RECOVERY OF FRESH LATENT FINGERPRINTS ON BLACK CLOTHING FABRICS USING LUMICYANO™

By

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Declaration

I declare that this thesis does not contain any material submitted previously for the award of any other degree or diploma at any university or other tertiary institution. Furthermore, to the best of my knowledge, it does not contain any material previously published or written by another individual, except where due reference has been made in the text. Finally, I declare that all reported experimentations performed in this research were carried out by myself, except that any contribution by others, with whom I have worked is explicitly acknowledged.

Saesario Putra

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This work could not have been done without the help and support of a number of individuals.

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ABSTRACT

When a finger comes in contact with a solid surface, residues present on the friction ridges of the finger are deposited. Fingerprint residues are a mixture of sweat components from eccrine, sebaceous, and apocrine glands, contaminants from the environment such as grease and dirt, and compounds from the epidermis.[1] The ridge impression of the finger created by these compounds is called a latent fingerprint. In a forensic context, latent fingerprints are often important as they are the most common type of fingerprint found at crime scene. However, latent fingerprints are often invisible; thus, either physical or chemical enhancement is required for visualisation. The quality of the developed prints is affected by a number of factors such as the amount and type of fingerprint residues, the type of enhancement methods, temperature, and the nature of the surface.

A porous substrate such as fabric is considered as a difficult surface for fingerprint recovery due to two main reasons. Firstly, porous substrates tend to absorb fingerprint deposits very quickly. Water-soluble deposits from eccrine and apocrine glands are absorbed within seconds, which makes the enhancement method such as Cyanoacrylate (CA) fuming and silver nitrate more difficult as they utilise water-soluble compounds to initiate the reaction.[1, 2] Fabric materials (natural or synthetic) affect the absorption rate of fingerprint compounds, with natural materials such as cotton tending to be more absorbent than synthetics.[3] This was reflected in studies focusing on fingerprint recovery on fabrics, in which no fingerprint was recovered on cotton, while a more successful outcome was obtained from other less porous fabrics such as nylon and polyester.[4, 5, 6] Secondly, the compactness of fabrics also adds to the

challenge. The presence of gaps in fabrics reduces the surface area.[6] Thread count and weave pattern determine the compactness of fabrics, with higher thread counts and tighter weave such as plain weave generally resulting in a larger surface area.[7] All of these factors have a significant impact on the amount of fingerprint compounds on the surface of fabrics, which decrease the likelihood success of fingerprint recovery. The difficulty of fingerprint enhancement on fabrics may be one of the reasons why forensic laboratories rarely attempt to recover fingerprints on such substrates.[8]

Cyanoacrylate (CA) fuming is one of the very few fingerprint enhancement methods that can be used on fabrics.[6] CA fuming is a fingerprint enhancement method by fuming cyanoacrylate glue, commonly known as superglue. Liquid CA is heated to 90 – 120 ^{o}C and 80% humidity level to create CA vapour, which reacts with eccrine and sebaceous components in a latent fingermark. This results in the formation of a white polymer along the fingerprint ridges known as polycyanoacrylate.[1] The limitation of the CA fuming method is due to the lack of contrast of the developed fingerprints on light-coloured substrates; therefore, CA fuming is usually followed with fluorescent dye staining, such as Rhodamine 6G, which get embedded within the polycyanoacrylate.[9, 10] When examined under 495 – 540 nm of a forensic light source (FLS), the developed fingerprint would appear as a bright fingermark on a dark-coloured surface. On non-porous substrates such as glass and metal surfaces, this method has proven to be successful because the dye absorption only occurs on the CA polymer along the fingerprint ridges, and not on the whole surface. However, CA fuming coupled with dye staining has proven to be rather ineffective on fabrics because the entire surface readily absorbs the dye, causing excessive background staining. As a result, the desired contrast would not be achieved.[11] A recent study that utilised CA fuming coupled with infrared spectral mapping was shown to be successful on smooth and shiny fabrics such as polyester, nylon, and silk.[6] However, the spectral mapping process took eight hours to complete, which makes this technique less practical. In a separate experiment, this study also demonstrated that the use of CA fuming method alone was sufficient to enhance latent prints on dark polyester, dark nylon, and dark silk. This implies that CA monomer is able to polymerise onto the friction ridges of the fingerprints on some fabrics but the challenge arises from obtaining the contrast of the developed prints on light-coloured fabrics.

Recently, one-step CA products such as Lumicyano™ have been developed. This method incorporates a fluorescent staining dye powder 3-chloro-ethoxy-1,2,4,5-tetrazine ($C_4H_5ClN_4O$) and liquid ethyl CA into a solution. Therefore, Lumicyano™ can develop fluorescent fingerprints in a one-stage fuming process without the need for an additional visualisation method apart from Forensic Light Source (FLS).[12] The integration of fluorescent dye and CA into a mixture suggests that the fluorescent dye would selectively adhere to the polycyanoacrylate formed on the friction ridges of fingerprints. The readily visible fingerprints and the removal of the post-processing method indicate that Lumicyano™ could potentially be used on light coloured fabrics. A recent study demonstrated that Lumicyano™ offers a better or equal sensitivity for the enhancement of fingerprints on various non-porous and semi-porous substrates when compared to traditional CA fuming.[13] Moreover, this new method does not interfere with subsequent DNA analysis as it does not require a dye staining procedure.[14] To date, no study has utilised Lumicyano™ to recover latent fingerprints on fabrics.

1.0 INTRODUCTION

Fingerprints are one of the most valuable evidence that is often encountered at crime scenes. The permanence (i.e. persistency, durability, reproducibility) and the selectivity of fingerprint ridge skin suggest that fingerprints may be useful throughout three major facets of forensic science, which are to demonstrate whether or not a crime has been committed, to identify the individuals involved and how those individuals are associated with others and with the crime scene, and to reconstruct the sequence of events that occurred. [1, 8]

The suitable fingerprint enhancement method is determined by the type of substrates (i.e. porous, semi-porous, and/or non-porous) and the type of fingerprint contaminants (e.g. blood, grease, etc.). However, there is a limited option regarding appropriate fingerprint enhancement method on fabric. Cyanoacrylate (CA) fuming has been utilised in studies in fingerprint recovery on fabric. CA fuming is a fingerprint enhancement method by fuming a CA liquid to 90 – 120 ^{o}C and under 80% humidity level to create CA vapour, which selectively adheres to components in a latent fingerprint. This method has proven to be effective for developing latent prints on some dark coloured fabrics.[6] However, on light coloured fabrics, the desired contrast cannot be achieved as the CA developed print appears as a white deposit. A common visualisation method such as fluorescence dye staining cannot be used as the whole surface of fabric would absorb the dye, causing excessive background staining.[11]

Recently, a fluorescent cyanoacrylate product Lumicyano™ has been developed. This product incorporates a fluorescent staining dye powder 3-chloro-ethoxy-1,2,4,5-tetrazine ($C_4H_5ClN_4O$)

and liquid ethyl CA into a solution, which enables one step development of fluorescent fingerprint.[12] The removal of the dye staining process suggests that Lumicyano™ may be used to enhance latent fingerprint on dark and light coloured fabric. This literature review aims to evaluate the efficacy of Lumicyano™ to recover latent fingerprint on fabric. The results of such study could provide information on the potential alternative to the existing fingerprint enhancement methods on fabric.

2.0 FINGERPRINTS

Friction ridge skin on the end joint of the fingers create a number of basic patterns. These patterns are highly variable among individuals; thus, fingerprints can be used as a means of identification. There are three main classes of fingerprint that may be encountered at a crime scene: visible or patent fingerprints, latent fingerprints and plastic fingerprints. Visible fingerprints are readily visible to the naked eye without any particular enhancement. Latent fingerprints are invisible and require enhancement technique to visualise them. Plastic fingerprints are friction ridge impressions present on a soft substrate. Latent fingermark is the most common type of fingerprint found at a crime scene.

2.1 Anatomy of Friction Ridge Skin

The skin is divided into three anatomical layers: epidermis, dermis, and hypodermis (Figure 1). These distinct layers act as a protective barrier, regulate body temperature, secrete sweat components, play a role in the body immunity, and synthesise vitamin D.[15] The epidermis, which is the outermost layer of skin, consisted of keratinocytes, melanocytes, Langerhan cells, and Merkel cells. The keratinocytes are responsible for the regeneration of the skin. Figure 2 shows the five sublayers of the epidermis: Basal generating layer (Stratum germinativum), spinous layer (Stratum spinosum), granular layer (Stratum granulosum), transitional hyalin layer (Stratum lucidum), and horny cornified layer (Stratum corneum). The cornified layer exposed to the environment consists of 15 – 20 layers of dead cells that are continuously lost at the surface and regenerated by keratinization. This process starts in the basal generating layer and produces the new skin cells, which gradually migrate towards the skin surface.

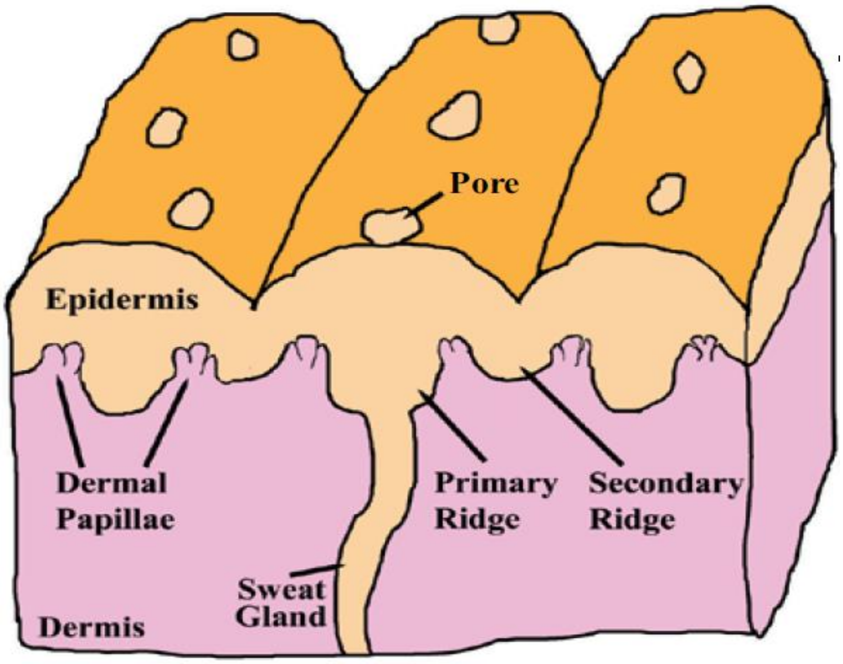

Figure 13. The structure of friction ridge skin.[16]

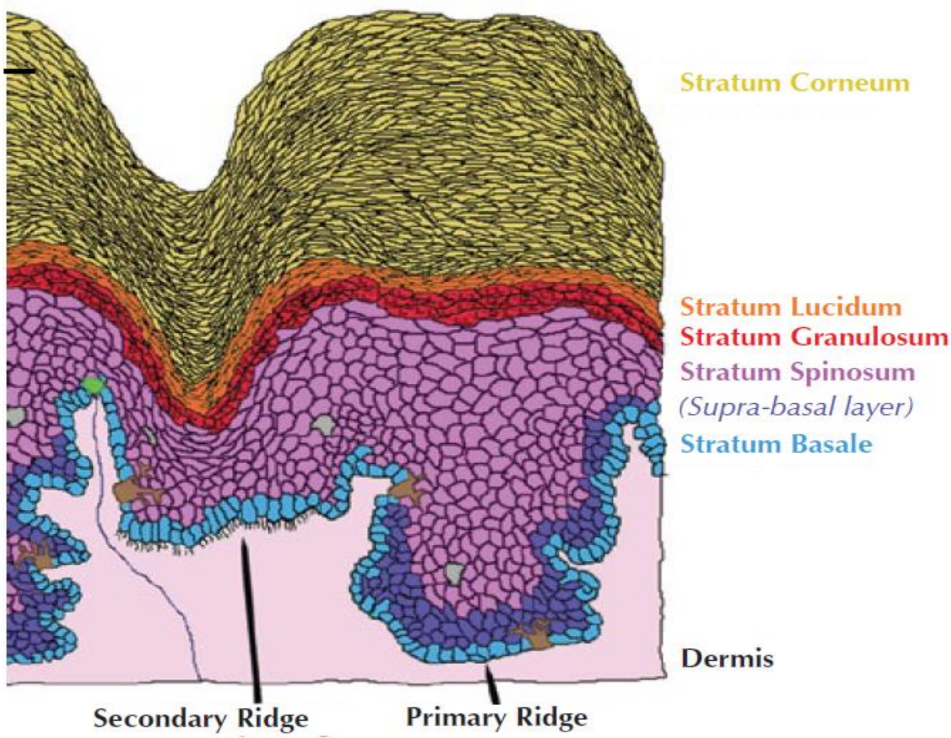

Figure 14. Division of the epidermis.[16]

The dermis is made up of connective tissue, blood vessels, and gelatinous material that provides structural support and nourishment for the epidermis. The dermis layer is 15 – 40 times thicker than the epidermis and constitutes the primary mass of the skin. Eccrine sweat glands are the only appendage of the friction ridge skin (fingers, palms of the hands, soles of the feet). The concentration of eccrine gland in these regions is between 2500 – 3000 glands/cm^2, which is the highest compared to other regions in the human body.[17] The eccrine glands on the friction ridge skin are larger, more active, and denser than in any other area of skin. The ridges and valleys on the surface of the friction ridge skin are firmly ingrained in the dermis by structures called primary ridges (under the surface ridges/hills) and secondary ridges (under the valleys/furrows). Both ridges are rooted in the dermis and function to provide strength to the friction ridge skin.

2.2 Latent Fingerprint

A latent fingerprint deposited by the friction ridges of the finger is a complex mixture of sweat secretions, epidermis cells, and contaminants from the environment. Natural secretions of the skin can be produced by three different types of gland: Eccrine, Apocrine, and Sebaceous. Each of them has specific functions; therefore, their secretions consist of different chemical compositions.

The eccrine gland is the only type of sweat gland present in the palmar surfaces. Eccrine sweat glands are responsible for the regulation of body temperature and the excretion of metabolic waste.[18] Eccrine glands produce water-soluble deposit (WSD), which is a mixture of inorganic salts and water-soluble organic components. Sebaceous glands are located in all areas of human skin except in the palms of the hands and soles of the feet. The forehead and the back have the highest concentration of sebaceous gland. This type of gland secretes sebum, which helps to protect the skin and hair against water, acts as a lubricant, and also helps to absorb lipid-soluble substances.[19] Secretions from sebaceous glands are semisolid combinations of fatty acids, wax esters, glycerides, and long-chain hydrocarbons that result in a non-water soluble deposit (NWSD). Apocrine glands are distributed on the axillae, areola of the nipple, and genital areas. Apocrine glands produce apocrine sweat, which contain pheromones. This type of gland is inactive before puberty and responsive to emotional stress. Similar to eccrine gland secretions, apocrine glands secrete WSD and water. The main chemical constituents of the glandular secretions are given in Table 1.

Table 1. Chemical Constituents of Glandular Secretions. [20, 21, 22]

Secretion	Chemical Constituents	
	Organic	**Inorganic**
Eccrine sweat	Amino acids Proteins Urea Uric acid Lactic acid Sugars Creatinine Choline Polypeptides	Water (>98%) Chloride Metal ions (Na^+, K^+, Ca^{2+}) Sulphate Phosphate Bicarbonate Ammonia
Sebum	Glycerides (20%–25%) Fatty acids (30%–40%) Wax esters (20%–30%) Squalene (10%–15%) Sterol esters (2%–3%) Sterols (3%–4%)	
Apocrine sweat	Proteins Carbohydrates Sterols	Iron Water (98%)

Since the ridges of the hands are covered exclusively by eccrine glands, their secretions are expected to be present in the latent fingerprint at the moment of deposition. It is also common for a latent fingerprint to contain sebaceous gland secretions, due to activities such as combing the hair and touching the face. Contamination from apocrine gland secretions is rare but may occur in crimes of a sexual nature such as sexual assaults.[1]

Most published references[16, 23, 24, 25] quote that water constitutes 98% of eccrine and sebaceous sweat production. However, this does not mean that typical latent fingerprints would constitute 98% of water. Some water on palmar skin surfaces is reabsorbed into the skin, while a significant portion of water evaporates to keep the body temperature down. Some authors state that the palmar surface is the region in the human body where water evaporation occurs at a high rate, approximately at 0.5 mg/cm^2/minute in adult male.[26] Croxton[27] indicates that on average, a typical latent fingerprint weighs up to 4–5 µg. Approximately 4 µg of the mass is thought to consist of fats, amino acids, chloride salts, and skin debris.[22, 27, 28] Therefore, this indicates that the approximate amount of water content in a typical fingerprint is 1 µg or 20% of the total constituent of a latent fingerprint.

There are various factors that may affect the initial chemical constituents of a latent fingerprint. These include donor characteristics (age, gender, ethnicity, medication, etc.), environmental contaminants (food, cosmetics, etc.), recent activities (exercise, hand washing), the manner of fingerprint deposition (pressure, duration of contact), environmental factors (temperature, humidity, exposure to light, the presence of bacteria) and the type of substrate (porous, semi-porous, non-porous).[22, 23] The importance of chemical constituent of latent fingerprint in Cyanoacrylate fuming process will be explained in Chapter 4.

2.3 Features of Fingerprint Ridge Skin

The features of friction ridges of fingerprint are classified into level 1, level 2, and level 3.[29] These levels refer to ridge pattern, ridge path deviations, and intrinsic ridge formations respectively.

Level 1 detail is the overall pattern created by the flow of fingerprint papillary ridges. Numerous classification system were developed in the early days of dactyloscopy. The most popular classification systems for fingerprints classifies the ridge impression pattern types as either loops, whorls, or arches.[30, 31, 32] There are sub-classifications for these patterns as well (Table 2). The path of the ridges and pattern type are useful characteristics, but their discriminating power is low. Thus, level 1 detail is only utilised for exclusion and classification, but it is not sufficient alone for individualization. Moreover, the flow of the ridges can be distorted easily and appear differently in latent fingerprint than in the reference/exemplar print.[1] In order to increase the discriminative power of the system, sometimes fingerprint examiners add ridge counting and ridge tracing to level 1 features.[1]

Table 2. Fingerprint General Patterns.[33]

Pattern	Illustration	Characteristics
Plain Arch		The ridges enter on one side of the impression and tend to flow out on the other side, with a rise in the centre.
Tented Arch		Similar to plain arch, except that the ridges in the centre form a definite angle.
Ulnar Loop		The pattern in which the loops flow in the direction of the little finger. The illustration shows an ulnar pattern if it presents on the right hand. It is also called a right slant loop, regardless of which hand it appears on.
Radial Loop		The pattern in which the loops flow in the direction of the thumbs. The illustration shows a radial pattern if it presents on the right hand. It is also called a left slant loop, regardless of which hand it appears on.
Plain Whorl		Plain whorl consists of two deltas and at least one core. An imaginary line drawn between the two deltas must cross at least one of the recurving ridges.

Central Pocket Loop		This pattern contains one or more recurving ridges, with two deltas. An imaginary line drawn between the deltas would not touch the recurving ridge.
Double Loop		Double loop pattern consists of two separate loop formations, with two deltas and two distinct sets of shoulders.
Accidental Whorl		Accidental whorl contains two or more deltas and a combination of two or more different patterns exclusive of the plain arch. This pattern also includes any pattern that does not match the definition of any other classes.

