

Spectra Analysis

In order to determine the impact that different fingermark techniques had on the ability for the software to identify the type of tape, the untreated tapes (controls) were analysed by FTIR and introduced into the spectral library. After fingermark detection chemicals were applied and a spectrum of the treated tape was collected, it was then run again the library of tape controls. Table 3 and Table 4 show the average match quality (calculated as a percentage similarity) of the tapes after each treatment. The results from the backing results show that the treatments had a minor effect on the library match quality (only one of the tapes return a match quality below 50%, only four were below 80% after CA fuming only). This result is not surprising as it was only the polyethylene backed tapes that were affected by the CA fuming. In all cases when the CA fumed specimens were sequenced with CA-WP, or in all but one case with CA-R6G, the match quality improved. This is likely due to the fact that both processes require a washing step with water to remove excess powder or stain. By washing the tape with water, cyanoacrylate that had remained on the surface but was not bound to fingermark residue would potentially be removed.

Table 3: Average library match quality (%) of tape backing specimens to the original untreated tapes

Tape Number and Type	**Untreated Control**	**CA Fumed**	**WP**	**CA-WP**	**CA-R6G**
1 (Duct)	98.77	83.83	98.68	95.34	95.43
2 (Duct)	99.01	73.52	99.24	95.80	94.76
3 (Duct)	96.31	49.12	97.88	89.80	86 .61
4 (Duct)	96.02	60.11	95.51	95.02	56.04
5 (Duct)	98.36	74.36	98.47	92.35	91.11
6 (Duct)	99.17	86.71	99.08	91.11	95.51
7 (Electrical)	99.50	80.49	99.45	91.19	95.35
8 (Electrical)	98.43	60.19	98.35	98.42	89.10
9 (Electrical)	99.56	89.30	99.46	82.78	93.64
10 (Masking)	99.04	90.02	98.99	91.16	91.22
11 (Packaging)	99.46	96.41	99.45	99.12	99.24

The adhesive match quality saw a more significant impact after cyanoacrylate only treatment, two of the tapes having a less than 50% library match and an additional five tapes having a less than 80% library match. Unlike the backings, post cyanoacrylate treatment of wet powder or rhodamine 6G had a slight impact but this was tape and technique specific. The primary reason for this is the rubber adhesive used on the duct and masking tapes were most affected by the CA fuming. Unlike the backings, there was no major increase in library match scores for CA-WP or CA-R6G. This would indicate that once bound to the adhesive side, the cyanoacrylate is more difficult to remove.

Table 4: Average library match quality (%) of tape adhesive specimens to the original untreated tapes

Tape Number and Type	**Untreated Control**	**CA Fumed**	**WP**	**CA-WP**	**CA-R6G**
1 (Duct)	98.28	25.03	96.98	32.06	25.48
2 (Duct)	98.00	50.86	98.67	61.88	51.16
3 (Duct)	99.66	85.97	99.61	78.70	86.15
4 (Duct)	97.07	70.79	97.66	75.84	69.61
5 (Duct)	85.87	53.21	97.47	50.65	49.86
6 (Duct)	98.94	39.30	98.81	44.82	38.59
7 (Electrical)	99.11	90.47	98.88	76.99	90.75
8 (Electrical)	99.04	94.41	98.81	95.77	96.44
9 (Electrical)	99.31	71.14	99.12	67.62	90.30
10 (Masking)	98.01	85.23	98.05	90.63	86.26
11 (Packaging)	99.60	69.44	96.61	98.22	94.73

Background subtraction with a CA standard

In an attempt to remove the peaks attributed to the CA, a few drops of cyanoacrylate were applied to a glass slide and left to dry for over 24 hours. This CA standard was then used for spectral subtraction to determine if the removal of CA specific peaks would allow for better classification of the tape. When the CA standard was applied, due to the changes in CA peak intensity from the tape it became difficult to remove the CA peaks without disrupting the baseline. Often the CA standard peak intensity surpassed those from the tape resulting in a negative baseline. This presents a challenge since some tapes share common peaks with CA and this may potentially lead to a misidentification, since the original tape spectra is not known to an examiner.

Operational Considerations

From the results presented in this study, the use of CA to develop fingermarks can have a negative impact on the ability to classify certain types of tapes. While these results in isolation may lead to a misidentification, it is important to consider these results in the context of an operational workflow. Based on the optical examination, observations could be made to determine the type of fingermark development treatment performed on a tape. The appearance of white deposits, pink staining or darkening of the tape were all visual indicators for the type of treatment applied.

In the case of CA developed tapes, this would then alert examiners to consider the potential for contamination from the CA treatment. Sequencing with other techniques such as Raman, XRF or pyrolysis GC-MS might be necessary to determine the type of adhesive and backing. Cleaning the surface of the tape may also remove some of the residue to allow for a more accurate reading of the specimen, however introducing other substances or cleaning solvents may damage the tape or introduce additional artifacts.

Alternately to assist fingermark examiners and tape analysts in ensuring the integrity of the traces, initial FTIR screening of the tapes could be performed prior to the application of fingermark detection methods. This would firstly ensure the tape composition is known prior to any fingermark enhancement and secondly it can be used as a comparison tool after fingermark enhancement has been performed and criminalists are analyzing the tape. If appearance of additional peaks after treatment occurs, the tape analyst can make more informed conclusions and prevent any potential misidentification or incorrect classification.

Conclusion

This study examined the potential effects that common fingermark detection techniques, namely Wet Powder^{TM}, cyanoacrylate and cyanoacrylate stained with rhodamine 6G, could have on adhesive tape analysis and comparison from a forensic sequencing perspective. These methods had minimal impact on the physical or optical characteristics of the tapes selected, with the exception of porous tapes or acrylate-based adhesives, which absorbed some of the fluorescent dye solution used as a fingermark treatment enhancer. Most noticeable impact was observed with FTIR analysis. After cyanoacrylate treatment, some of the backings and adhesive tapes had peaks present in their FTIR spectra attributable to the cyanoacrylate treatment. This may not be a significant issue in a one-on-one spectral comparison. However, this can lead to a poorer library match, which may make the tape classification challenging. Wet powder suspensions had no observable impact on the chemical characterisation of the adhesive or backings of the tapes. The authors suggest that further work should be conducted to determine if wet powder suspensions are a more suitable method for development of latent fingermarks with respect to fingermark quality on the adhesive and backing of tape.

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