Effect of Substrate Surface Topography on Forensic Development of Latent Fingerprints with Iron Oxide Powder Suspension

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Abstract

Latent fingerprint deposition and effectiveness of detection are strongly affected by the surface on which prints are deposited. Material properties, surface roughness, morphology, chemistry and hydrophobicity can affect the usefulness or efficacy of forensic print development techniques. Established protocols outline appropriate techniques and sequences of processes for broad categories of operational surfaces. This work uses atomic force microscopy and scanning electron microscopy to investigate a series of surfaces classified as smooth, non-porous plastic. Latent prints developed with iron oxide powder suspension are analysed on a range of scales from macro to nano to help elucidate the interaction mechanisms between the latent fingerprint, development agent and underlying surface. Differences between surfaces have a strong effect, even within this single category. We show that both average roughness and topographical feature shape, characterized by skew, kurtosis and lay, are important factors to consider for the processing of latent fingerprints.

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Effect of Substrate Surface Topography on Forensic Development of Latent Fingerprints

Abstract
Latent fingerprint deposition and effectiveness of detection are strongly affected by the surface on which prints are deposited. Material properties, surface roughness, morphology, chemistry and hydrophobicity affect the usefulness or efficacy of forensic print development techniques such as dry powder, powder suspension, cyanoacrylate fuming or vacuum vapour deposition, and lack of development agent adhering to deposited print as well as excess background staining are both problematic. The deposited fingerprint is further affected by the contact conditions and the individual donor. Additional factors affect the detection algorithm such as pre- and post-deposition environment of the surface, humidity, contamination and cleaning agent or solvent spray.

This work uses atomic force microscopy and scanning electron microscopy to investigate a series of surfaces and the interaction between latent fingerprint, surface and development agent. Latent prints developed with various techniques are analysed on a range of scales from macro- to nano- to help to elucidate the mechanisms of fingerprint development and aims to aid detection technique enhancement and algorithm improvement.

1. Introduction

Forensic casework and research laboratory studies show that latent fingerprint development efficiency can be affected by characteristics of the deposition surfaces as well as the donors [1-12].

Protocol tables have been developed that apply broad classification to surfaces and outline appropriate development techniques such as dry powder, small particle reagent, cyanoacrylate fuming (CA) or vacuum metal deposition (VMD) [1,2]. Powder suspensions, fine particles suspended in a surfactant, are increasingly used in development of latent fingerprints [1-4]. Powders may be based on titanium dioxide, aluminium, iron oxide or a range of carbon based materials, allowing choice of technique that is optimum for a particular sample. However, development of fingerprints utilising routine techniques may in some cases be sub-optimal or impossible. Azoury [7] shows a case where routine application of reagents for developing prints on a particular set of banknotes gave no results, but prints could be developed with non-routine application of CA followed by magnetic powder. This difference in optimal technique was found to be related to the paper chemical composition and surface free energy [7]. Other workers [9,10] have shown certain surfaces can give rise to reverse development of ridges and background when developed with VMD. Research groups also show latent print chemistry and development effectiveness is related to donor and time from deposition [11,12].

Protocol tables are continually evolving as technology develops. Advances in nanotechnological techniques enable the use of new methodologies for making and augmenting crime scene identifications [13-15]. Research into nanostructured particles [4, 16,17] has helped develop techniques with improved latent fingerprint development, though efficacy remains surface dependent [4,17]. Development efficacy of powders and suspensions is related to lack of development agent adhering to deposited print as well as excess background staining; different powders and powder suspension formulations have been shown to have optimum efficacy depending on the surface on which the print is deposited [4,5,8,18]. This demonstrates that an understanding of the substrate surface properties, beyond a broad classification, is important in forensic development of latent fingerprints.

This work studies latent prints developed with iron oxide based powder suspension. The study analyses the development powder and thoroughly characterises a series of three representative surfaces, studying both clean surfaces prior to print deposition and effect of the surface characteristics on the development of latent prints. The morphology of the sample surfaces is studied and the deposition and distribution of deposited powders on the latent prints and background areas is investigated.

2. Experimental

Three surfaces, classified as smooth, non-porous plastic and relevant to crime scene investigations, were identified as formica, polyethylene and uPVC. Latent fingerprints from a single donor were deposited on sample surfaces and developed at the Home Office Scientific Development Branch with a powder suspension designated as magnetic iron oxide. Subsequent examination of the powder by X-ray fluorescence and X-ray photoelectron spectrometry shows the formulation also contains levels of Al, Ca, Na, Ti, Cr, Mn, Cu and Zn. Developed prints and samples of clean surfaces were examined to investigate the print-surface-powder interactions.