Level 2 refers to major ridge path deviations, also known as minutiae, points of identification, or Galton characteristics.[1] The friction ridges are not continuous, as they can split into two ridges (bifurcations), and abruptly (ending ridges), or sometimes appear as a single dot (dots).[34] Combinations of these basic forms are possible, as shown in Figure 3. The distance between pairs of minutiae connected by a ridge, also known as the lengths of ridges, also classified as level 2 detail. In addition, features such as warts, scars, and wrinkles are sometimes referred to as level 2. Minutiae have strong discriminating power, thus often used in fingerprint identification. The quantity, quality, location, and rarity of the minutiae possess discriminating value that can be useful in the comparison of fingerprints.

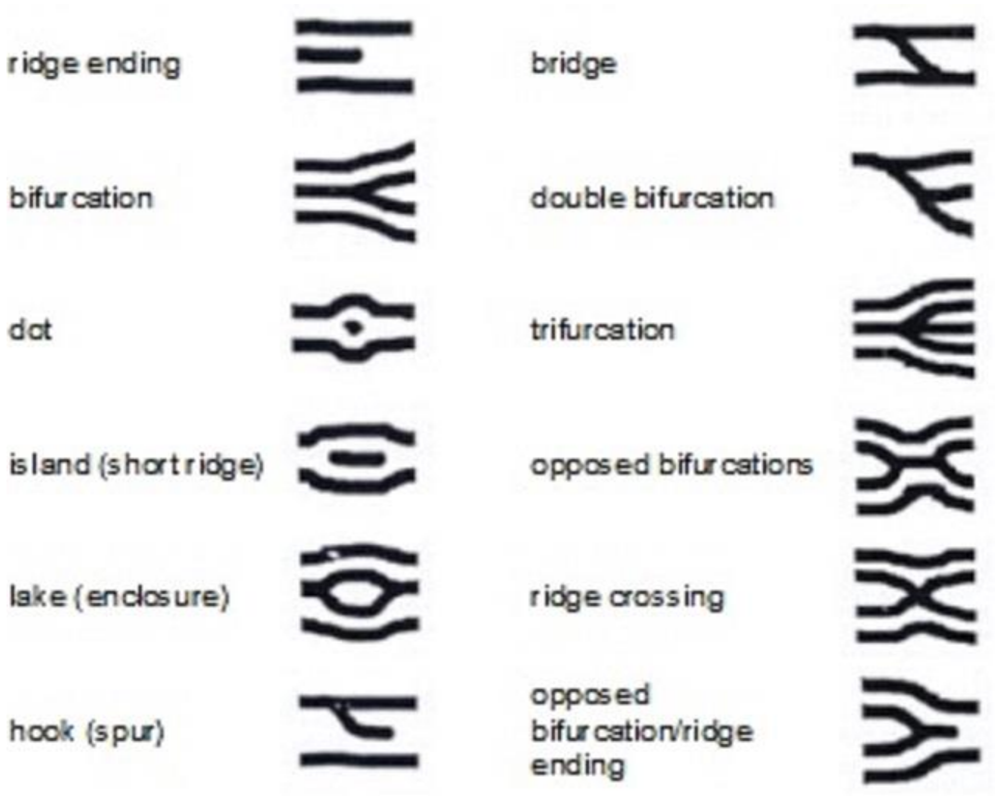

Figure 15. Level 2 detail of fingerprints.

Level 3 detail relates to the shapes of the ridges and pores and the relative pores position. These characteristics are thought to be varied significantly among individuals.[35] These features can be useful in fingerprint comparison when the quality of the print is sufficient and they are reproduced in the latent mark and the reference/exemplar prints. However, due to the flexibility of the skin and the three-dimensional nature of friction ridge skin, the shapes of the pores and ridges can appear differently. Level 3 detail is also vulnerable to distortion due to the pressure and movement of the skin.[36] Moreover, fingerprint experts often have different opinions on how they describe, classify, and determine the value of level 3 detail.[37] Generally, level 3 detail is only present in 5%–10% of latent fingerprints.[38]

3.0 FABRICS

Fabrics are made out of yarns, which are constructed by twisting or spinning textile fibres. There are two main classes of textile fibre material: natural and man-made (Figure 4). Natural fibres refer to fibres derived from vegetable and animal material, and inorganic minerals. Man-made fibres are artificially made by using raw material of various type. One of the subclasses of man-made fibres is synthetic fibres, which are synthesised using chemicals.

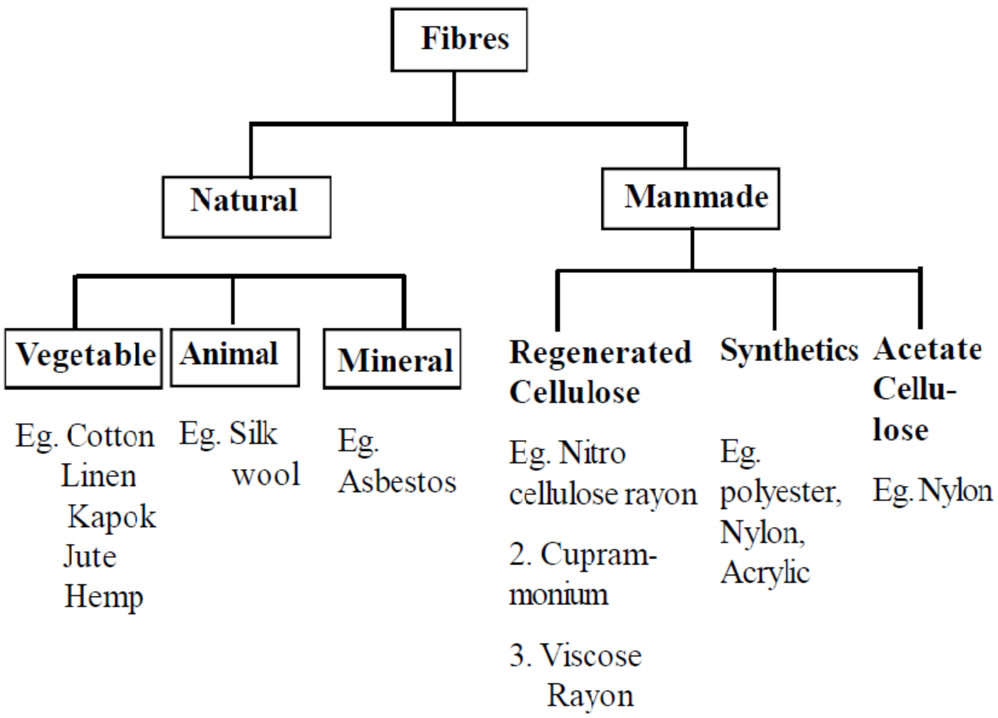

Figure 16. Classification of textile fibres.[39]

Based on the structure, fabrics made from yarns can be categorized into woven, knitted, stitched knit, knotted, and braided fabrics. Woven fabrics are formed by the interlacement of warp and weft. These two sets of threads are interloped with one another according to the type of weave or fabric pattern. Warps are the threads that run longitudinally along the length of the fabric. Wefts are crosswise threads of the fabric.[40]

3.1 Fabric Properties that Affect Absorption

Porous substrates such as fabrics are considered difficult surfaces for fingerprint recovery. Substrates with higher degree of porosity have greater adhesion forces; thus, the migration of fingerprint residues into the substrate will be faster and greater.[41, 42] Porous surfaces can be defined as any surface that have gaps or pores that allow a quick absorption of external matter such as water, air, and particles.

In general, the absorption of a water soluble deposit (WSD) into the porous substrate starts immediately after the deposition of a fingerprint. During this process, water quickly evaporates, leaving amino acids, urea, and sodium chloride behind. Over time, urea and sodium chloride migrate gradually into the substrate, while amino acids will remain relatively stable on the surface of the substrate. As a result, fingerprint enhancement methods that utilise urea and sodium chloride to initiate the reaction are unlikely to work effectively on porous substrates, especially if the fingerprints are old. Relative humidity (RH) of the environment and the porosity of the substrate determine the absorption rate and the depth of the penetration of the fingerprint deposition. Higher RH (>80%) and a substrate with higher porosity result in faster migration of fingerprint deposition into the substrate.[1] The absorption of non-water soluble deposits (NWSD) such as fats, waxes, and long-chain hydrocarbons occurs at a slower rate compared to the absorption of WSD. The mobility of NWSD relies primarily on the environmental temperature. Temperature above 35^{o}C significantly increases the absorption of NWSD into the substrate.

Absorption of liquid in fabrics requires processes called wetting and wicking. Wetting is the ability of a liquid substance in maintaining contact with a solid substrate. Wicking is the movement of liquid into the voids between the fibres, which is driven by capillary forces. Since the capillary forces are created by wetting, wicking cannot take place without wetting.[43] In woven fabrics, the liquid is stored in the intersections of warps and wefts, the capillary spaces between the fibres, and the capillary spaces in the fibres.[44]

Fibre type is one of the most important factors that affect water absorption. Generally, natural fibres have higher water absorbency than man-made fibres.[45] One of the most absorbent fibre types is cotton. The hydrophilic nature of cotton is due to the high presence of hydroxy (OH^-) groups on its surface. On the other hand, many man-made fibres are purposely made hydrophobic by having less hydrophilic functional groups on their surfaces. Another factor that can affect the absorbency of fabrics is TPI (twist per inch) of the yarns.[46] Textile fibres are twisted to make stronger yarns. Yarns with higher TPI tend to pack closely to each other; thus, capillaries in the void space in fibres are reduced. As a result, their wicking properties are also lowered. Additionally, the size, the construction, and the shape of individual yarn can influence the absorption capabilities of the fabrics. [45]

Chemical pre-treatment of fabrics can also affect the absorbency of fabrics. Bleaching and mercerization can increase the wetting property of fabrics.[47] Crease resistant, flame retardant, and scouring finishes can increase the wettability of the fabrics.[44] Wettability is the potential of a surface to interact with liquids with specified characteristics.[48] Wettability can be reduced if the yarns of the fabric are treated with colouring dyes.[49] Fabric softeners tend to make the fabrics slightly hydrophobic.[50]

3.2 Fabric Properties that Affect the Surface Area

The thread count of a woven fabric may influence the amount of fingerprint residue that is deposited on the fabric. Thread count is the sum of horizontal and vertical threads per square inch.[51] Fabrics with higher thread counts indicate that the threads that are used to make these fabrics are finer, and sometimes resulting in softer, smoother, more expensive, and more luxurious fabrics.[52] Moreover, fabrics with higher thread counts will have fewer gaps, and this will affect the quality of the fingerprint.[6] Fabrics with fewer gaps have a larger surface area and will allow more deposition of fingerprint residues. As a result, when these fingerprints are enhanced, the continuous ridges of the fingerprint are more likely to be observed. The U.K manual of fingerprint suggests that recovery of fingerprint is possible in fabrics with thread count no less than three threads per millimetre.[53] It is not clear whether fingerprint recovery is possible on fabrics with thread count less than three threads per millimetre.

Similarly, the weave pattern of woven fabric may affect the amount of fingerprint residue deposited on the fabric surface. There are various weave patterns such as plain weave, satin weave, and twill weave. Some of these patterns can be further classified into sub-classes based on the number of weft floats (a weft residing on the top of a warp) and warp floats (a warp residing on the top of a weft), for example, twill weaves have 2-1 and 3-1 variation, in which two weft floats are followed by one warp float and three weft floats are followed by one warp float, respectively. The firmness of any woven fabric depends on the number of intersections between the warp and the weft.[7] Higher number of intersections will result in higher compactness of the fabric. Figure 5 illustrates the four patterns of woven fabric. Since the frequency of intersections between the warp and the weft is higher in plain weave compared to the other three weave patterns, the plain weave will be firmer and have stronger texture than the others.

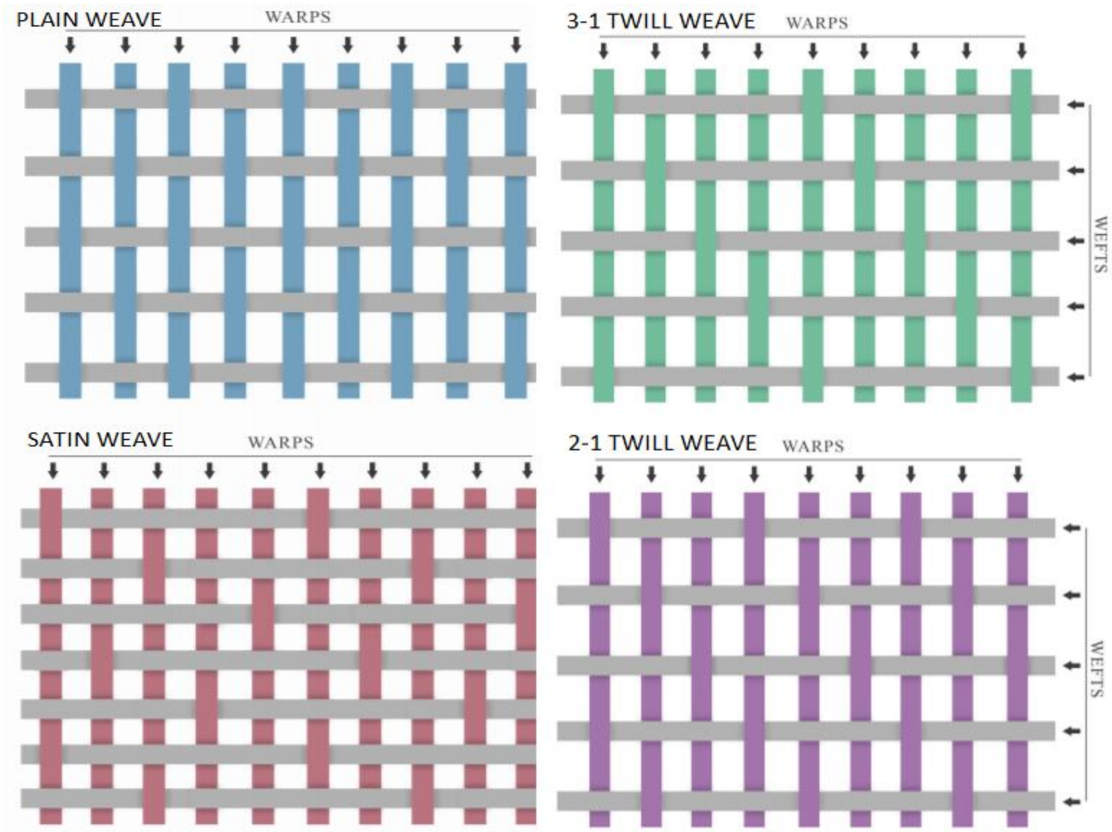

Figure 17. Illustration of four weave patterns of woven fabric.[54]

4.0 CYANOACRYLATE FUMING

Cyanoacrylate (CA) fuming, often referred to as superglue, utilises adhesives containing alkyl 2-cyanoacrylates. Most of these adhesives are based on methyl-2-cyanoacrylate, ethyl-2-cyanoacrylate, or a combination of the two.[55] CA fuming has been utilised as an effective means of enhancing latent fingerprints on non-porous surfaces since the 1970s in Japan and North America.[56] Initially, CA fuming was carried out in a relatively uncontrolled manner by treating the exhibits inside containers, such as fish tanks, with various amount of superglue being used. The CA fuming process can be accelerated by heating the superglue or by adding accelerating agents such as sodium hydroxide.[57]

In 1986, the commercial 'Sandridge' fuming chamber was developed in order to increase the efficacy of CA fuming. This chamber was designed to perform fingerprint enhancement under optimum humidity, temperature, and CA vapour circulation in order to achieve better results.[58] However, non-commercial chambers are still used by various police forces around the world. Figure 6 shows a typical instrumentation of CA fuming method in a non-commercial chamber. The superglue is heated to a certain temperature by utilising a hot plate as the heat source. Additionally, a small beaker of water is heated up in order to increase the humidity of the environment inside the fuming chamber. The container has to be tightly sealed to prevent the escape of the CA vapour, and also in order to maintain the temperature and humidity to a constant range. However, most non-commercial chambers are not equipped with air ventilation/circulation system. The main advantage of having a circulation system is that the CA vapour is more likely to be distributed evenly on the exhibits; therefore, the developed prints are likely to be better, especially if more than one exhibit is processed at the same time. In addition, the air ventilation system can remove CA vapour automatically when the CA fuming process is completed, which is important from a health and safety perspective.

The superglue-developed fingerprints appear as a white deposit; therefore, it is difficult to examine and photograph, especially on light-coloured surfaces. In order to improve the contrast, coloured powders or fluorescent dyes are often used as the visualisation method. The most common fluorescence dyes used in conjunction with CA fuming are Rhodamine 6G and Basic Yellow 40.

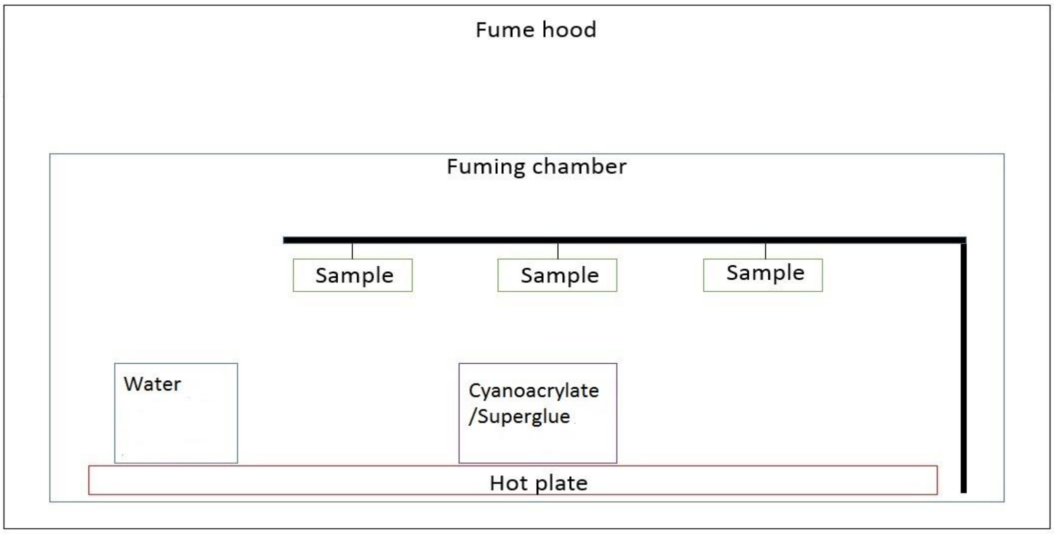

Figure 18. CA fuming equipment schematic in a non-commercial chamber.

4.1 Mechanism of CA Fuming

Cyanoacrylate (CA) is one class of acrylate resin. CA esters such as ethyl ester are colourless monomeric liquids. CA liquid forms a vapour that reacts with certain eccrine sweat components of fingerprint residues. The vapour selectively polymerizes on fingerprint ridges and form white deposits known as polycyanoacrlate.[59] The chemical reaction behind CA polymerization is well understood.[60] The process is an anionic polymerization that is commenced by the interaction between anionic initiator such as OH^- and CA monomer. This process creates active monomer, which can react with subsequent monomers, as illustrated in Figures 7a and 7b. In the case of alkyl cyanoacrylates with two electron withdrawing groups on the same carbon atom, the polymerization reaction is still considered as anionic, but it can be initiated by a water molecule, as shown in Figure 7c.[60] The propagating product is zwitterionic, which possesses both positive and negative charge. This can be followed by the formation of linear and branched oligomers that can lead to more than one anionic reactive site. Therefore, the presence of superglue monomers and water alone is sufficient to initiate polymerization.

