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Development of Latent Fingermarks Exposed to Simulated Destructive Environment using Powder Suspension

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Abstract

Recently, there has been increasing attention on improving the procedural fairness and scientific accuracy of crime-scene evidence collection to promote objective and impartial case analysis. Fingermarks, which can objectively link individuals to specific objects or places, remain essential evidence. On nonporous surfaces, the powder and cyanoacrylate fuming methods are commonly used to visualize fingermarks. However, they often perform poorly when exposed to harsh environmental conditions such as rain, deliberate submersion, or damage from fire, heat, and smoke. Thus, developing fingermark visualization methods on prints exposed to such challenging environments is essential. The wet powder suspension (WPS) technique—also called powder suspension—uses a liquid mixture containing solid powders and surfactants to visualize fingermarks. It includes the older small-particle reagent (SPR) and more recent, thicker paint-like formulations (Wetwop™ and Wet Powder™). The latter are effective on sticky surfaces such as tape. They can also be applied to other nonporous surfaces. In 2014, police in the United Kingdom recommended adding the WPS method to their Fingermark Visualization Manual. Owing to its simplicity and reliability, WPS performs effectively even under difficult conditions, including moisture or surface contamination. In this study, three commercial WPS reagents were tested on 11 nonporous substrates commonly found at crime scenes, including garbage bags, zip-lock bags, ceramic tiles, glass slides, rubber boots, polypropylene containers, aluminum foils, stainless-steel boxes, and gloves (PVC, nitrile, and latex). Four types of fingermark residues, namely natural, standard, sebaceous (oil-based), and amino acid-based prints, were deposited on these substrates before treatment with three reagents. Substrates that displayed good results will be exposed to simulated harsh environments before being processed for prints. ImageJ grayscale analysis was performed on the resulting images to evaluate for completeness and contrast in order to create objective evaluation criteria. Results from the experiment suggested that surface properties, residue composition, and environmental exposure do affect the clarity of fingermark ridges. The powder type also influences its adhesion and deposition on the surface for visualization. These findings under simulated destructive conditions provide practical recommendations for improving fingermark visualization success at real crime scenes.

Keywords: ***forensic science, fingermark, wet powder suspension, destructive environment, water immersion, arson scene***

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Introduction

In modern forensic practice, scene investigation and evidence collection focus primarily on individualized characteristics, such as fingermarks and DNA. Fingermarks possess unique and persistent attributes; they are distinct among individuals, remain stable over time, leave impressions upon contact, regenerate after damage, and are resistant to short-term degradation. Long before the advent of DNA profiling technology, fingermarks were already used for personal identification. Fingermark evidence can link individuals—victims or suspects—who have interacted with a crime scene to specific locations or objects. In current forensic practice, the most frequently applied latent fingermark visualization techniques for non-porous surfaces include the powder and cyanoacrylate fuming methods [1]. However, their effectiveness tends to be high under ideal conditions, such as relatively clean surfaces, recent depositions, and absence of deliberate evidence destruction. Under destructive environments, these methods often fail to yield satisfactory results.

The wet powder suspension (WPS) method, recently advocated by the United Kingdom's Centre for Applied Science and Technology, is a fingermark visualization technique designed primarily for use on nonporous and semiporous substrates [2-3]. Since the first publication describing the preparation of fingermark reagents by suspending solid powders in surfactant solutions in 1978, related studies have continued to evolve. Based on the solid powder concentration, WPS formulations can be categorized into the following two types: (1) small particle reagent (SPR), which is the earlier-developed formulation containing a lower concentration of surfactant and exhibiting a watery consistency, making it suitable for fingermark visualization on wet surfaces; and (2) powder suspension which is a viscous, paint-like formulation developed in recent years and commonly applied to adhesive or nonporous surfaces, exemplified by commercial products such as Wetwop™ and Wet Powder™.

According to the Fingerprint Source Book (v3.0) [3] and Fingerprint Development Techniques: Theory and Application [4], the precise mechanism of the WPS method remains incompletely understood. It is hypothesized that micelles or surfactant layers form around powder particles suspended in solution. Lipid constituents within the latent fingermark disrupt these micelles, causing the suspended powder to adhere onto the ridge areas, thereby revealing the fingermark. Given that the powder particles interact with the encapsulated nonwater-soluble fingermark components, visualization is still possible even on moist surfaces.

As the latent fingermark dries, the distance between the encapsulated sweat residue and suspended powder particles decreases, enhancing micelle disruption and facilitating particle deposition. Consequently, under identical environmental conditions, aged fingermarks often exhibit better visualization than freshly deposited prints.