Surface morphology and structures of clean substrate materials were examined with atomic force microscopy (AFM) utilising a Digital Instruments Dimension 3100 scanning probe microscope, operating in intermittent contact (tapping) mode with a Nanosensors silicon probe with a resonant frequency of approximately 160kHz. Scans were conducted over a range of area from 300nm to 100 µm square; data was taken after first order plane subtraction, from analysis of at least five separate areas. The uncertainty range quoted is indicative of variation in the surface between areas studied.

A Zeiss Supra 35VP field emission scanning electron microscope (SEM) operating in high vacuum mode was utilised for subsequent analysis of the samples of developed prints on each surface after samples were sputter-coated with a thin, conductive layer of gold. A low accelerating voltage is used to maximize surface sensitivity. Images were collected at various magnifications. Qualitative elemental evaluation was conducted with an Oxford Instruments INCA energy dispersive X-ray analysis (EDX) system fitted to this microscope. Increased accelerating voltage was utilised to facilitate elemental analysis.

3. Substrate Surfaces

Figure 1 shows atomic force microscopy (AFM) images of the three surfaces, and the extracted surface parameters are given in table 1. The sample surfaces cannot be accurately characterised with a single parameter such as the commonly used roughness measurement, R_a. Figures from average over 50µm square areas are shown in table 1 and comprise sample roughness R_a (average deviation from mean line), R_{max} (maximum height variation), skewness (symmetry) and kurtosis (peak sharpness).

Figure 1 (a,b) show AFM images of the formica surface over 10µm square and 50µm square, respectively. The measurements highlight a flat, smooth surface, with a low level waviness amplitude ~100nm and lateral scale ~30µm. The main features are sharp ridges of height approximately 100nm, a few larger, up to approximately 0.5 µm with side-troughs, perhaps formed as impressions of grooves in a contact surface during production. The general lay direction is constrained within about 20^o. The sharp ridges contribute to the high kurtosis value and positive skew given in table 1.

Predominant features of the polyethylene (PE) surface are ridges from 2µm to over 5µm in height, and ~50µm wide, as shown in AFM images figure 1 (c). These major ridges are formed in some cases by 'minor' ridges perpendicular to the general lay, which are 3-10µm wide with a depth of up to 1µm, as shown in figure 1 (d). Minor ridge features are not ubiquitous and there are some much flatter areas between major ridges.

The surface of the uPVC sample features pits and holes from less than 1µm to, occasionally, over 20 µm in diameter and reaching a depth of ~ 0.5 µm, as shown in figure 1 (e,f) and contributing to the negative surface skew. There are additionally some score marks, which give a lateral element to the surface, though don't contribute significantly to roughness figures such as R_a.

4. Developed Fingerprints

4.1 Developed print on formica

Figure 2 shows a latent print on formica developed with iron-oxide based powder suspension. Figure 2 (a) shows a low magnification SEM imaged of the developed print, indicating generally good development contrast. Figure 2 (b) shows a boundary of a print ridge showing primarily good definition and contrast to the background coverage. However, powder coverage on the background shows levels of adhesion to the substrate ridge structure; smearing from the fingerprint ridge boundary at the top of the image follows the general direction of lay. Figures 2 (c and d) show SEM images of print ridge boundaries with good and poor definition respectively. Here the particle size range and uniformity can be seen; the particles acting in the development process include the majority of range of particle sizes in the powder, up to approximately 1µm, but exclude any aggregations that may be observed in the dry powder. There is no obvious difference in particle size or morphology on print or adhering to background. In figure 2 (c) the surface direction of lay is parallel to the print ridge boundary. For the poorly defined boundary in figure 2 (d), the direction of lay is approximately 45^o to the ridge edge. It can be hypothesised that in this sample, surface linear features parallel to latent print ridges act to reinforce the demarcation, whereas substrate ridges at a greater angle to the boundary act to degrade print quality and promote smearing. This is also shown in figure 2 (a), although showing generally good contrast, does also exhibit some disruption of ridge boundary detail by powder adhering along lay direction of substrate, as well as some light smearing disregarding directional substrate structure.

4.2 Developed print on PE

Scanning electron microscope images of the developed print on PE are shown in figure 3. An SEM image showing the general overview of the developed print is shown in figure 3 (a) with an insert showing the light microscopy image of the full print. The substrate surface outlined earlier dominates the SEM image; developed print ridge are just visible. A higher magnification SEM image is shown in figure 3 (b). This highlights a boundary of the latent print ridge and shows that development is unaffected by the major substrate variations that dominate the surface, leading to development contrast shown in figure 3 (a, insert). However, where the substrate is formed of minor ridges perpendicular to the primary direction, these have a strong affect on the print development. This is shown clearly in figures 3 (c and d) that show surface on and off latent fingerprint ridge, respectively. Figure 3 (c) shows even powder coverage on fingerprint ridge, interrupted only by few highest peaks, figure3 (d), away from the print ridge shows powder adhering to the surface in the 'minor ridge' furrows. The minor furrows trap the powder away from the print, but are almost evenly covered under a well developed latent print ridge. The major ridges have little effect on the development process.