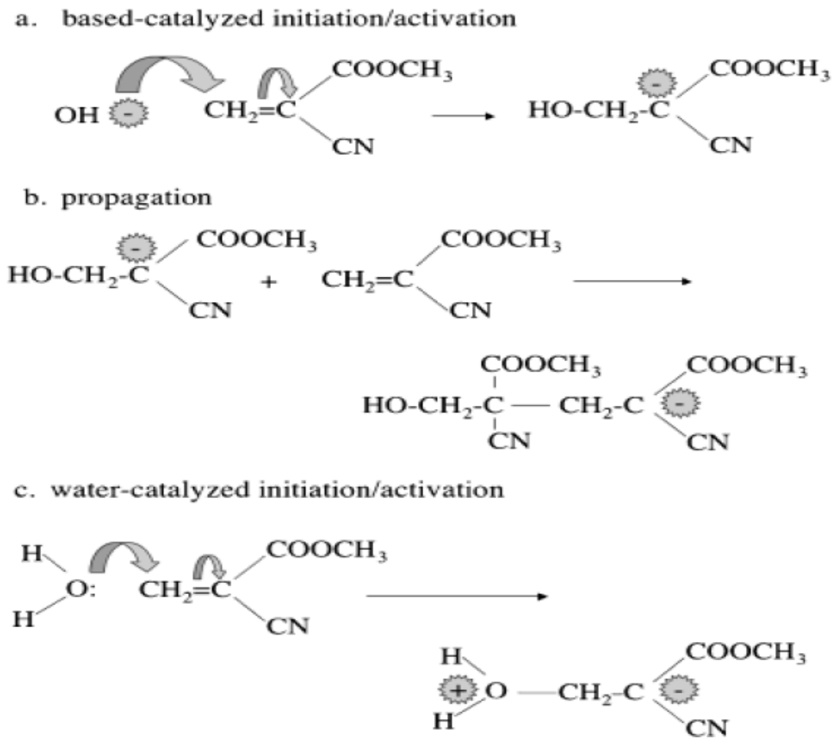

Figure 19. Mechanism of cyanoacrylate polymerization initiated by base (a), followed by chain propagation (b). In the presence of water, the propagation product is zwitterionic molecule (c).[61]

However, the precise mechanism of polymerization nor the reason as to why polymerization only occurs on fingerprint ridges, but not on area between the ridges, is not well understood. Wargacky et al [62] focused exclusively on eccrine fingerprints, reasoning that since sebaceous sweat components are not necessary for the polymerization of CA, the primary initiator of CA polymerization is unlikely to be found in sebaceous fingerprint[2], even though the reason behind it is not clear. Initially, the study considered sodium chloride, lactic acid, and amino acids as the contenders. However, sodium chloride was disregarded as it was thought to not be capable of initiating polymerisation of CA.[63] The study concluded that lactate and alanine were shown to be capable of initiating polymerization of ethyl cyanoacrylate. The similarity in the data supports that both initiators grow the polymer by initiation by the carboxylate functionality. Additionally, the same study postulated that water cannot be the main initiator of CA fuming because the polymer chain that was initiated by pure water was short in size and fragmented. In contrast, the polymer chain morphology of typical latent fingerprint tends to be continuous.

Lewis at al [2] suggested that the initiator of superglue polymerization are water-soluble components, which are less effective when the water is removed. The authors did not propose that the water itself is the main initiator of polymerization. Another study [61] proposed that the polymer growth in CA fuming is not catalysed by any single compound in fingerprint residue, but rather by the accumulation of CA monomers and water molecules within the film of fingerprint. Mankidy et al [64] suggested that different types of anions create different type of polymer morphologies. Very soft anions such as iodide and bromide produced no polymer, intermediate anions (chloride, monophosphate, diphosphate, sulphate) produced noodle-type polymer, and hard anions (acetate, hydroxide, triphosphate, carbonate, and bicarbonate) produced a tortellini-like film of polymer.

4.2 Factors Affecting CA Fuming Result

The amount of water vapour present in air, known as Relative Humidity (RH), is one of the most important factors in the CA fuming method. A study conducted in 1980s concluded that the best developed print by CA fuming was obtained in an environment with 80% RH.[57] More recently, Paine et al [55] examined the effect of RH on the CA developed fingerprints. The quality of developed eccrine prints increased steadily from 55% to 85% RH, and then decreased gradually as the RH reached towards 95%. As shown in Figure 8, the eccrine print developed at 80% RH showed more level 1 detail than prints developed at 60% and 100% RH. According to the authors, this result was expected because inorganic salts in eccrine sweat deposit, such as sodium chloride salt, absorb water in the environment at higher RH.[65] As a result, the build up of water on fingerprint ridges leads to CA polymerization. When too much water is absorbed into the fingerprint, the water beginning to condense on the surface and between the ridges of fingerprint, resulted in over developed print as shown in Figure 8c. However, as mentioned in the previous section, there is no evidence that a certain compound in fingerprint residue is responsible for the initiation of CA polymerization. In contrast, the quality of sebaceous fingerprints was less affected by RH. Figure 9 shows the comparison of sebaceous fingerprint developed at 60%, 80%, and 100% RH. There was a slight increase in quality of sebaceous fingerprints developed at 65% – 85% RH, but the difference was minimal compared to eccrine fingerprints. Mucoproteins in sebum are thought to form a barrier against humidity, thus preventing the absorption of water from the environment.[2] The lack of details observed in developed sebaceous fingerprint is due to the smudging of sebaceous material between the ridges, rather than over development by the CA fuming process. The limitation of this study is that Paine et al [55] only observed week old fingerprints. Moreover, they only utilised one type of substrate, which was smooth black polypropylene sheet.

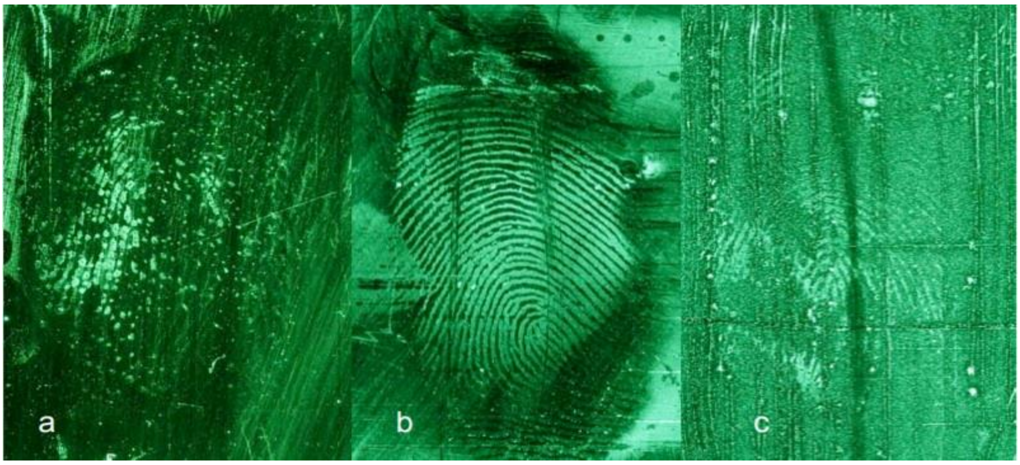

Figure 20. Eccrine fingerprints developed by CA fuming at 60% (a), 80% (b), and 100% RH (c).[55]

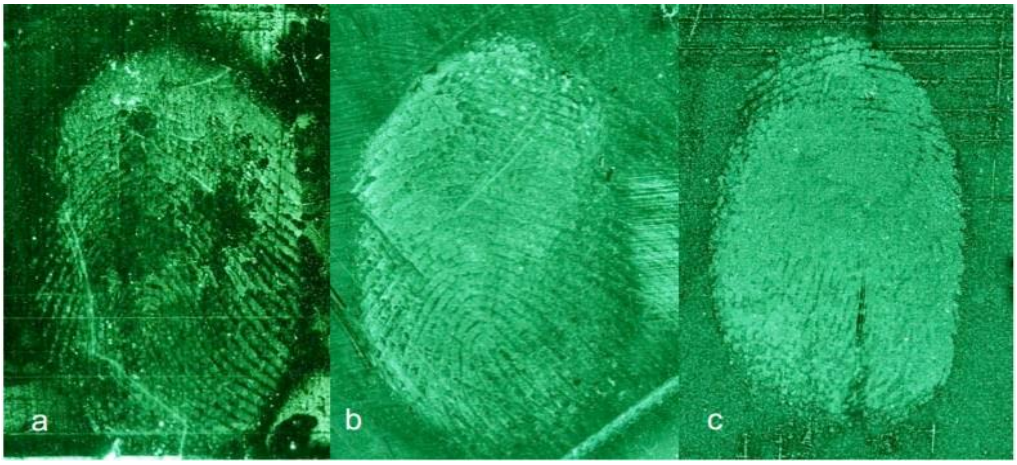

Figure 21. Sebaceous fingerprints developed by CA fuming at 60% (a), 80% (b), and 100% RH (c).[55]

Most published fingerprint guidelines recommend heating CA liquid up to 120 ^{o}C to speed up the CA fuming process.[24] Another processing technique called microburst is recommended by the Federal Bureau of Investigation. This method is performed by heating superglue up to 400 ^{o}C in less than 2 minutes.[66] When CA fuming is carried out in a relatively high temperature, the vaporization of CA liquid occurs within minutes, thus allowing a quick development of the fingerprint exhibit. Reducing the processing time is deemed as necessary in order to reduce the risk of overdeveloping the fingerprint sample. On the contrary, higher quality fingerprint may also be obtained by lowering the temperature of CA fuming. Algaier et al [67] showed that there was gradual increase in the mass of CA polymer developed as the temperature (20 – 80^{o}C) was lowered, indicating that there was an inverse relationship between temperature and the mass of polycyanoacrylate. The authors proposed that this was due to the loosening of the ion pair that initiate polymer chain growth. Lower temperature may create more solvated/less tightly bound ion pairs at the end of the growing polymer chain, which then increase the rate of polymerisation and eventually more polycyanoacrylate is formed. This theory may also be the reason to the effectiveness of precooling treatment of exhibits to 8 – 10 ^{o}C prior to CA fuming.[68, 69] While CA fuming by heating is a popular method, the impact of this process to the fingerprint is not fully understood. Further study is clearly required to examine the relationship between temperature and the quality of CA developed fingerprints.

Regarding the processing time, it is recommended to place a control fingerprint on a glass microscope slide next to the exhibit to be treated.[9] When the control fingerprint sample is sufficiently developed, the exhibit should be removed from the chamber and examined for ridge detail. The CA fuming process can be resumed if insufficient fingerprint development is observed on the exhibit. However, it might be better to deposit the control fingerprint on the same substrate type as the exhibit. Although no study has proved that different type of items would require different processing time, great precaution should be taken when performing CA fuming method since the process is irreversible; once the fingerprint overdeveloped, it cannot be reversed. It is important to note that a difference in optimum processing time between control and exhibit is still expected, even when the control fingerprint is deposited on the same substrate as the exhibit. This is due to the difference between the environmental condition in which control fingerprints and latent fingerprints on the exhibit are deposited or left. A control fingerprint is expected to be deposited in a controlled environment, while the environmental condition in which the latent print was deposited on the exhibit is relatively unknown. If the latent print was exposed to light and air current in the scene, then its development rate would be much lower than the control print.[59] This is due to the fact that ultraviolet light degrades one of the possible primary initiators in fingerprint residue: the lactate ion. Moreover, water evaporation would make the latent fingerprint brittle, which makes it susceptible to erosion by air current. As a result, the amount of fingerprint initiator compounds in fingerprint subjected to such environment would be less. This would indicate that the development rate of these fingerprints would be slower.

5.0 FINGERPRINT ENHANCEMENT METHODS ON FABRICS

Due to the difficult nature of visualising fingerprints on fabric, there have been limited studies and a completely efficient enhancement method is yet to be developed. As a consequence, forensic laboratories rarely attempt to recover fingerprints from fabric.[8] The two common techniques for enhancing latent fingerprint on fabrics are CA fuming and Vacuum Metal Deposition (VMD). Table 3 summarizes the studies exploring a number of fingerprint enhancement methods on fabric. Table 4 shows the Bandey five-point scale system that was used to assess the quality of level 1 detail of the developed prints in these studies.

Table 3. The Summary of Studies on Fingerprint Recovery on Fabric.

Method	Strength	Limitation
CA fuming + Basic Yellow 40 on white fabrics[11]	• -	• Due to background staining caused by BY40 dye, this method was not able to develop any fingerprint on white fabrics (cotton, polyester, and poly cotton blend). • Enhancement on white nylon fabrics only produced "empty marks".

CA fuming + infrared spectral mapping[6]	• The method was able to develop fingerprints with sufficient ridge details for identification (grade 3 or 4) on light coloured fabrics (nylon, acetate, silk).	• The production of a complete fingerprint image took eight hours to complete. • Infrared microscope is an expensive tool. • The method was not tested on cotton and poly cotton blend.
Gold and Zinc VMD on white fabrics[11]	• -	• The method was not able to develop fingerprints on cotton. • Most developed fingerprints on polyester, nylon and poly cotton blend did not have sufficient ridge details for identification (grade 1 or 2).
Silver VMD on dark fabrics[4]	• -	• Almost all the developed fingerprints on polyester, nylon, satin and poly cotton blend did not have sufficient ridge details for identification (grade 0, 1 or 2).

Table 4. The Bandey Five-Point Scale System.

Grade	Description
0	No development – no visible or recognisable marks.
1	"Empty marks" – fingerprint impression can be seen, but without any ridge details.
2	Fair – One-third of continuous ridges/pattern can be seen, but not enough detail for identification.
3	Good – Two-thirds continuous ridges/pattern can be seen.
4	Full development – whole continuous ridges/pattern can be seen.

An enhancement method using CA fuming/Basic Yellow 40 to recover latent fingerprint on white cotton, white nylon, white polyester, and white poly cotton (60% cotton and 40% polyester) was tested by Fraser et al. [11] The age of latent prints that were tested ranged from 1–7 days, 14, 21, and 28 days. The study showed that this method failed to develop any fingerprint (all developed prints were graded 0) on white cotton, white polyester, and white poly cotton. The results for white nylon were slightly better as approximately 50% of the developed prints were graded 1 and around 10% of the developed prints were graded 2. The results showed that Basic Yellow 40 caused excessive background staining as the dye soaked into the entire fabric surface. As a result, the desired contrast between the fingerprint ridges and the fabric were notachieved. The results for white nylon were slightly better because nylon is less absorbent than the other fabric materials that were tested. In conclusion, CA fuming coupled with dye staining is not a feasible method to recover fingerprint on fabrics mainly because the absorption of the fluorescence dyes onto the entire surface of the fabrics.

In order to test the ability of CA polymer to selectively adhere onto the fingerprint ridges on fabrics, Sonnex et al [6] performed CA fuming method on latent fingerprints on various dark coloured fabrics (polyester, nylon, acetate, silk, cotton, and poly cotton). Figure 10 shows the developed fingerprint on dark acetate fabric. The result showed that CA polymer was able to selectively adhere onto the fingerprint ridges. As a result, a good quality fingerprint with ridge details was obtained. Similar results were obtained on dark polyester, dark nylon, dark acetate, and dark silk. However, CA fuming was not able to develop a good quality fingerprint on dark cotton and dark poly cotton. The authors suggested that this was due to the absorbency of cotton and poly cotton materials. As previously mentioned in Chapter 3, the abundance of hydroxy (OH^-) groups in cotton materials resulted in fabrics with high absorbency.

Figure 22. A latent fingerprint developed using CA fuming on dark acetate.[6]

Sonnex et al [6] went further by developing an enhancement method that can recover latent fingerprint on light coloured fabrics. The method is referred to as CA fuming and Fourier Transform Infrared Spectroscopy (CAF & FTIR). Firstly, a spectral map of a CA fuming developed fingerprint on a brass substrate was performed in order to determine the optimum spectroscopic feature to map and produce a good image of the fingerprint. It was determined that the peak carbonyl peak was at 1700 cm^{-1}. Principal component analysis was also performed to identify different substances within the spectra that were not visible to the naked eye. CAF & FTIR was then tested on CA developed prints on light polyester, light nylon, light acetate, and light silk. The authors decided to exclude light cotton and poly cotton fabrics because their previous experiment showed that CA fuming was proven to be insufficient in developing latent fingerprints on dark cotton and poly cotton. The results of fingerprint development using CAF & FTIR on light polyester, light nylon, light acetate, and light silk showed that this method was able to develop fingerprints with high quality details. Figure 11 shows the developed print on light coloured acetate. The results for light polyester, light nylon, and light silk were similar in terms of quality. The image of the developed print showed clear continuous ridges, which make it possible for the fingerprint examiner to determine level 1 detail, which is the fingerprint class/pattern. The last part of the study was the comparison of the quality of developed fingerprint using CAF & FTIR and Gold/Zinc VMD [11], based on the Bandey five-scale scoring system. Even though the comparison showed that CAF & FT-IR method provided better results than Gold/Zinc VMD [11], a conclusion cannot be drawn due to the difference in the number of samples and different donors between the two studies. The disadvantages of CAF & FTIR are the practicality and the cost of the instrument. The production of one fingerprint image took eight hours to complete. Moreover, the cost of infrared spectroscopy may be considered expensive for some forensic agencies.

Figure 23. A latent fingerprint developed using CAF & FT-IR on light coloured acetate fabric.[6]

The efficacy of Gold/Zinc VMD and Silver VMD in enhancing latent fingerprint was tested in two separate studies.[4,11] With the Gold/Zinc VMD, gold is evaporated under vacuum to produce a thin layer of metal on the surface of the fabric. A second layer of zinc is deposited in the same manner. This method produces a negative mark, as the zinc is selectively adhered to the gold layer on the surface but does not penetrate the area where the latent print is deposited. Silver VMD has the same mechanism, except that only one metal (silver) is evaporated during the process. Silver VMD produces fingerprints with better contrast than Gold/Zinc VMD.[4] Studies have shown that VMD could develop fingerprints on paper with some success.[70] However, the majority of latent fingerprints on fabrics that were developed using Gold/Zinc VMD or Silver VMD in these studies did not have sufficient ridge details for identification (Grade 3 or 4). Gold/Zinc VMD developed some fingerprints with good detail on white nylon, white polyester, and white poly cotton. On the other hand, Silver VMD only produced a few good quality prints on dark polyester. Clearly, future studies looking at the efficacy of other fingerprint enhancement methods on fabrics are needed.

6.0 LUMICYANO™

Lumicyano™ is a new fluorescent cyanoacrylate product developed by Crime Scene Technology (CST) in association with the Ecole Normale Supérieure (ENS) de Cachan. Lumicyano™ powder contains a low-molecular weight fluorophore 3-chloro-ethoxy-1,2,4,5-tetrazine ($C_4H_5ClN_4O$) that makes the developed fingerprints fluoresce under UV (315–340nm) or visible intense light radiation (450–550nm).[12] Lumicyano™ solution contains liquid ethyl CA, therefore Lumicyano™ is assumed to work on similar principle as the conventional CA fuming. The Lumicyano™ process requires the combined use of Lumicyano ™ powder and Lumicyano™ solution. Figure 12 shows the fingerprint developed using Lumicyano ™ on a black plastic bag. The quantity of Lumicyano™ powder, Lumicyano™ solution and processing time depend on the capacity of the fuming chamber. However, it is not clear whether different types of substrate would have the same optimum fuming time. A stronger fluorescence can be obtained by increasing the Lumicyano ™ powder concentration to 8%.

Figure 24. The fingerprint developed using Lumicyano ™ on a black plastic bag.[13]

The main advantage of Lumicyano™ compared to other fluorescent cyanoacrylate products is that the Lumicyano™ process has the same optimum humidity level (80% RH) and temperature (120 ^{o}C) as the CA fuming method, therefore Lumicyano™ does not require a modification of CA fuming cabinets. Other fluorescent cyanoacrylate products such as Polycyano UV, CN yellow, and Fuming Orange require higher heating temperature, therefore a modification of the fuming chambers may be required.[13] Lumicyano™, although more expensive when compared to CA fuming followed by dye staining, might be faster and have minimal interference with subsequent DNA analysis.[71] The removal of dye staining procedure also suggests that Lumicyano™ might be used to enhance latent fingerprints on light-coloured fabric. No studies were found in the literature that investigated the efficacy of Lumicyano™ to visualise and recover latent fingerprints present on fabrics.