The United Kingdom's forensic science agencies have promoted the WPS method for several years. Although the technique has been introduced into Taiwan, practical applications remain limited. According to the 2014 Fingermark Visualization Manual [2], WPS is suitable for use on nonporous and semiporous surfaces, particularly for visualizing latent, bloody, or greasy fingermarks. It is effective on moist and slightly heated surfaces. The technique works by enabling powder particles to adhere to the lipid components within the fingermark residues, yielding superior results for aged prints. Previous studies have highlighted the challenges of fingermark collection in extreme environments, such as fire scenes [5-10] and cases where perpetrators have attempted to destroy evidence by submerging items in water [11-12]. For a long time, the training of fire scene investigators and forensic personnel has varied domestically and internationally, limiting cross-disciplinary collaboration and making fingermark collection in extreme situations challenging, thus leading to a scarcity of such efforts.

First, a fundamental shift in thinking is needed. In 2006, British fingerprint and crime-scene expert Deans Jack [5] simulated a fire scene by imprinting latent, grease, and blood fingermarks onto seven types of evidence (guns, lighters, plastic bags, matchboxes, candles, plastic bottles, and petrol bombs). He conducted a "realistic" fire test and found that nearly one-fifth of the items clearly retained detailed fingermark lines. Subsequent literature has mentioned the impact of extreme environments, such as the high temperatures [6, 7] of a fire or soot residues. When collecting evidence, soot-removal techniques [8-10] must be used according to the soot thickness. Thick soot must be removed first before using appropriate development techniques to reveal the fingermarks. In the scenario of evidence being submerged in water, the type of immersion—freshwater, seawater, or sewage—and its duration are all crucial factors. Sea water has a greater impact than fresh water and the longer the immersion time, the greater the impact [11, 12]. Therefore, evidence should be processed with appropriate development techniques as quickly as possible. In other words, destructive crime scenes, including those involving sewage, fires, or explosions, require forensic assistance to reveal latent fingermarks [13].

The present study explores the usage of WPS on substrates in a fire scene or have been exposed to water immersion. Thanks to its surfactant content, WPS can directly reveal fingermarks without the need to remove the soot, making it convenient for onsite personnel and fire investigators to use. We aimed to address the conceptual bottleneck of fingermark development under destructive conditions in current practice, enhance onsite fingermark visualization capabilities, provide stronger scientific evidence to forensic, fire, and investigative units, and improve evidence completeness in court to increase the likelihood of criminal conviction.

Materials and Methods

Substrates

Altogether, 11 non-porous substrates commonly found at crime scenes were used as substrates, denoted as Materials 1–11 in Table 1.

Table 1. The substrates used in the present study

No.	Substrate	Brand	Surface characteristics
1	Garbage bag (HDPE)	Nai Mi Jia Zu	Pink, slightly rough plastic bags
2	Zip-lock bag (PE)	ZIPPER	Transparent, resealable polyethylene plastic bags
3	Tile	Johnson Tiles	White, glossy ceramic tiles
4	Glass slide	FEA	Transparent, smooth
5	Rubber boot	Bai Zhen Jiang	Black, slightly reflective water proof boot
6	Plastic container (PP)	Mi Lin	Blue, smooth surface
7	Aluminum foil	Diamond	Silver, shiny metallic surface
8	Stainless-steel box	Hua Chang	Silver, with metallic luster
9	PVC glove	3Q	Matte, smooth and elastic PVC gloves
10	Nitrile glove	Medicom	Blue, slightly rough nitrile gloves
11	Latex glove	Wu Chou	Ivory, powder free latex glove

Latent fingermark deposition

A total of four different fingermark compositions were deposited on the 11 substrates in this study, which were as follows: natural groomed (sebum-rich) fingermarks; latent print standard pad (purchased from *SIRCHIE*®, Youngsville NC); sebaceous oil latent print reference pad (*Lightning Powder*® purchased from Safariland, Jacksonville FL); and amino acid latent print reference pad (*I.D. Technologies* purchased from Safariland, Jacksonville FL). Three of the fingermarks were prepared using different chemical pads, whereas one was a natural groomed (sebum-rich) fingermark for deposition on the substrates.

The four fingermark compositions were labeled as *N*, *S*, *O*, and *A*, respectively. All natural groomed (sebum-rich) fingermarks were collected from the same donor, who washed his hands before deposition and rubbed his finger against his facial or body skin to reapply natural oils before pressing the finger onto the substrate. The samples were air dried for 1 hour to ensure complete adherence of the residue.