4.3 Developed print on uPVC

Figure 4 shows SEM images of the developed latent fingerprint on uPVC. A general overview of the developed print is shown in figure 4 (a), here powder coverage is denser around pores, showing preferential development of eccrine deposit. This is further shown in figure 4 (b), demonstrating different levels of powder coverage around a pore. Figure 4 (c) shows a fingerprint ridge boundary, highlighting that the pits and holes in the substrate have little effect on latent print development, but the linear score marks in this surface have some effect on reinforcing parallel ridge edges, and disrupting transverse ridge edges, but this is a less prominent effect than the sharp ridges on the formica surface. Figure 4 (d) shows some smearing of ridges along predominant direction of substrate lay.

5. Conclusions

Three types of solid plastic surfaces were examined to investigate how the surface structure affects latent fingerprint development with iron oxide based powder suspension. The powder adhering to the fingerprint consists primarily of cubic magnetite crystals formed into clusters of a range of sizes from a few hundreds of nanometres to approximately one micron in diameter. There is no significant difference in particle size adhering to fingerprint ridge or background areas; larger particle aggregates seen in the raw powder are not observed on the developed print.

Sharp, ~100nm high ridges in the formica surface strongly affect print development, despite overall smoothness of surface. The angle of the substrate feature to the fingerprint ridge edge acts to control boundary disruption, with substrate ridges parallel to a print ridge boundary acting to contain the print, but when at an increased angle to latent print ridge edge contribute to degradation of the ridge-background contrast. uPVC, with furrows rather than sharp ridges, shows a similar tendency but to a significantly reduced extent. Pits in uPVC are the dominant surface characteristic, but seem to have little effect on fingerprint ridge development. The PE sample studied has significant directionality, with parallel surface ridges exceeding 5µm in height, and periodicity about 50µm. These ridges contribute substantially to perceived roughness and roughness figures, but have little effect on the print development. Some substrate ridges are formed of minor ridges perpendicular to the general lay, with furrows 1-10 µm in width these trap development powder, significantly degrading print quality by reducing background-ridge contrast.

In summary, surface structures are not adequately described by a single roughness parameter for classification of relevance to fingerprint development. Figures for roughness, R_a, R_{max} have been calculated, and surface morphology is further characterised by skewness (symmetry) and kurtosis (sharpness of peaks / troughs) and dominant direction of surface structure (lay). Lay and lateral scale are important, with linear features acting as boundaries or channels. Scratch lines (or other linear features) influence print development even when not the dominant characteristic. Sharpness of features and whether features stand proud of the substrate or are recessed are of importance, and can be characterised by parameters such as skew and kurtosis, in conjunction with traditional roughness measurements.

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Figures and table

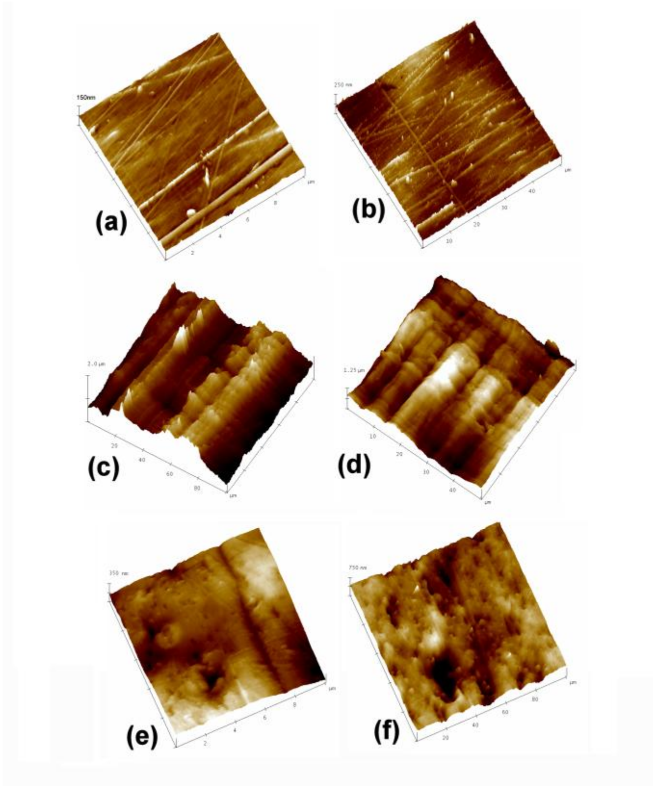

Figure 1: AFM images showing surface structure of (a,b) formica (c,d) PE and (e,f) uPVC samples