7.0 EXPERIMENTAL AIMS AND HYPOTHESES

Aims and Objectives

This preliminary study is aimed at examining the efficacy of Lumicyano™ to enhance fresh latent fingerprints on four different black clothing fabrics – nylon, polyester, cotton, and poly-cotton blend. This aim will be achieved by performing the following objectives:

1. Collecting latent fingerprints from 20 fingerprint donors on four different fabric samples. This group will be treated as test samples.
2. Processing the test samples using Lumicyano™.
3. Photographing the developed samples under the green light 530 nm and an orange barrier filter.
4. Performing qualitative assessment of the photos of the developed samples using the Bandey five-point scoring system.
5. Assessing the effectiveness of Lumicyano ™ based on the percentage of developed fingerprints with a grade of 3 and 4.
6. Determining the quality value of each fabric material by multiplying the number of fingerprints and the quality of the fingerprints (grades 0–4).
7. Assessing the effect of fabric material on the quality of developed fingerprints based on the quality value of each fabric material.

Hypotheses to be tested

Hypothesis 1

H_0: Lumicyano™ is not an effective method to develop fresh latent fingerprints on black clothing fabrics.

$H_{1:}$ Lumicyano™ is an effective method to develop fresh latent fingerprints on black clothing fabrics.

Hypothesis 2

H_0: The type of fabric material does not affect Lumicyano's™ sensitivity in enhancing fresh latent fingerprints on black clothing fabrics.

$H_{1:}$ The type of fabric material affects the sensitivity of Lumicyano's™ sensitivity in enhancing fresh latent fingerprints on black clothing fabrics.

8.0 CONCLUSION

In conclusion, due to the nature of porous surfaces such as fabric, the recovery of latent fingerprint on such surfaces can be a difficult and complicated process. Studies have shown that CA fuming was able to initiate polymerization on latent fingerprints on some dark coloured fabric materials. However, CA fuming coupled with dye staining has proven to be ineffective on light coloured fabrics because the whole surface of the fabric would readily absorb the dye, causing excessive background staining. Lumicyano™ is capable of developing fluorescent fingerprint without the need of dye staining, therefore this method can potentially be used to recover latent fingerprint on dark and light coloured fabrics.

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Part Two

Manuscript

RECOVERY OF FRESH LATENT FINGERPRINTS ON BLACK CLOTHING FABRICS USING LUMICYANO™

RECOVERY OF FRESH LATENT FINGERPRINTS ON BLACK CLOTHING FABRICS USING LUMICYANO™

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ABSTRACT

The importance of fingerprint evidence cannot be underestimated as it can provide valuable information pertaining to perpetrator of a crime. However, there is no recognised method for the enhancement of latent fingerprints on clothing fabrics. As a result, forensic laboratories rarely attempt to recover fingerprints from such substrates. Recently, new cyanoacrylate (CA) products such as Lumicyano™ have been developed. This method incorporates a fluorescent staining dye powder 3-chloro-6-ethoxy-1,2,4,5-tetrazine ($C_4H_5ClN_4O$) and liquid ethyl CA into a solution. Therefore, Lumicyano™ can develop fluorescent fingerprints in a one-stage fuming process without the need for an additional visualisation method apart from Forensic Light Source (FLS). The integration of fluorescent dye and CA into a mixture suggests that the fluorescent dye would selectively adhere to the polycyanoacrylate formed on the friction ridges of fingerprints. The readily visible fingerprints and the removal of the post-processing method indicate that Lumicyano™ could potentially be used on fabrics. Thus, this preliminary study aimed at assessing the efficacy of Lumicyano™ on recovering fresh latent fingerprints on dark coloured clothing fabrics. This was achieved by developing fresh latent fingerprints deposited on four different types of dark clothing fabric materials; polyester, cotton, poly cotton, and nylon. The results showed that Lumicyano™ was able to develop fresh latent fingerprints on dark coloured clothing fabrics. Furthermore, an indirect comparison between Lumicyano™ and silver VMD was performed. The results suggest that Lumicyano™ is a better enhancement method to enhance fingerprints on dark polyester and poly cotton fabrics than silver VMD. The thread count, weave pattern of the clothing fabrics, and the fingerprint donor were proven to be significant in determining the quality of the developed prints.

Keywords: Forensic science, Fingerprint evidence, Lumicyano™, Fabric.

INTRODUCTION

Fingerprints are one of the most valuable evidence types often encountered at crime scenes. The permanence (i.e. persistency, durability, reproducibility) and the selectivity of fingerprint ridge skin suggest that fingerprints may be useful throughout three major facets of forensic science, which are to demonstrate whether or not a crime has been committed, to identify the individuals involved and how those individuals are associated with others and with the crime scene, and to reconstruct the sequence of events that occurred.[1, 2]

Currently, there are numerous methods available for the recovery of fingerprints on different surfaces. For example, fingerprints on non-porous items (i.e. glass, plastic, metal, gloss-painted surfaces) can be enhanced using fingerprint powder, cyanoacrylate (CA) fuming, vacuum metal deposition (VMD), or powder suspension,[1, 3] ninhydrin is used for light-coloured paper, and VMD techniques are capable of enhancing prints on metal surfaces.[4, 5] However, there are limited options regarding established enhancement methods for developing fingerprints on fabric. As a result, forensic laboratories rarely attempt to recover latent fingerprints from such substrates.[2] Therefore, it is clear that studies exploring the recovery of fingerprints on fabric are needed.

A porous substrate such as fabric is considered as a difficult surface for fingerprint recovery due to two main reasons. Firstly, porous substrates tend to absorb fingerprint deposits very quickly. Water-soluble deposits from eccrine and apocrine glands are absorbed within seconds, which makes the enhancement method such as CA fuming and silver nitrate more difficult as they utilise water-soluble compounds to initiate the reaction.[1, 6] Substrates with higher degree of porosity have greater adhesion forces; thus, the migration of fingerprint residues into the substrate will be faster and greater.[7, 8] Fabric materials (natural or synthetic) affect the absorption rate of fingerprint compounds, with natural materials such as cotton tending to be more absorbent than synthetics.[9] Secondly, the compactness of fabrics also adds to the challenge. The presence of gaps in fabrics reduces the surface area.[10] Thread count and weave pattern determine the compactness of fabrics, with higher thread counts and tighter weave such as plain weave generally resulting in a larger surface area.[11] Fabrics with fewer gaps have a larger surface area and will allow more deposition of fingerprint residues. As a result, when these fingerprints are enhanced, the continuous ridges of the fingerprint are more likely to be observed. All of these factors have a significant impact on the amount of fingerprint compounds on the surface of fabrics, which affect the likelihood success of fingerprint recovery.

To date, there is no single technique that has proven to be completely successful for developing fingerprints on fabric. The efficacy of Gold/Zinc VMD and Silver VMD for enhancing fingerprints on light-coloured and dark-coloured fabrics respectively has been investigated in two separate studies. Most of the developed fingerprints on light-coloured polyester, nylon and poly cotton blend using Gold/Zinc VMD did not have sufficient ridge details for identification (graded 1 or 2 using the Bandey scoring system).[12] Moreover, this method was not able to develop fingerprints on cotton. The results of fingerprints enhancement using Silver VMD on dark-coloured fabrics were similar, in which the majority all the developed fingerprints on polyester, nylon, satin and poly cotton blend did not have sufficient ridge details for identification (graded 0, 1 or 2 using the Bandey scoring system).[13] Furthermore, VMD is considered as complex and relatively expensive to carry out.[14] It is important to note that this does not necessarily mean that VMD techniques should not be used to recover fingerprints on fabrics at all because most fingerprints developed using this technique have been proven to be capable of producing "empty marks", in which the developed prints contained no friction ridge information, just an impression of a touch or a grab by fingermarks. This information allows further testing in the area of the fabric, such as DNA swabbing.

The most successful work done so far has utilised CA fuming method followed by Fourier transform infrared spectral mapping (CAF & FT-IR), which proved to be successful on smooth and shiny fabrics such as polyester, nylon, and silk.[15] Another advantage is that this technique worked on dark-coloured, light-coloured, and also patterned fabrics (i.e. polyester, nylon, and silk). However, the spectral mapping process took eight hours to complete, which makes this technique less practical. Moreover, the authors suggested that this method would not work on cotton and poly cotton fabrics due to the abundance of carbonyl groups on such materials. This may result in a poor contrast between the fingerprints and the fabric material when visualised using the FT – IR spectrometer. The use of CA fuming in this study implies that CA monomer is able to polymerise onto the friction ridges of the fingerprints on some fabrics but the challenge arises from obtaining the contrast of the developed prints on light-coloured and patterned fabrics.[15]

Recently, one-step CA products such as Lumicyano™ have been developed. This method incorporates a fluorescent staining dye powder 3-chloro-ethoxy-1,2,4,5-tetrazine ($C_4H_5ClN_4O$) and liquid ethyl CA into a solution. Therefore, Lumicyano™ can develop fluorescent fingerprints in a one-stage fuming process without the need for an additional visualisation method apart from utilising an appropriate Forensic Light Source (FLS).[16] The integration of fluorescent dye and CA into a mixture suggests that the fluorescent dye would selectively adhere to the polycyanoacrylate formed on the friction ridges of fingerprints. The readily visible fingerprints and the removal of the post-processing method indicate that Lumicyano™ could potentially be used on both dark-coloured and light-coloured fabrics. A recent study demonstrated that Lumicyano™ offers a better or equal sensitivity for the enhancement of fingerprints on various non-porous and semi-porous substrates when compared to traditional CA fuming.[17] Moreover, this new method does not interfere with subsequent DNA analysis as it does not require a dye staining procedure.[18] To date, no study has utilised Lumicyano™ to recover latent fingerprints on fabrics.

Thus, this study aimed at examining the efficacy of Lumicyano™ to enhance latent fingerprints on four different clothing fabric materials — polyester, cotton, poly-cotton blend, and nylon. As this is a preliminary study, it was decided that this study would be limited to examine the efficacy of Lumicyano™ to recover fresh latent fingerprints on black clothing fabrics. The secondary aim was to determine whether the type of clothing fabric material would affect Lumicyano's™ sensitivity in enhancing fresh latent fingerprints on black clothing fabrics.

MATERIALS AND METHODS

Fabric Specimens and Fingerprint Deposition Method

Four different black clothing fabric materials were used in the study; polyester, cotton, poly-cotton blend, and nylon (Lincraft Australia). All fabrics were washed three times with a liquid detergent (Biozet Attack) and were cut into swatches (8 cm × 10 cm) before use. The fabric swatches were examined using a magnifier loop to determine their properties. Table 1 shows the thread count and weave pattern of the fabrics.

Table 1. The Properties of the Fabrics.

Fabric Material	Thread Count (per square inch)	Weave Pattern
Polyester	168	Warp rib regular
Cotton	118	Warp rib regular
Poly cotton	117	Honey comb
Nylon	136	Satin regular

The experiment was carried out with a total of 20 donors (10 male and 10 female, aged 20–36). Prior to fingerprint deposition on each of the fabrics, the donors were asked to rub their right or left thumbs against the forehead and nose area. The fabrics swatches were laid on the clean table and the donors placed their selected thumbs with a moderate pressure for approximately two seconds on the middle of the fabric swatches. The samples were processed within one hour after the fingerprint deposition.

Lumicyano™ Fuming

As recommended by the manufacturer (Crime Scene Technology) [16], 13 drops of Lumicyano™ solution and half a scoop (approximately 0.4 g) of Lumicyano™ powder were mixed in an aluminium foil dish. Once the Lumicyano™ powder was dissolved into the Lumicyano™ solution, the aluminium foil dish was placed on the cooking double hot plate (Kmart Australia), which was used as the heat source inside the non-commercial plastic fuming chamber (85 L). Each set of samples (four fabric materials from each donor) was processed in one fuming cycle. The fabric swatches were clipped on a metal rack, fingerprint side down. The distance between the samples on the rack and the aluminium foil dish was set up to be approximately 16 cm to maximise the adherence of the Lumicyano™ fumes onto the fingerprints. One litre of 3 M potassium chloride (KCl) solution was added into a 2 L rectangle plastic container, which was then placed inside the fuming chamber, next to the hot plate. Finally, the fuming chamber was covered with a glass lid. The apparatus, shown in Figure 1, was designed to follow the operation of a commercially available fuming chamber as a model.

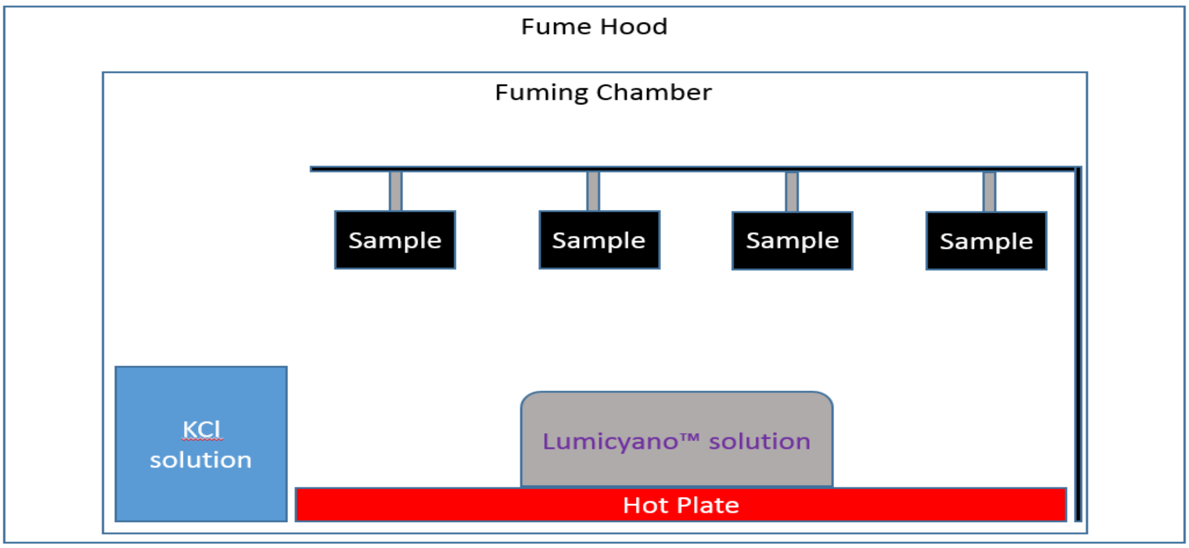

Figure 25. Lumicyano™ fuming equipment schematic.

The humidity of the chamber was monitored using a remote relative humidity monitor (IC800027, Instrument Choice Australia). Once the relative humidity reached 80%, the hot plate was turned on for 2.5 minutes, and then the fuming process was allowed to continue for a further 5 minutes. The fuming process was stopped by opening the fuming chamber lid and taking the samples out of the chamber. During the fuming process, the hot plate produced a temperature range of 72 – 155 ^{o}C, while the Relative Humidity (RH) of the fuming chamber was maintained at a level of 62 – 82% . Figure 2 shows the temperature of the hot plate and the humidity level of the fuming chamber throughout the Lumicyano™ fuming process.

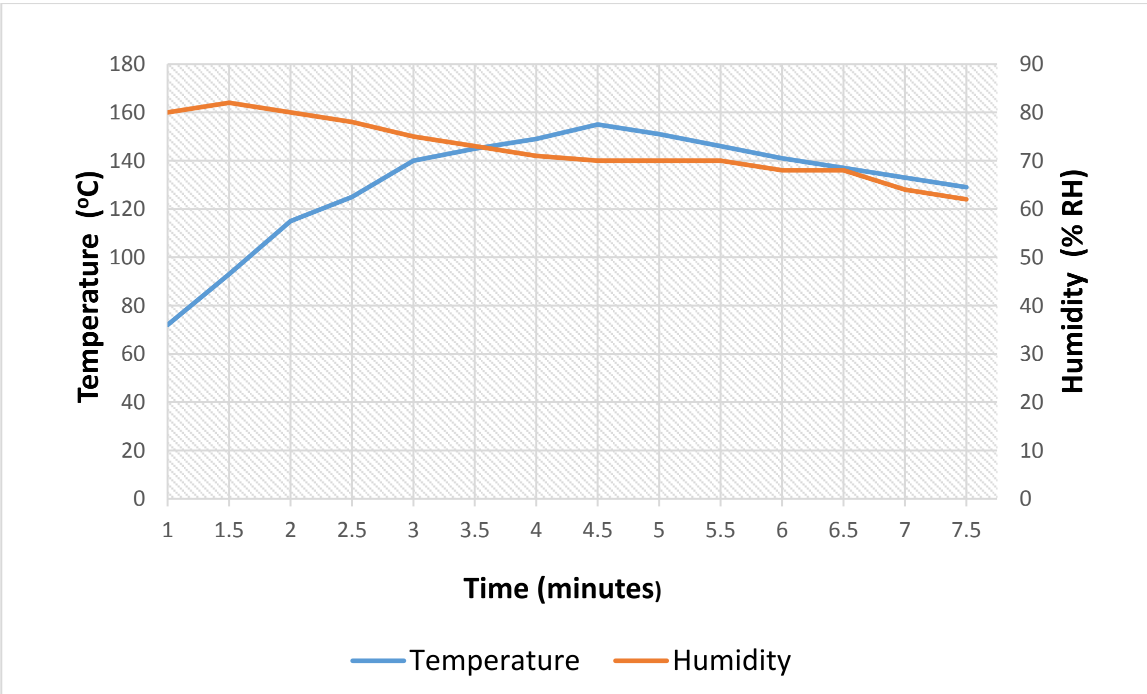

Figure 26. The temperature of the hot plate and the humidity level of the fuming chamber throughout the Lumicyano™ fuming process.

Examination and Photographic Recording of the Developed Samples

Each of the fabric samples was taped on a black rectangular plastic (12 cm X 12 cm), fingerprint side up, to ensure that the fabric was flat. The developed samples were examined under green Polilight-Flare Plus2 530 nm and orange filter goggles in a dark room. The angle and the distance of the light source were changed a number of times in order to examine the difference on the visualisation of the prints. A number of photographs were taken using a Nikon D5500 camera and 60 mm lens under green Polilight-Flare Plus2 530 nm. The orange filter goggle was attached to the camera and was used as the barrier filter. The angle and the distance of the light source and the camera settings were changed accordingly in order to obtain the best contrast between the developed prints and the fabrics.

Grading of the Developed Fingerprints

Based on the unedited photographs (see Appendix), the developed prints were graded using the Bandey five-point scoring system.[19] The grading was performed by the author of the study, who is not a fingerprint expert. Table 2 describes the Bandey five-point scoring system.

Table 2. Bandey Five-Point Scoring System.[19]

Grade	Description
0	No development – no visible or recognisable marks.
1	"Empty marks" – fingerprint impression can be seen, but without any ridge details.
2	Fair – One-third of continuous ridges/pattern can be seen, but not enough detail for identification.

3	Good – Two-thirds continuous ridges/pattern can be seen; identifiable fingermark.
4	Full development – whole continuous ridges/pattern can be seen; identifiable fingermark.

RESULTS AND DISCUSSION

Fabrics

Figure 3 shows the overall fingerprint grading on all fabrics. In order to determine the "quality value" of each fabric material, a simple numerical calculation was performed by multiplying the number of fingerprints and the quality of the fingerprints (grades 0–4). The results showed that polyester (quality values of 44) was the best fabric material that allows Lumicyano™ development. Nylon was the second best (34), followed by cotton (26), and poly cotton (21). The fact that both synthetic fabrics (polyester and nylon) scored higher than natural fabric (cotton) and mixed fabric (poly cotton) proved that fabric type is one of the important factors that determine the quality of developed fingerprints on fabric. Most synthetic fabrics tend to be less absorbent (i.e. more hydrophilic) than natural fabrics, thus the fingerprint residues would remain on the synthetic fabrics surface for a longer period.[9] The higher amount of fingerprint residues on the surface of the substrate would allow better development of the fingerprint. The differences in absorption rate between each fabric type would likely to be more obvious in aging fingerprints, especially if the fingerprints are subjected to environmental factors such as sunlight and air current.[20]

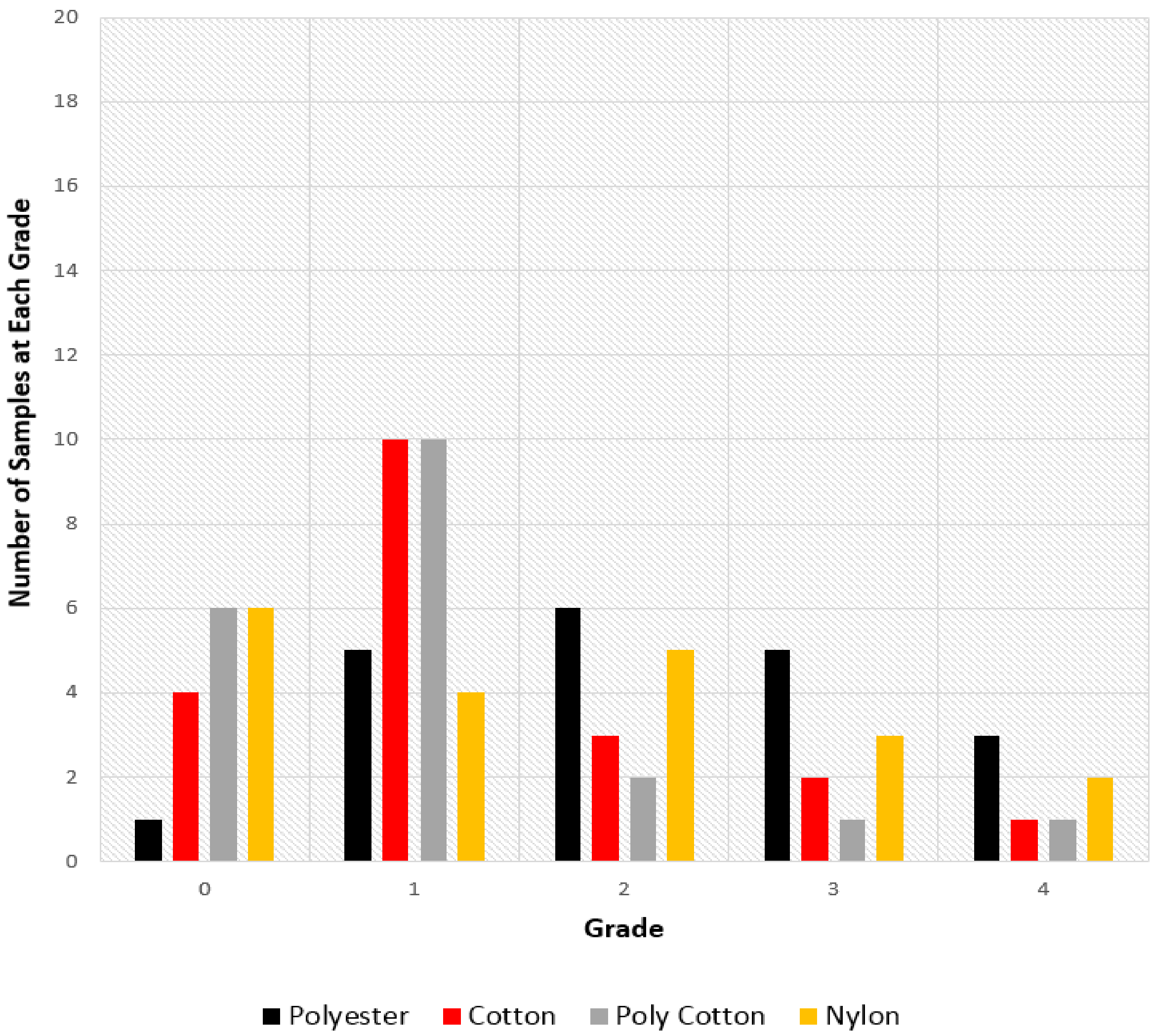

Figure 27. Overall fingerprint grading on all fabrics.

Since this study aimed at investigating the recovery of fingerprints on clothing fabrics, it did not follow the recommendation of the U.K manual of fingerprint guideline, which states that the fabric must have at least 3 threads per square millimetre or roughly equal to 2000 threads per square inch to attempt CA fuming.[21] On average, high quality clothing fabrics would only have around 120–150 thread count per square inch.[22,23] The fabrics that were used in this study originated from large fabric sheets commonly used to make different type of clothing. Thread count of a woven fabric is thought to be one of the main factors that influence the quality of the developed prints because it is one of the fabric properties that determines the compactness of the fabric.[10, 12, 15] Fabrics with higher thread count would have a larger surface area, which maximises the adherence of the fingerprint residues. As a result, when these fingerprints are enhanced, the continuous ridges of the fingerprint are more likely to be observed. This is likely to be one of the main reasons that developed fingerprints on polyester (thread count of 168) scored higher than nylon (136), cotton (118), and poly cotton (117) in this study.

The quality of the developed fingerprints on poly cotton seemed to be affected by its weave pattern, which was a honey comb pattern. This particular weave pattern is characterised by the cell like appearances with ridges and hollows. Due to the presence of warp and weft floats, honey comb pattern is often seen on fabrics designed to absorb moisture rapidly, such as towels and active wear clothing.[11] However, as shown in Figure 4, it was the presence of gaps on the fabrics that influenced the clarity of the developed prints. Even though it is still possible to classify the developed print on Figure 4 into a specific fingerprint class (a right slant loop), it was difficult to observe the fingerprint ridge details on some of the developed prints that scored less than 4 (see Appendix). On the other hand, the satin regular weave pattern of the nylon resulted in a smooth and shiny appearance of the fabric, which might help retain the fingerprint deposits on the surface of the fabrics.[24] It was not clear whether the warp rib regular patterns of the polyester and cotton fabrics in this study had any effect on the developed prints. It is possible that the weave pattern of the fabrics may influence the quality of the developed fingerprints, therefore further research is required to determine the effect of different weave patterns on the latent fingerprints.

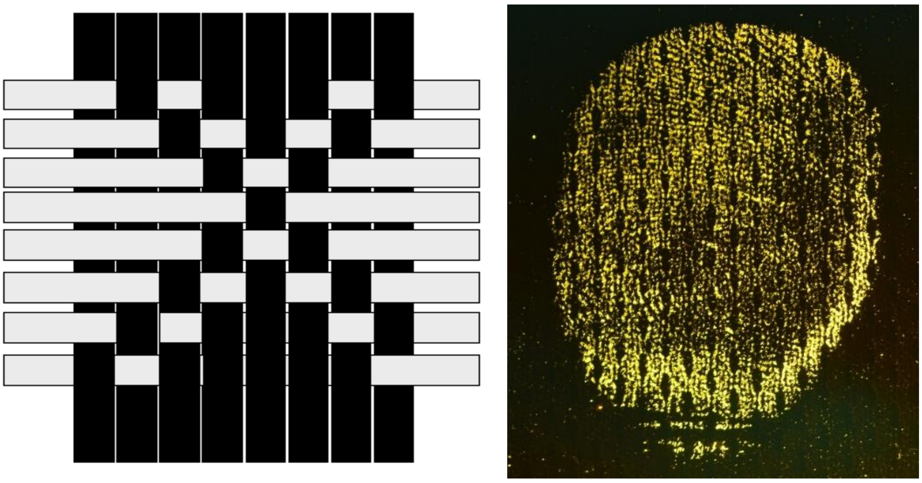

Figure 28. The honey comb pattern (left) and the developed print on poly cotton (right).

A background staining was observed in 30% of nylon samples (see Appendix), which might be due to a number of possible reasons. Firstly, a constant temperature of 120 ^oC was not maintained during the fuming cycle as the hot plate could not be set up to maintain a constant temperature (Figure 2). More importantly, the temperature of 120 ^oC was reached in 2.5 minutes, which is much quicker than the 15 minutes recommended by the manufacturer.[16] Moreover, the fuming chamber used in this study was not equipped with an air circulation fan. It is possible that the quick vaporization of Lumicyano™ and uneven distribution of Lumicyano™ fumes lead to the background staining observed in some of the nylon fabrics. Secondly, even though all the fabrics had been washed three times prior to use, a contamination of the fabrics might have still occurred. Fabrics contaminated with oily substances containing lactic acid and amino acid might lead to the polymerization of CA esters.[25] In a real case scenario, this could be the main limitation of Lumicyano™ to enhance fingerprints on fabrics because the clothing worn by the person involved in a criminal act is likely to be contaminated by sweat or other substances. Further research is required to examine the efficacy of Lumicyano™ to recover fingerprints on contaminated fabrics.

Donor

Total grading for each donor is shown on Figure 5, which was the sum of the fingerprint score (grades 0–4) on all fabric materials. The variation in the total score between donors could be explained by a number of reasons. The activity of the donor prior to the fingerprint collection and the natural secretion produced by each donor would have an effect on the amount of fingerprint residues. The temperature of the environment during the fingerprint collection may also play a role on the amount of the sweat produced by the donor. Moreover, donor characteristics such as age, gender, ethnic origin, diet, and medication can also influence the chemical composition of a fingerprint.[1] However, based on the average score, the difference between male (average total grade of 6.5) and female (5.7) donor in this study was not significant. Similar to other previous studies, variations may also have resulted from different contact pressure and duration between donors when depositing fingerprints.[13, 26] The difference between donors and their fingerprint quality on fabric is an area that requires further study.

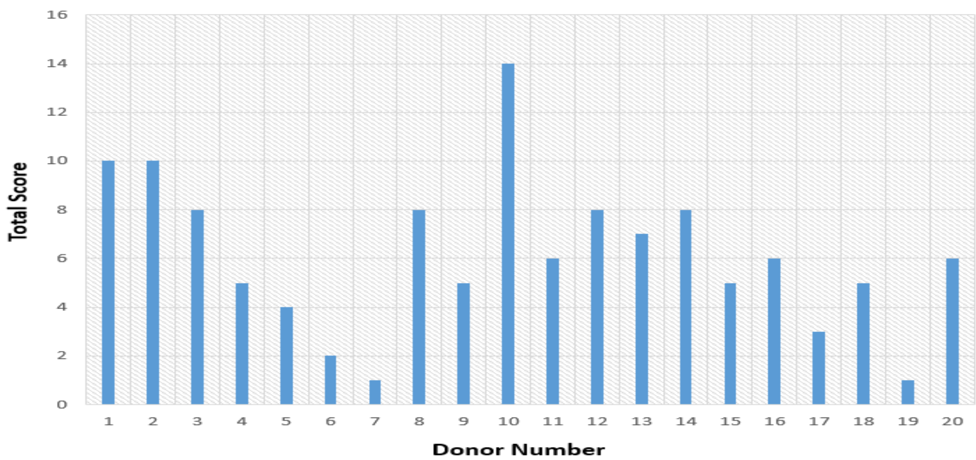

Figure 29. Donor grading on all fabrics.

The effectiveness of Lumicyano™

According to the study conducted by Sears et al [19], the effectiveness of a fingerprint enhancement method can be measured by the total number of developed fingerprints with a grade of 3 and 4. Fingerprints with a grade of 3 or 4 are thought to contain a sufficient area in which minutiae such as bifurcations and ridge endings can be observed. The fingerprint identification process relies on the number of matched minutiae between the reference/known print and the sample.[1] Occasionally, fingerprints of grade 2 can be classified as "identifiable" if the developed area of ridge detail contains sufficient number of minutiae.[19] Table 3 shows the distribution and the total number of marks and percentages of each fingerprint grade. It can be seen that 22.5 % of the overall fingerprint samples developed using Lumicyano™ were likely contain enough ridge details and minutiae to be classified as "identifiable" fingerprint. This figure can be slightly higher as a few of the developed prints with a grade of 2 might also contain sufficient number of minutiae. An attempt was made to observe the minutiae of the developed prints using the PiAnoS 4 software, however it could not be performed due to the time limitation of the study.

Table 3. The distribution of fingerprint grades of the developed samples.

FABRIC	GRADES				
	0	**1**	**2**	**3**	**4**
Polyester	1	5	6	5	3
Cotton	4	10	3	2	1
Poly cotton	6	10	2	1	1
Nylon	6	4	5	3	2
% of Total sample	21.25	36.25	20	13.75	8.75

Comparison between the efficacy of Lumicyano™ and silver VMD

In order to examine the efficacy of Lumicyano™ in recovering latent prints on dark fabrics further, a comparison between Lumicyano™ and silver VMD [13] results obtained from another study was performed. Figures 6 and 7 show the distribution of fingerprint scores between the two methods on polyester and poly cotton respectively.

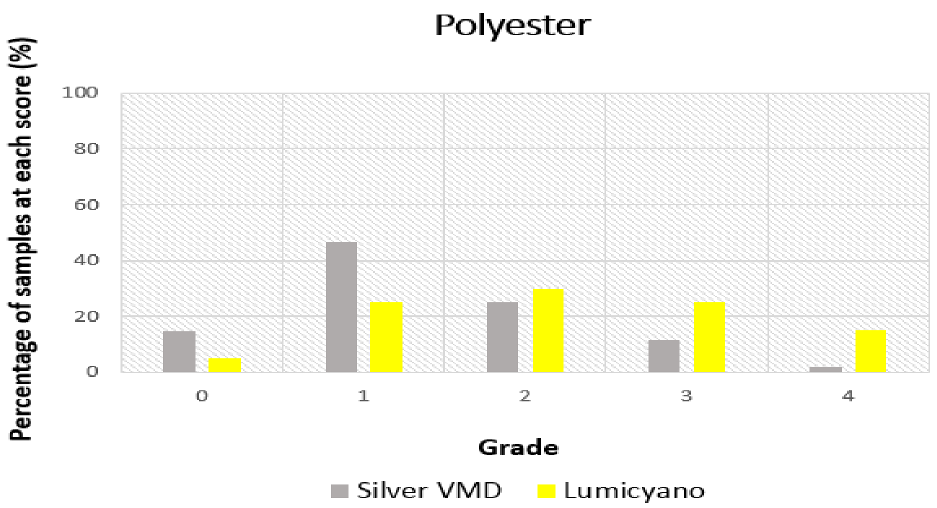

Figure 6. Comparison of the percentages of each score between Lumicyano and silver VMD [13] on polyester fabric.

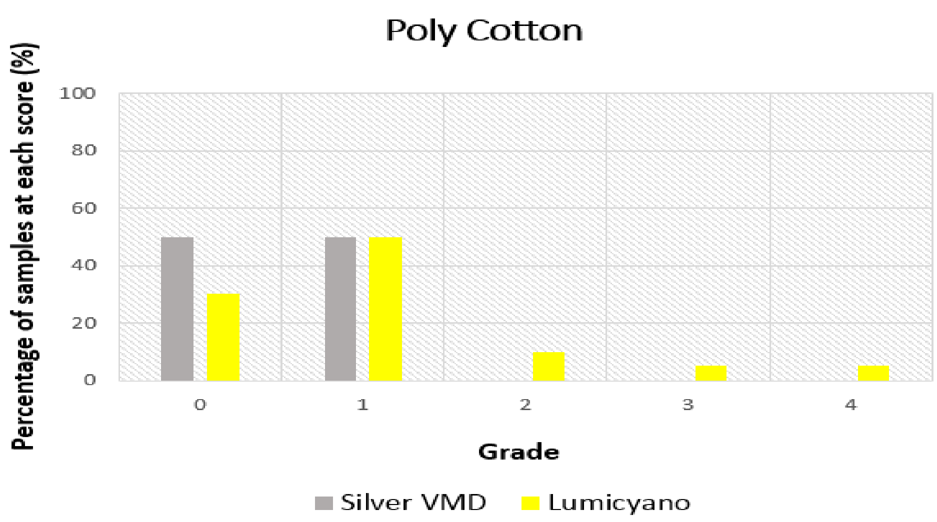

Figure 7. Comparison of the percentages of each score between Lumicyano and silver VMD [13] on poly cotton fabric.

The comparison on cotton fabric could not be performed as the study by Knighting et al [13] utilised a cotton fabric with a dark blue colour. Similarly, the comparison on nylon fabric could not be done as they did not test silver VMD on nylon fabric. Whilst this is an indirect comparison, it suggests that Lumicyano™ produces better fingerprints than silver VMD on both polyester and poly cotton fabrics. The percentage of the low scored (0 and 1) fingerprints developed using silver VMD (61.4 %) on polyester fabric was notably higher than the fingerprints developed using Lumicyano™ (30 %) on the same fabric material. The percentage of “identifiable” prints (Grade 3 and 4) was also higher for Lumicyano™ (40 %) compared to silver VMD (13.3 %). Similarly, Lumicyano™ provided better results than silver VMD in recovering latent prints on poly cotton fabric. Half of the prints developed using silver VMD had a score of 1, while the other half failed to develop at all. In contrast, 20 % of the fingerprints developed using Lumicyano™ scored higher than 1 and only 30 % of the prints failed to develop. Interestingly, half of the fingerprint samples developed using Lumicyano™ also had a score of 1. To sum up, Lumicyano™ appears to work better than silver VMD in enhancing latent fingerprints on dark coloured polyester and poly cotton fabrics. However, further work is required to verify this observation.

Furthermore, the comparison of results between the two methods should be taken with caution as the two studies differ in the materials and method. Different donors and sample sizes were used in the two studies. The study by Knighting et al[13] also included aging fingerprints in their samples, even though they suggested that the differences between the fresh and aged fingerprints was minimal due to the controlled storage of the specimens. Moreover, the polyester and the poly cotton fabrics that were used in the two studies might have different properties (i.e. thread count and weave pattern), which would make a difference in the quality of the developed prints. In order to examine the difference between the efficacy of Lumicyano™ and silver VMD in recovering fingerprints on dark fabrics, a further research which utilises the same donors and fabrics is required.

Scoring system

The Bandey scoring system was used to have some means of converting the visual appearance of the developed fingerprints to a numerical value, which enabled comparisons of fabrics, donors, and techniques (Lumicyano™ and silver VMD) to be carried out. Since most of those conducting research into fingerprint development may not be fingerprint experts, the Bandey scoring system was designed to rely on the ability to identify the fingerprint ridges rather than minutiae, which would require less skill and experience.[19] However, the person who conducted the fingerprint scoring assessment is still required to keep a consistent approach towards all of the samples. Despite the fact that such measures were being taken to keep the assessment process consistent, inaccuracies and errors might still occurr. As a result, the assessment of the developed prints could be one of the limitations in this study. Perhaps it would be better utilise software packages such as Universal Latent Workstation (U.S Federal Berau of Investigation) and Adobe Photoshop® as the fingerprint grading system. This quantitative method is an objective scoring system which removes the subjectivity.[27, 28] A request was made to obtain the Universal Latent Workstation software, but unfortunately it was turned down. In order to produce more reliable and accurate data, future studies looking at the efficacy of a fingerprint enhancement method are recommended to utilise these software packages.

CONCLUSION

The results of this study indicated that Lumicyano™ is an effective method to develop fresh latent fingerprints on dark coloured clothing fabrics. The indirect comparison between Lumicyano™ and silver VMD also suggested that Lumicyano™ may be a better enhancement method to enhance fingerprints on dark polyester and poly cotton fabrics. The thread count and weave pattern of the clothing fabrics are significant factors that influenced the quality of the developed prints. Moreover, the fingerprint donor was also shown to have a considerable effect on the quality of the fingermarks. This study also suggested that the use of a commercially available fuming chamber could improve the results by providing a constant temperature and humidity level during the fuming cycles. Future studies are required to perform a direct comparison between Lumicyano™, silver VMD, and CAF & FT-IR method on recovering latent fingerprints on dark and light coloured clothing fabrics.