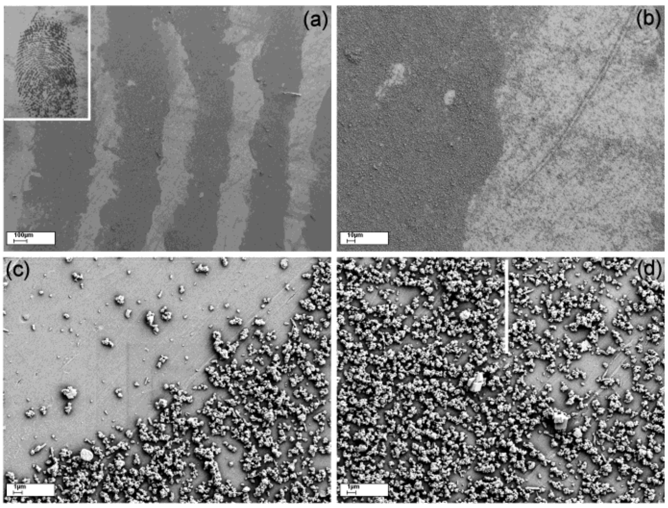

Figure 2: SEM images showing developed fingerprint on formica surface (a) general overview with light microscopy image of whole print, insert. (b,c,d) selected details outlined in the text

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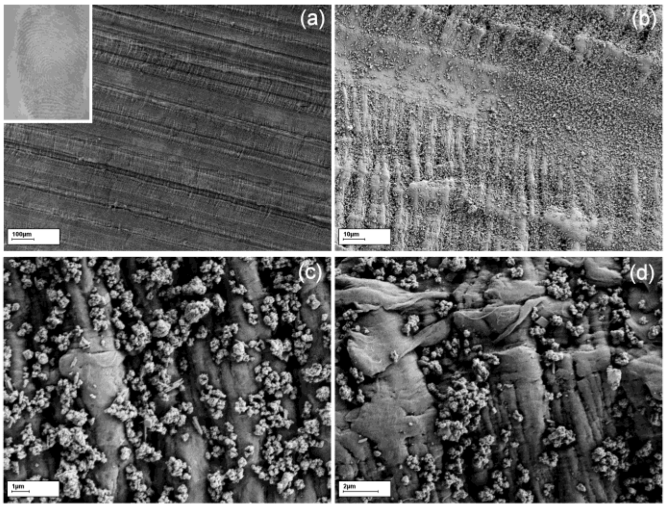

Figure 3: SEM images showing developed fingerprint on PEsurface (a) general overview with light microscopy image of whole print, insert. (b,c,d) selected details outlined in the text

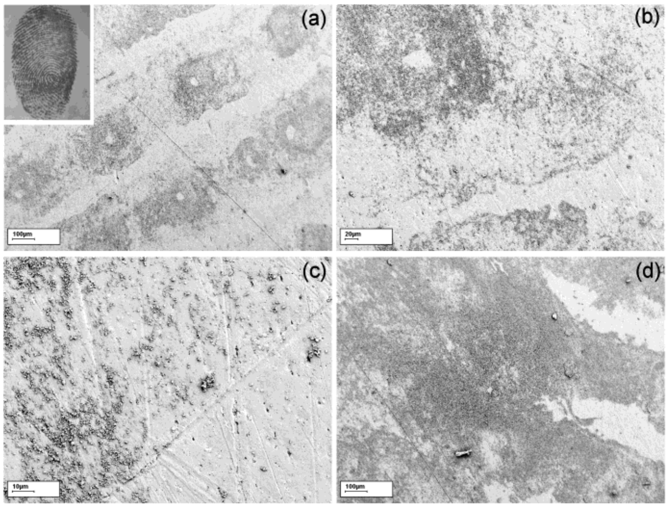

Figure 4: SEM images showing developed fingerprint on uPVC surface (a) general overview with light microscopy image of whole print, insert. (b,c,d) selected details outlined in the text

	R_a / nm	R_{max} / µm	Kurtosis	Skew
Formica	**22.8±3.5**	**0.49±0.1**	**6.8±1.6**	**1.0±0.4**
PE	**319±90**	**2.8±1.4**	**3.3±1.0**	**0.1±0.4**
uPVC	**83±6**	**0.89±0.12**	**3.7±0.3**	**-0.5±0.2**

Table 1. Surface morphology parameters calculated from AFM measurements