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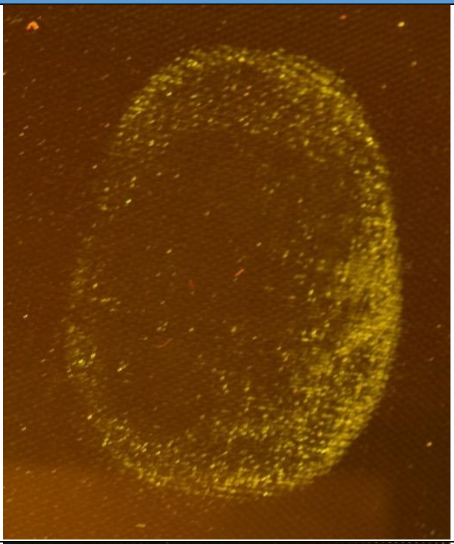
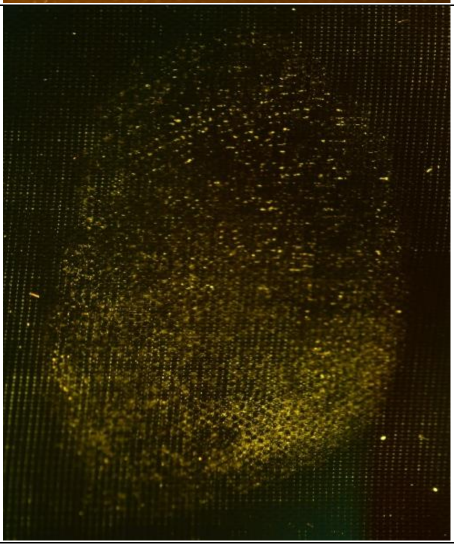
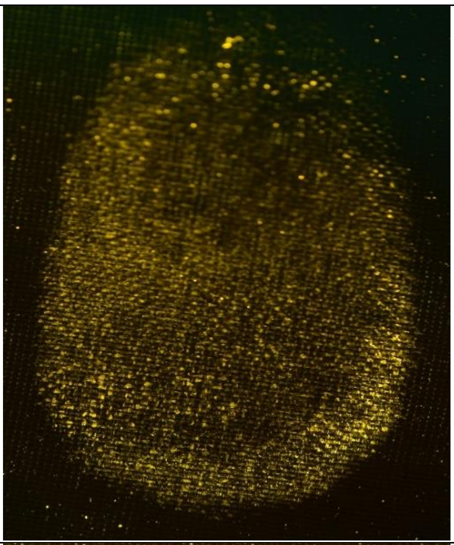
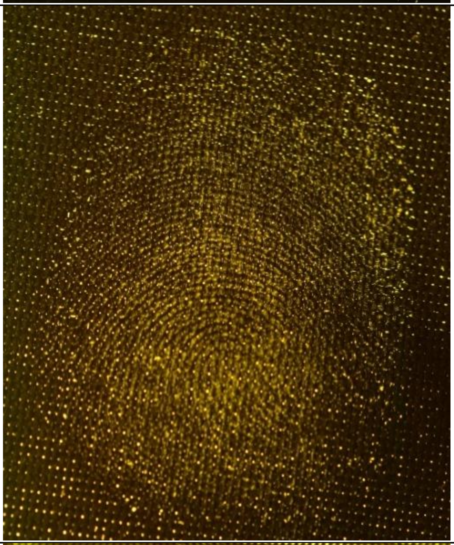
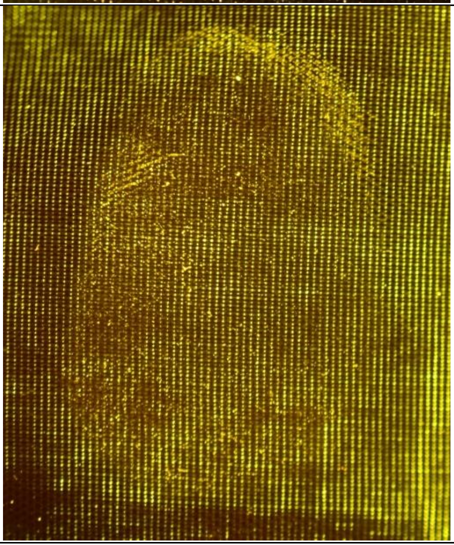
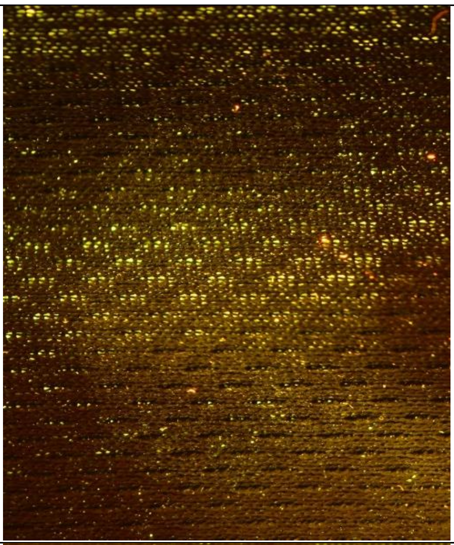
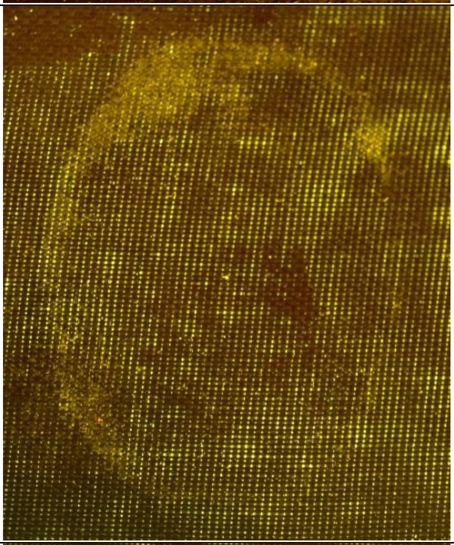
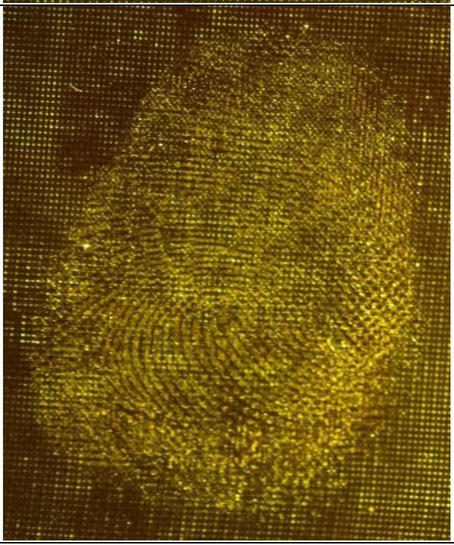
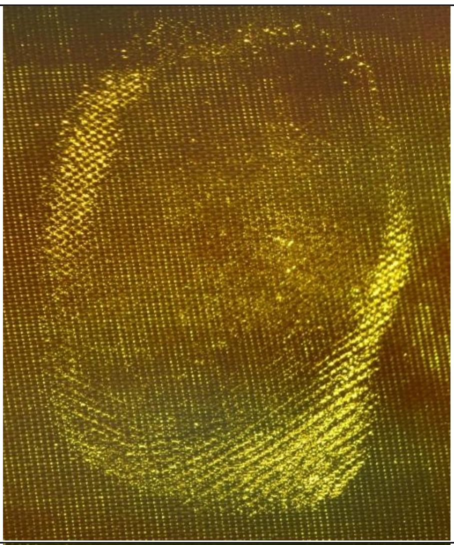
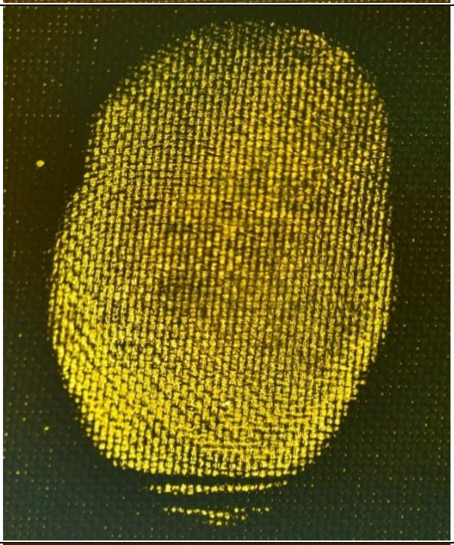
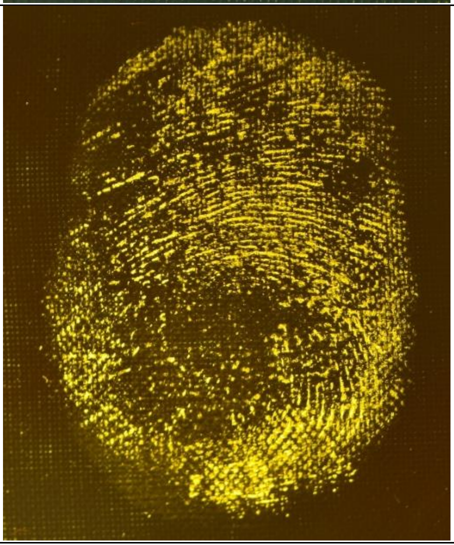
APPENDIX

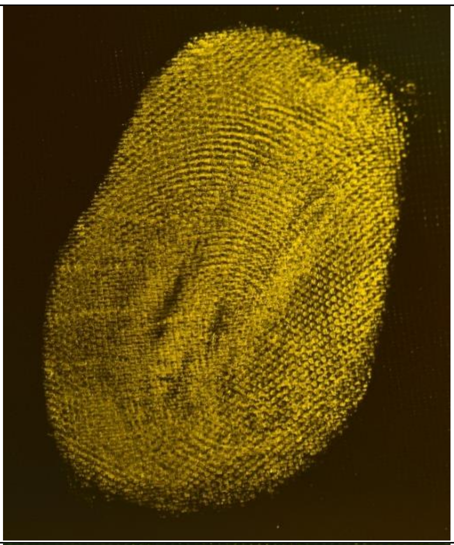
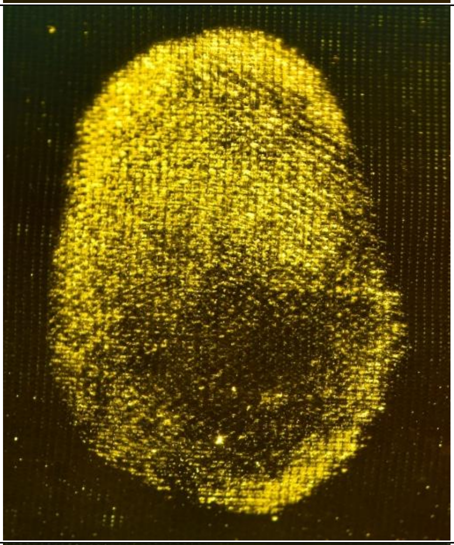
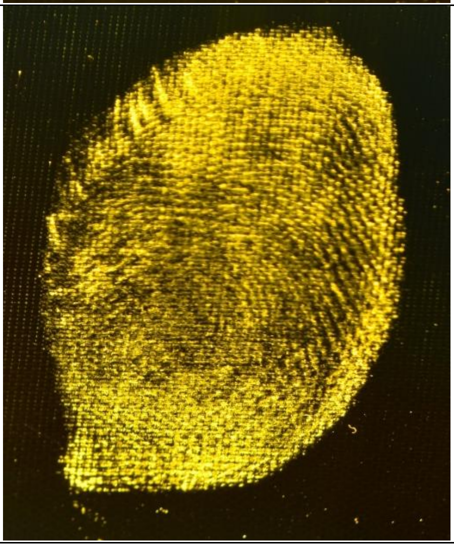
Table 4. The Photos and Scores of the Developed Fingerprints on Polyester.

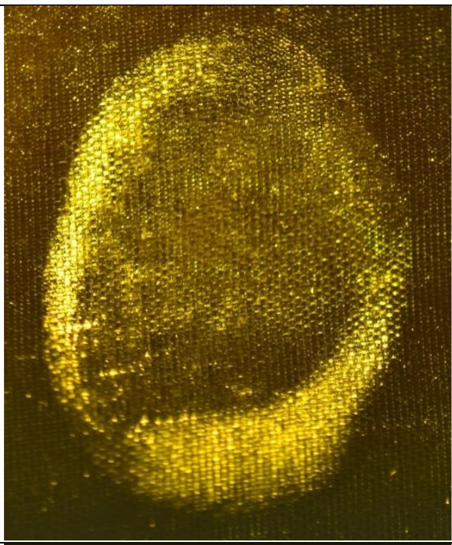
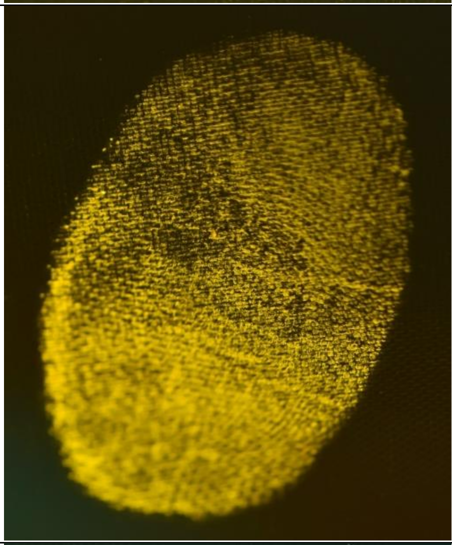
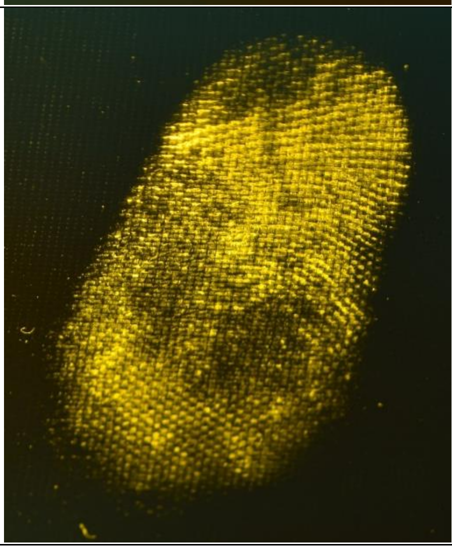
Polyester		
Donor number	**Photo**	**Score**
1		2
2		2

3		2
4		4
5		1

6		0
7		1
8		4

9		1
10		3
11		3

12		4
13		2
14		3

15		1
16		3
17		2

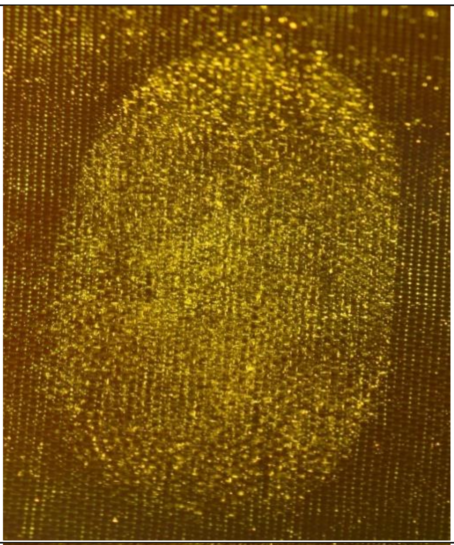
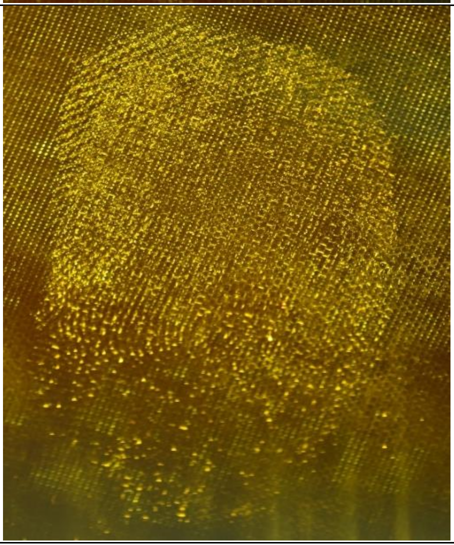
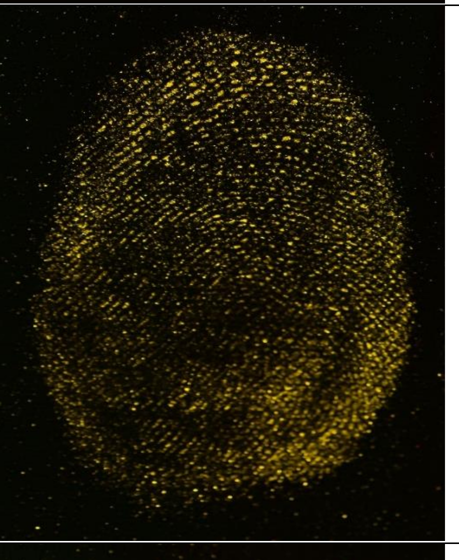
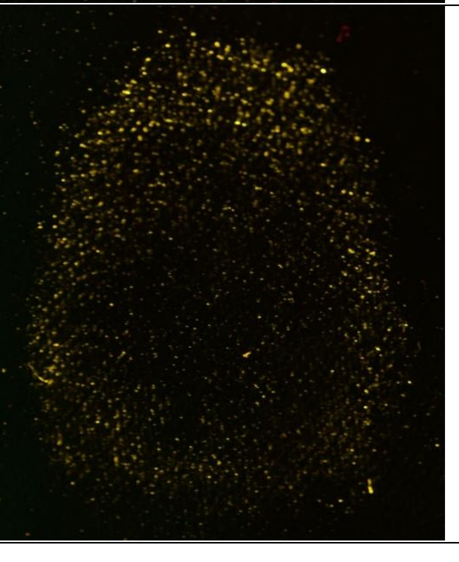
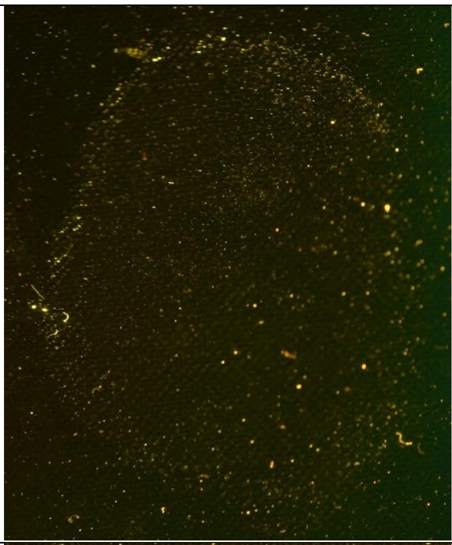
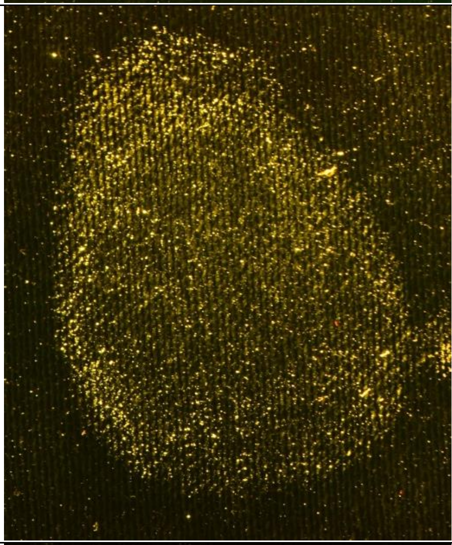
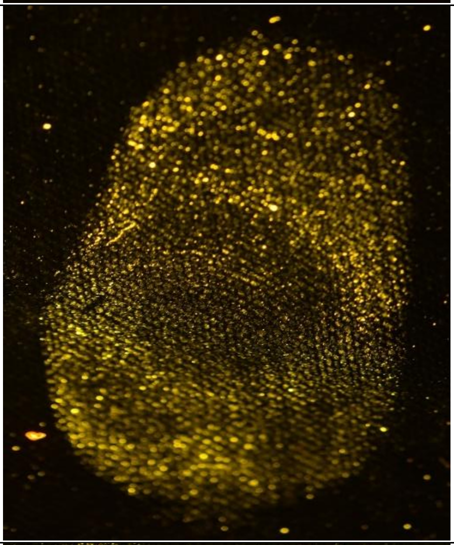
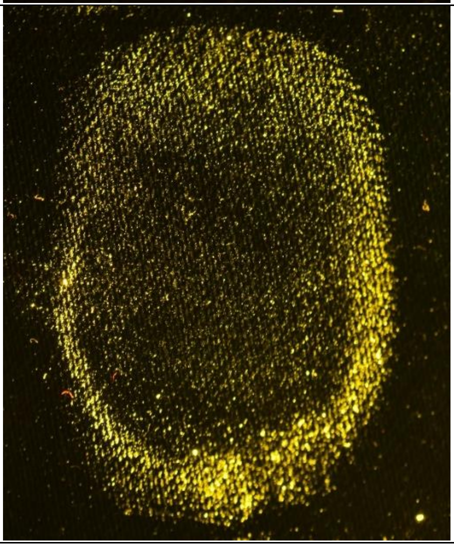
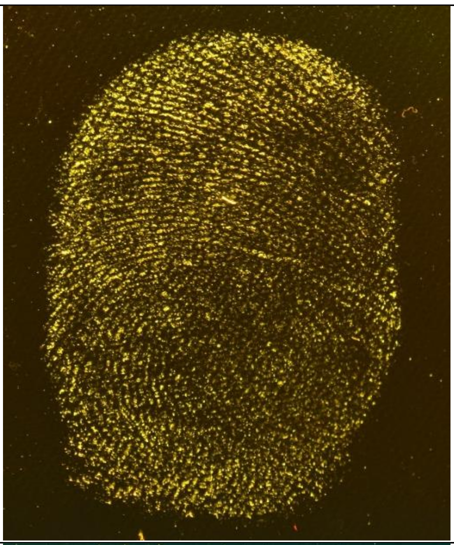
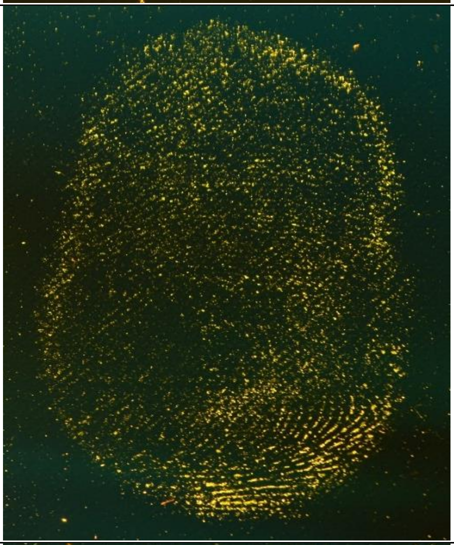
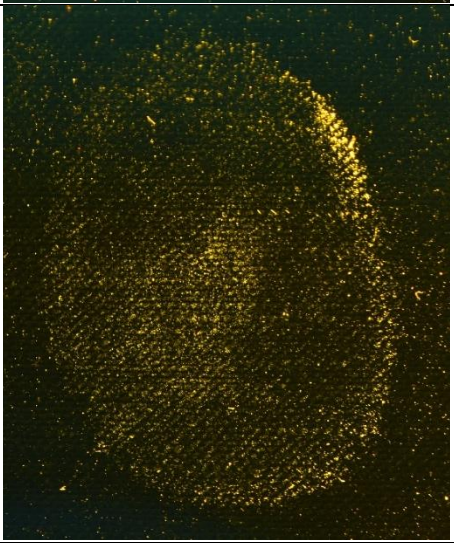
18		2
19		1
20		3

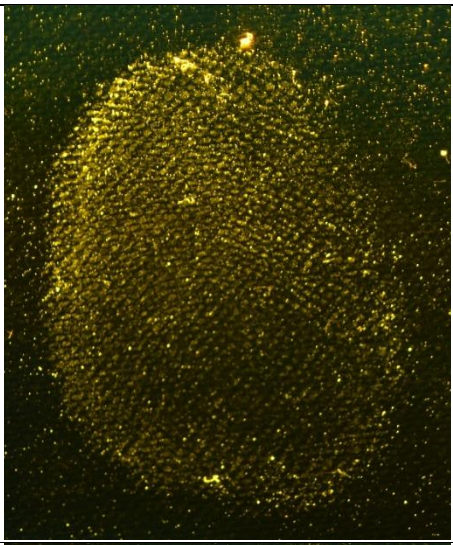
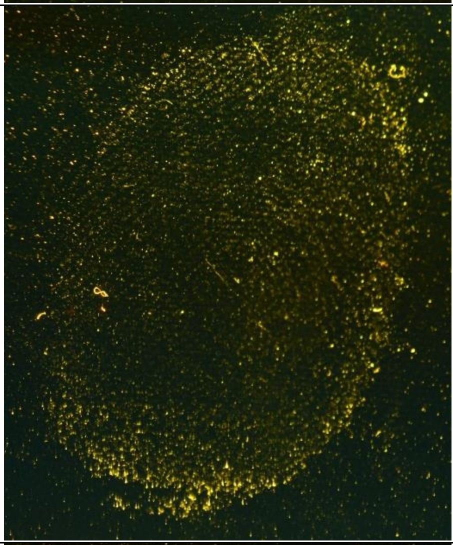
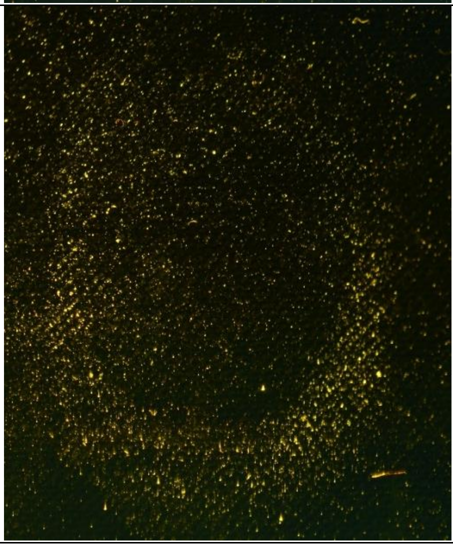
Table 5. The Photos and Scores of the Developed Fingerprints on Cotton.

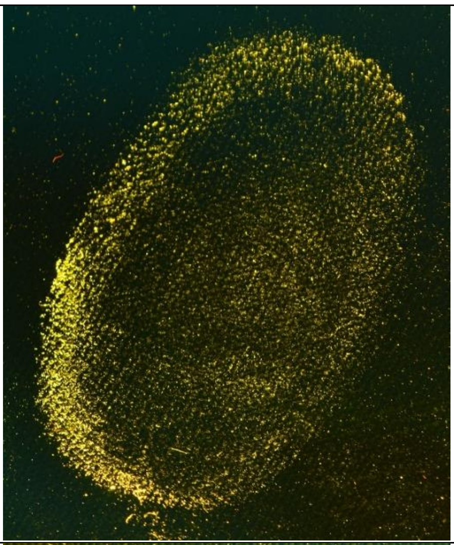
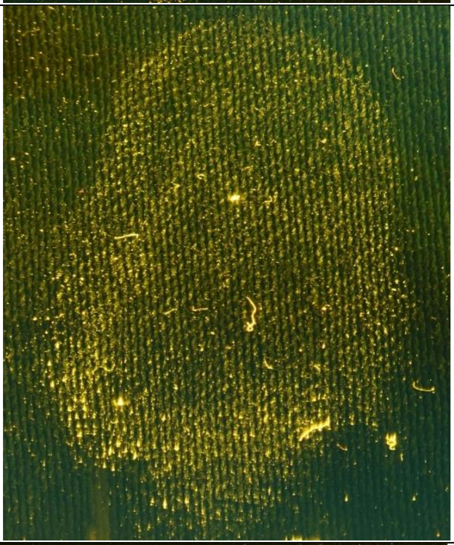
Cotton		
Donor number	**Photo**	**Score**
1		0
2		3
3		2

4		1
5		1
6		0

7		0
8		2
9		1

10		4
11		2
12		1

13		3
14		1
15		1

16		1
17		1
18		1

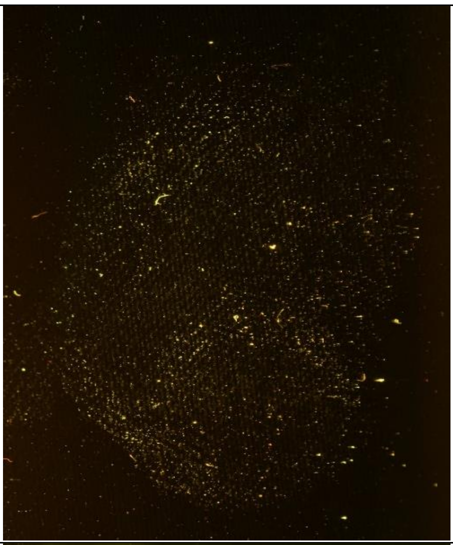
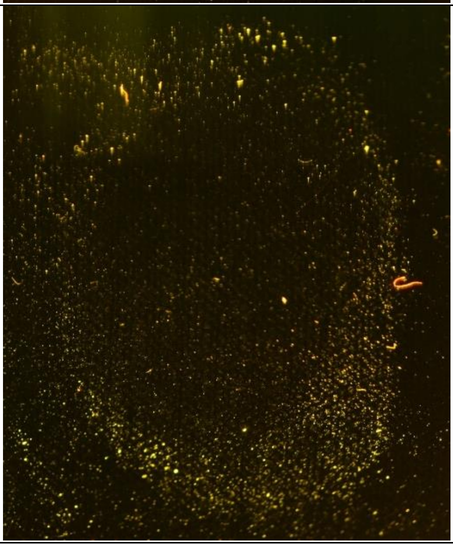
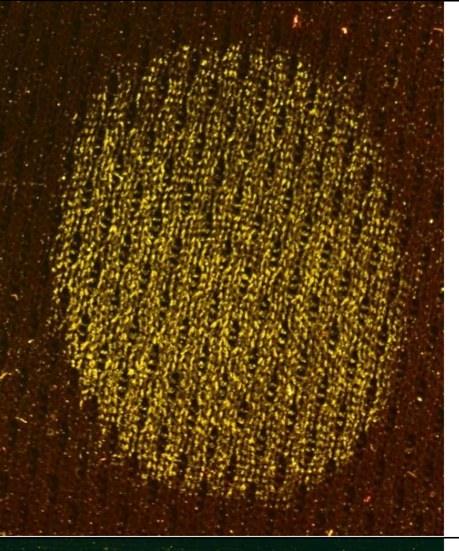
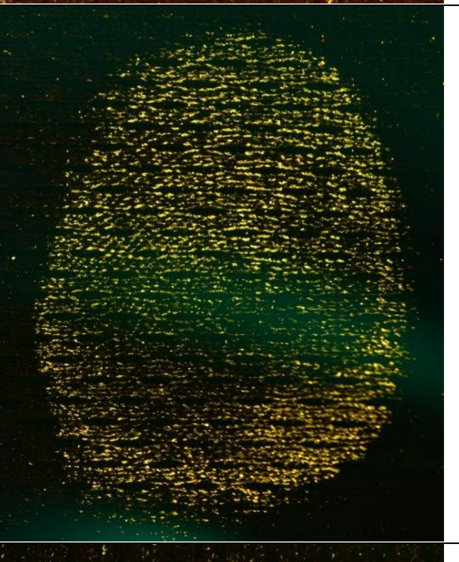
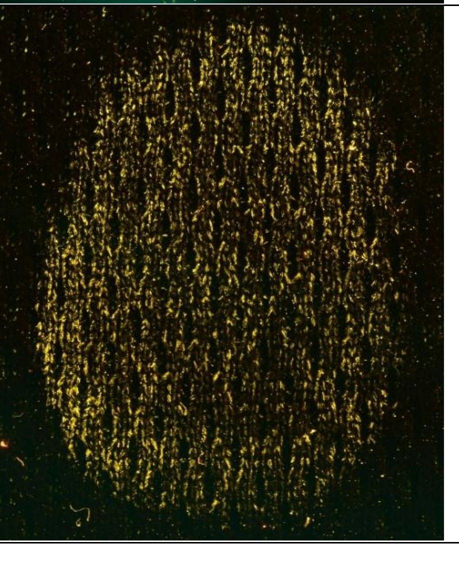
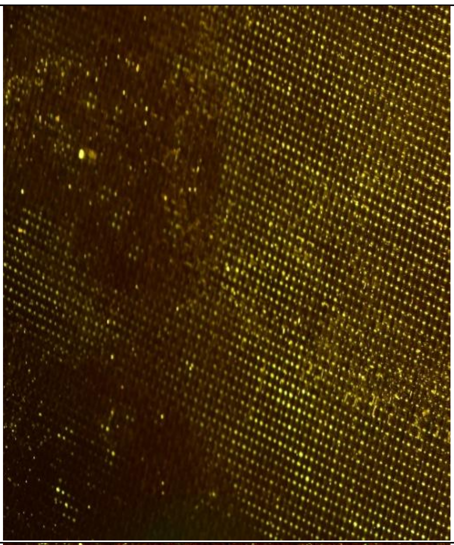
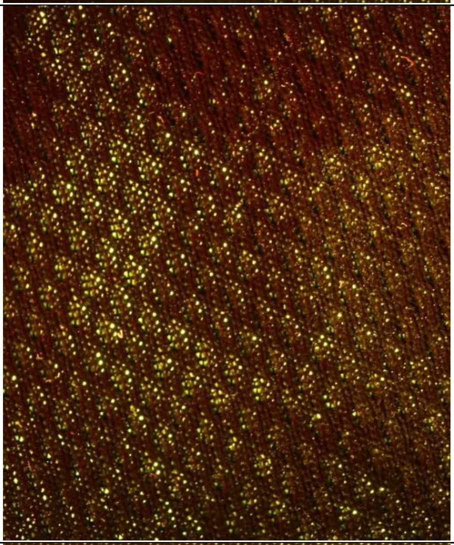
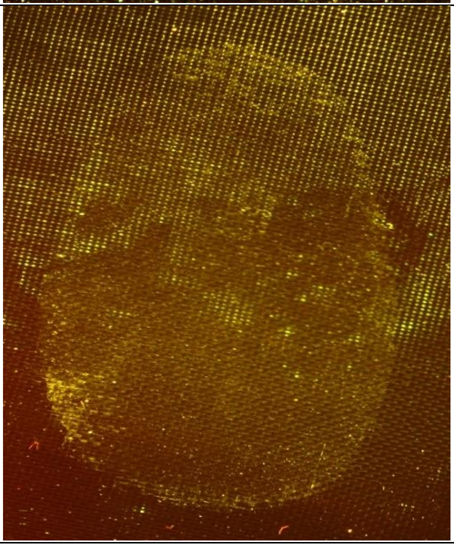
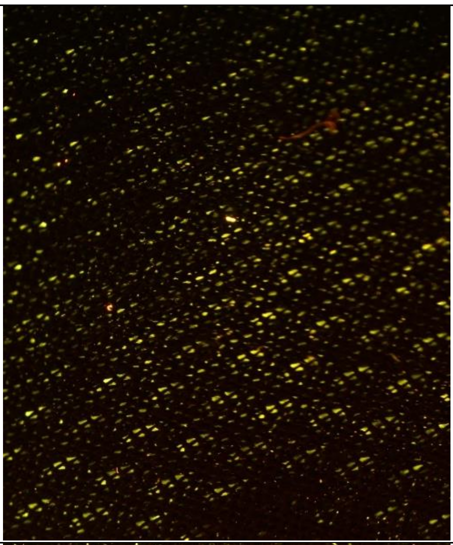
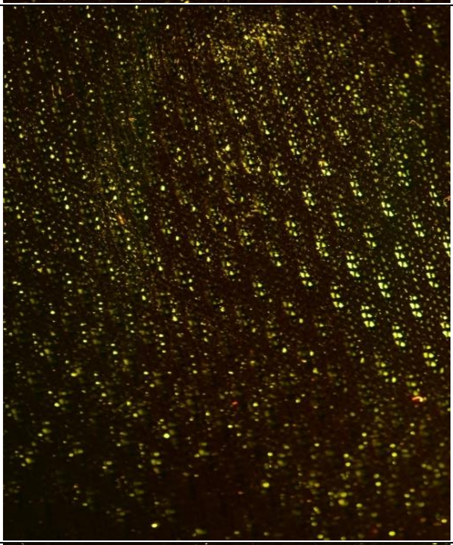
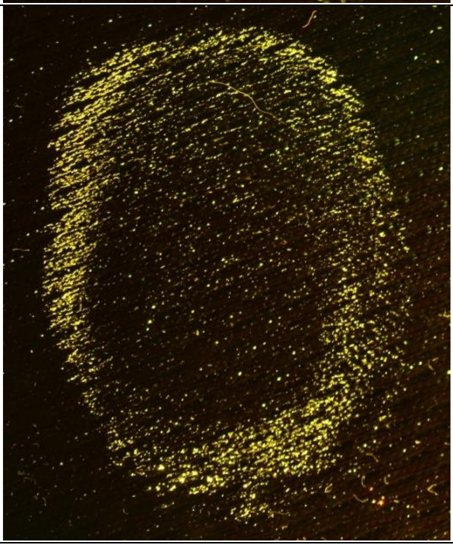
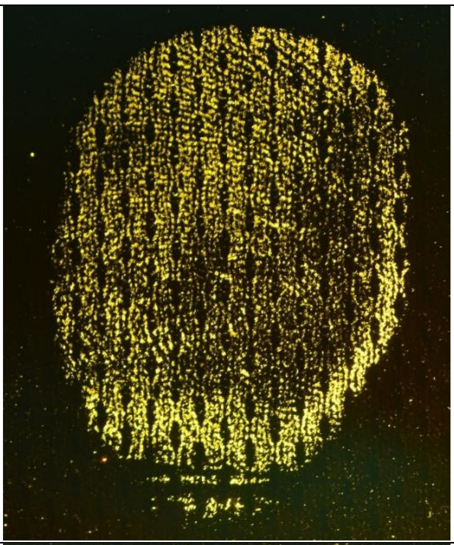
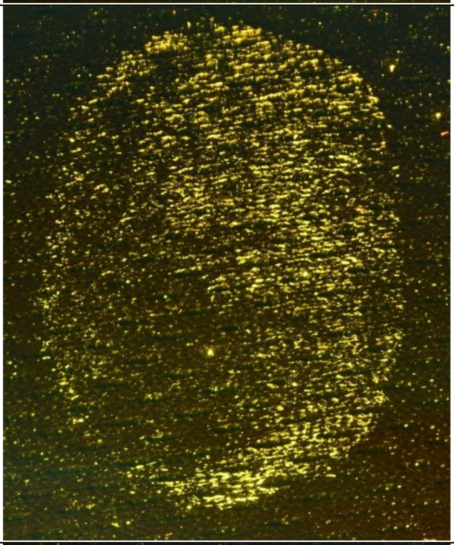
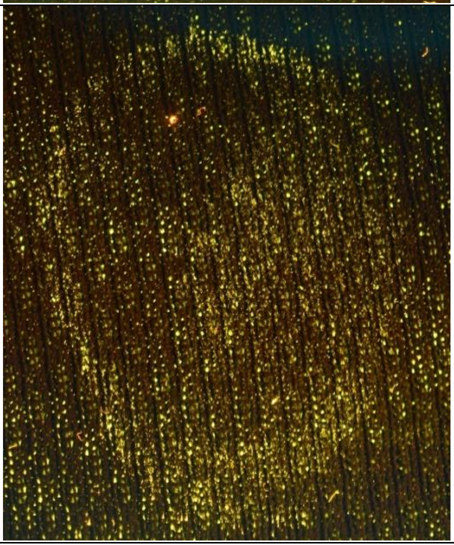
19		0
20		1

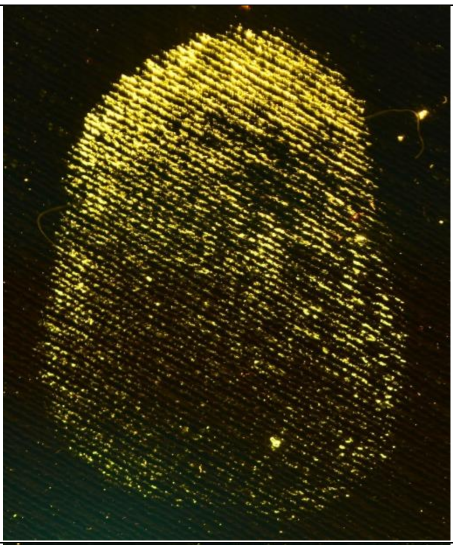
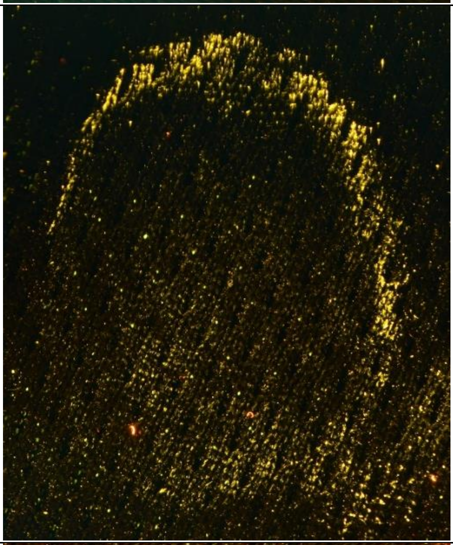
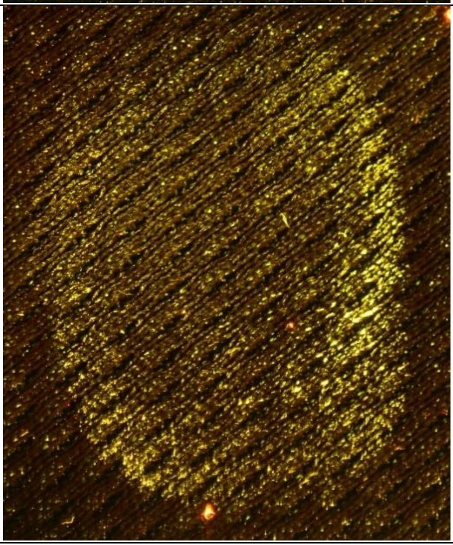
Table 6. The Photos and Scores of the Developed Fingerprints on Poly cotton.

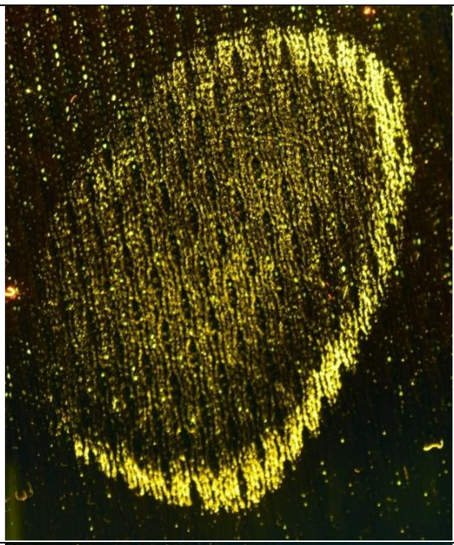
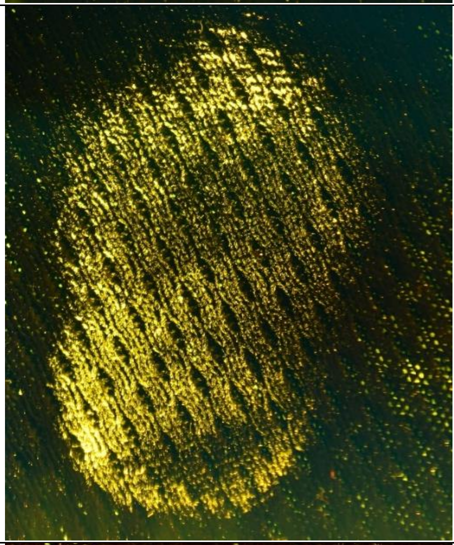
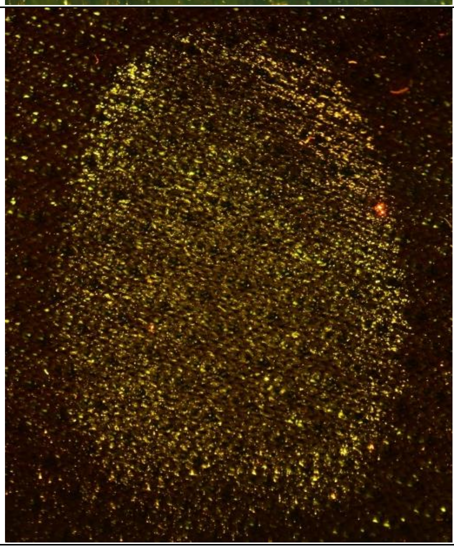
Poly cotton		
Donor number	**Photo**	**Score**
1		4
2		2
3		1

4		0
5		0
6		1

7		0
8		0
9		1

10		3
11		1
12		1

13		1
14		1
15		1

16		1
17		0
18		1

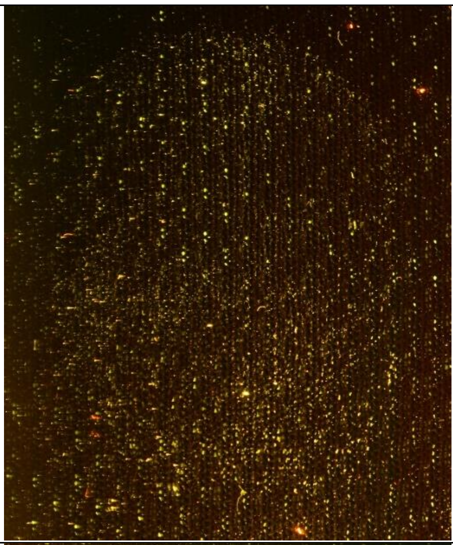
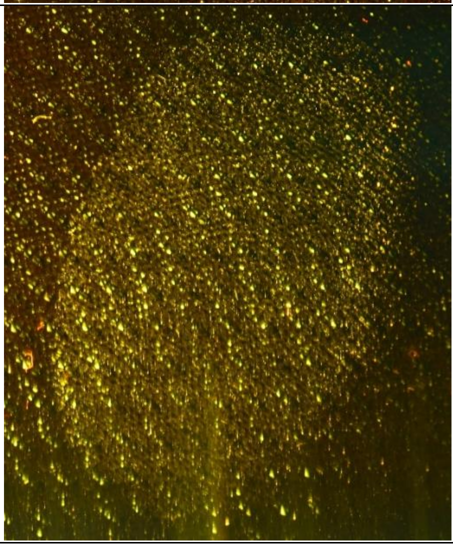
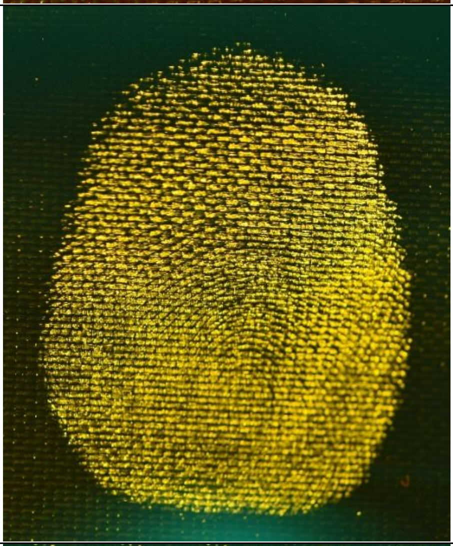
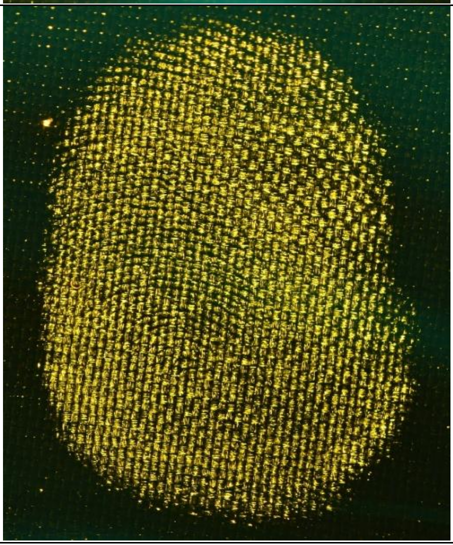
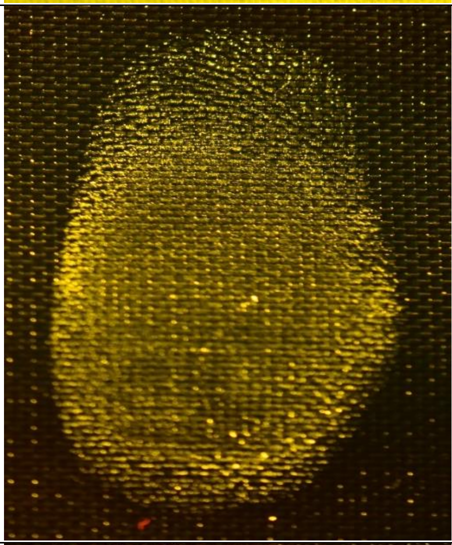
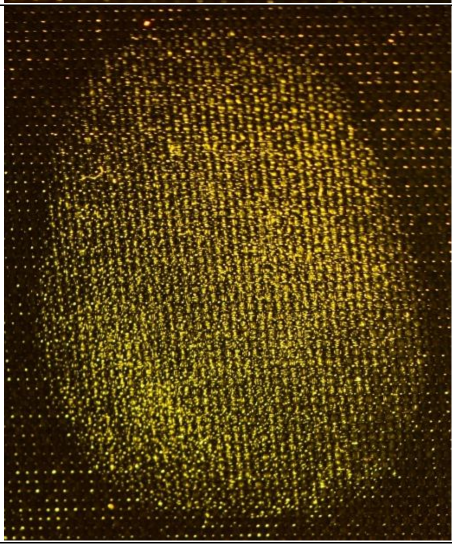
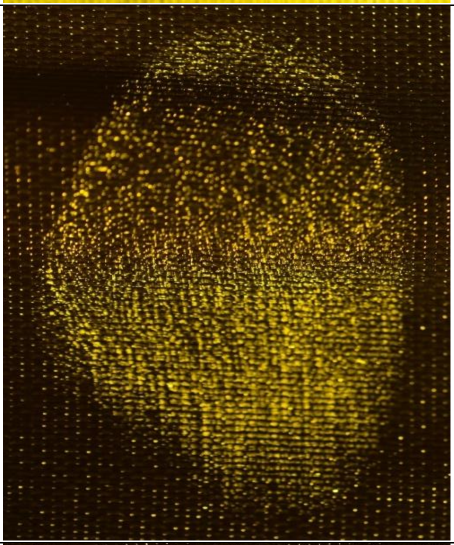
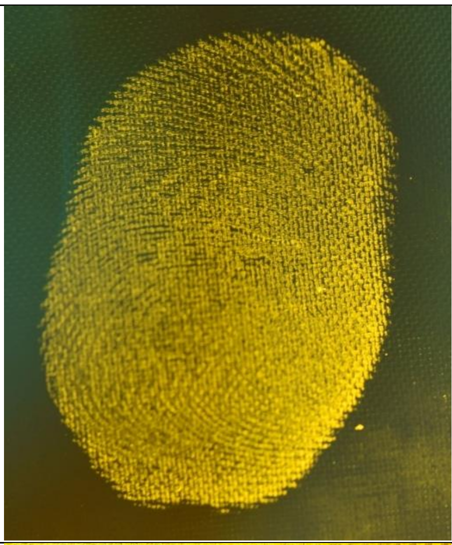
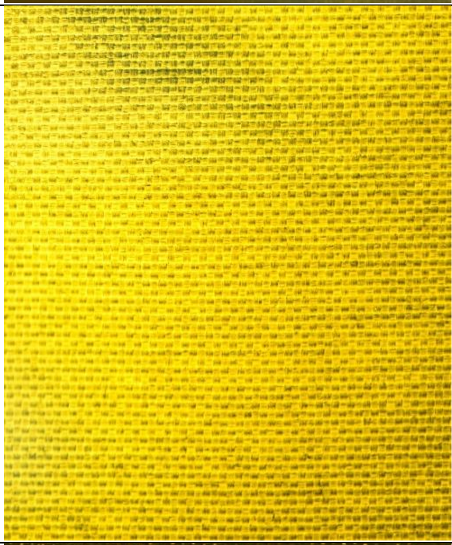
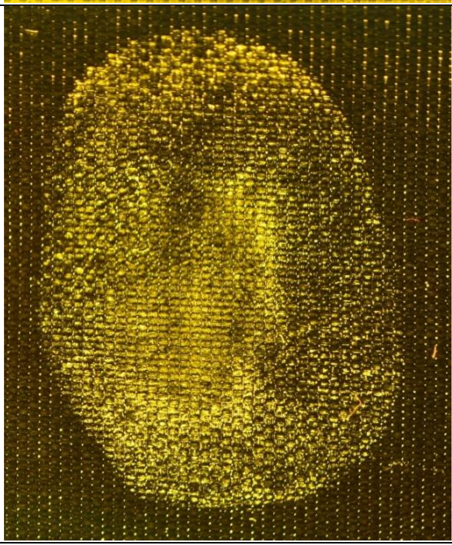
19		0
20		2

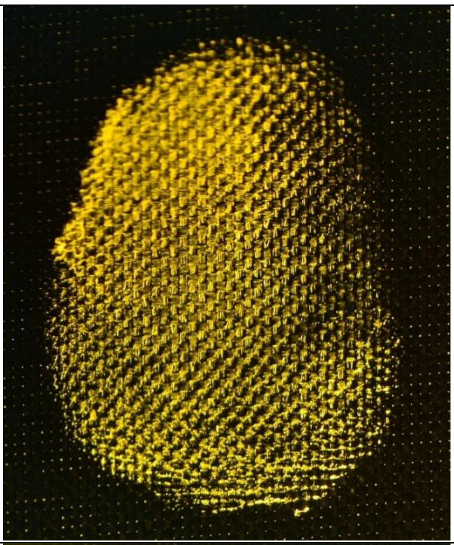
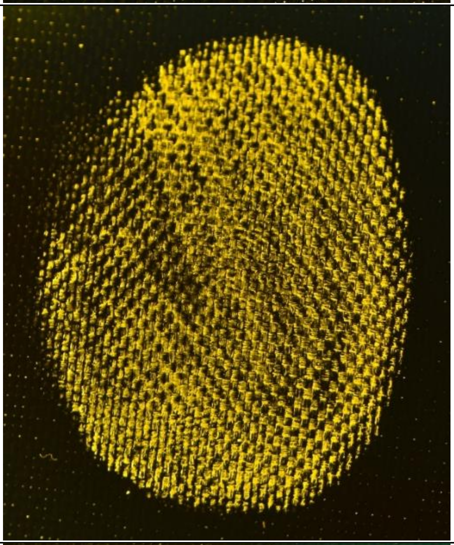
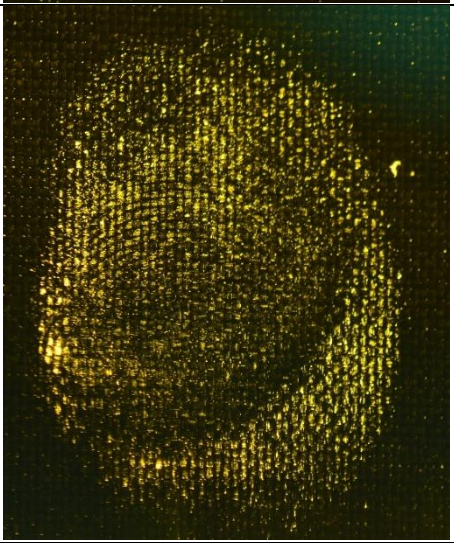
Table 7. The Photos and Scores of the Developed Fingerprints on Nylon.

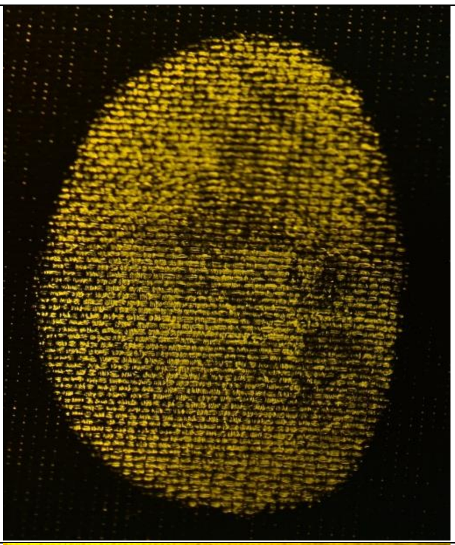
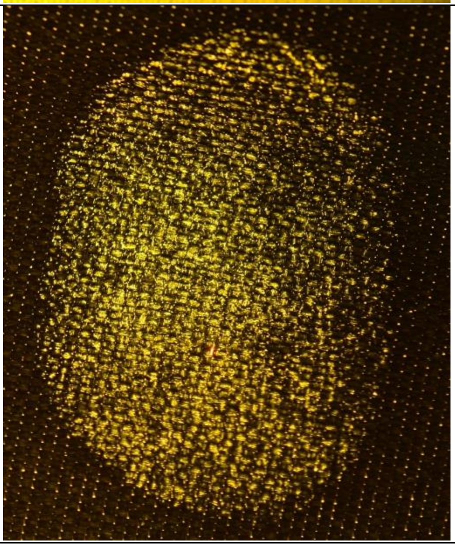
Nylon		
Donor number	**Photo**	**Score**
1		4
2		3
3		3

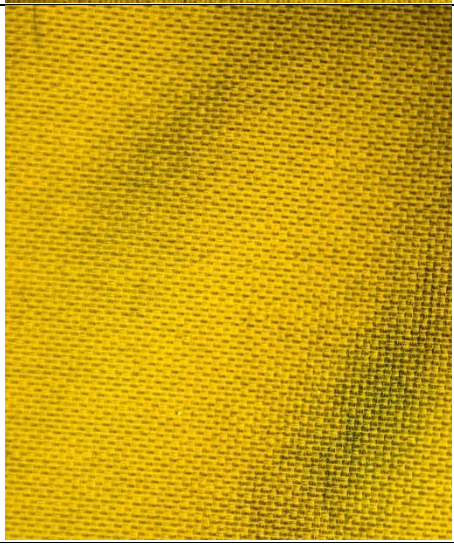
4		0
5		2
6		1

7		0
8		2
9		2

10		4
11		0
12		2

13		1
14		3
15		2

16		1
17		0
18		1

19		0
20		0