Artificial fingermarks were created by using home-made rubber stamps purchased from a stamp manufacturer. The stamps were produced on a 1:1 scale from images obtained from scanned inked prints (refer to representative outcomes in Figure 1). To deposit the artificial fingermarks, the stamps were pressed against the pad for a few seconds to ensure full coverage of whole surface with the solution. The stamps were then pressed against each of the 11 substrates selected for this study.

Fig. 1 Representative images of the four fingermark compositions deposited on substrates. (N) Natural fingermark from a live donor; (S) Standard, (O) Sebaceous, and (A) Amino acid fingermarks deposited using rubber stamps derived from scanned inked prints.

Visualization performance under simulated environmental conditions

For the substrates identified as yielding the best visualization in the initial tests, three serially depleted natural fingermarks were deposited at fixed intervals on each sample. All prints were provided by the same donor, following the same preparation process described above.

Fingermark development techniques

The following three commercially available reagents containing different powder compositions, which were all purchased from BVDA International, were used: Wet Powder™ (black/white) from Kjell Carlsson Innovation for latent print development, containing carbon or titanium dioxide as the powder component; and Silver/Gray, containing iron oxide as the powder component.

Experimental design

Two experiments were conducted. The first experiment evaluates ridge clarity and identified minutiae for visualization performance across different fingermark compositions. The second experiment compared the visualization performance under simulated destructive environments of two best-performing substrates from Experiment I.

- Experiment I: Visualization of different fingermark compositions on various substrates
  Experiment I was conducted under controlled laboratory conditions, this experiment evaluates ridge clarity and identified minutiae for visualization performance across multiple fingermark compositions and substrates under a standardized fingermark deposition process and development reagent application parameters.
- Experiment II: Evaluation of the visualization performance under simulated destructive environments
  Utilizing the best-performing substrates from Experiment I, Experiment II tests the effect of environmental degradation (e.g., water immersion, smoke, and soot exposure) on the visualization performance of the prints.

Assessment of developed fingermarks

Visualization was first performed using Wet Powder™ reagents (black for light surfaces, white for dark surfaces). The reagent was applied over the latent fingerprints using a soft brush and is allowed to react for approximately 15 mins as the results of an preliminary test shows that this duration tend to yield the best visualization performance. The substrate was then gently rinsed with running water, and then allowed to dry under natural conditions.

To objectively assess the fingermark visibility, the following two parameters were used: ridge completeness and background contrast (grayscale differential value). In both scales, the scores can range from 0 to 4. The two scales were added to yield an overall score of 8. The scoring criteria and experimental flow chart used in this research are shown in Table 2. Both standards were evaluated by using *ImageJ* (from National Institutes of Health and The Laboratory for Optical and Computational Instrumentation, based on Java 1.8.0_345) and following the scoring standard proposed by Francesca Lucy Stubbs-Hayes [14]. Images were imported into *ImageJ* and converted to 8-bit grayscale, and the threshold values were adjusted to distinguish the ridges (dark regions) from the background (light regions). Figure 2 illustrates the grayscale contrast analysis; where green and blue represent the light and dark ridge regions respectively. The difference in mean gray values yielded the contrast score.

While the CAST (Centre for Applied Science and Technology) grading scheme is widely used for assessing identification value, this study adopted the quantitative method proposed by Stubbs-Hayes [14] combined with ImageJ analysis. This approach was selected to objectively measure the physicochemical adhesion efficiency and contrast variations of the reagents under destructive conditions, minimizing subjective observer bias.

Table 2. Workflow and scoring criteria for fingermark clarity evaluation

Step	Scoring	Level of detail	Example
1. Completeness	0	No development.	Example image completeness score = 3. 
	1	Limited signs of development.	
	2	Development of the outer edge, no development to the inner fingermark.	
	3	Development of the outer edge, some development of the inner fingermark.	
	4	Complete development of both, the outer edge and the inner fingermark.	
2. Contrast (ImageJ difference Value)	0	No development. (0–10)	By ImageJ, example grayscale difference = 39 → Contrast score = 3
	1	Very poor contrast between the background and developed fingermark.(10–19)	
	2	Poor contrast between the background and developed fingermark. (20–34)	
	3	Good contrast between the background and developed fingermark. (35–59)	
	4	Very good contrast between the background and developed fingermark. (≥59)	
3. Sum of completeness and contrast scores, get the score of clarity.			3 + 3 = 6

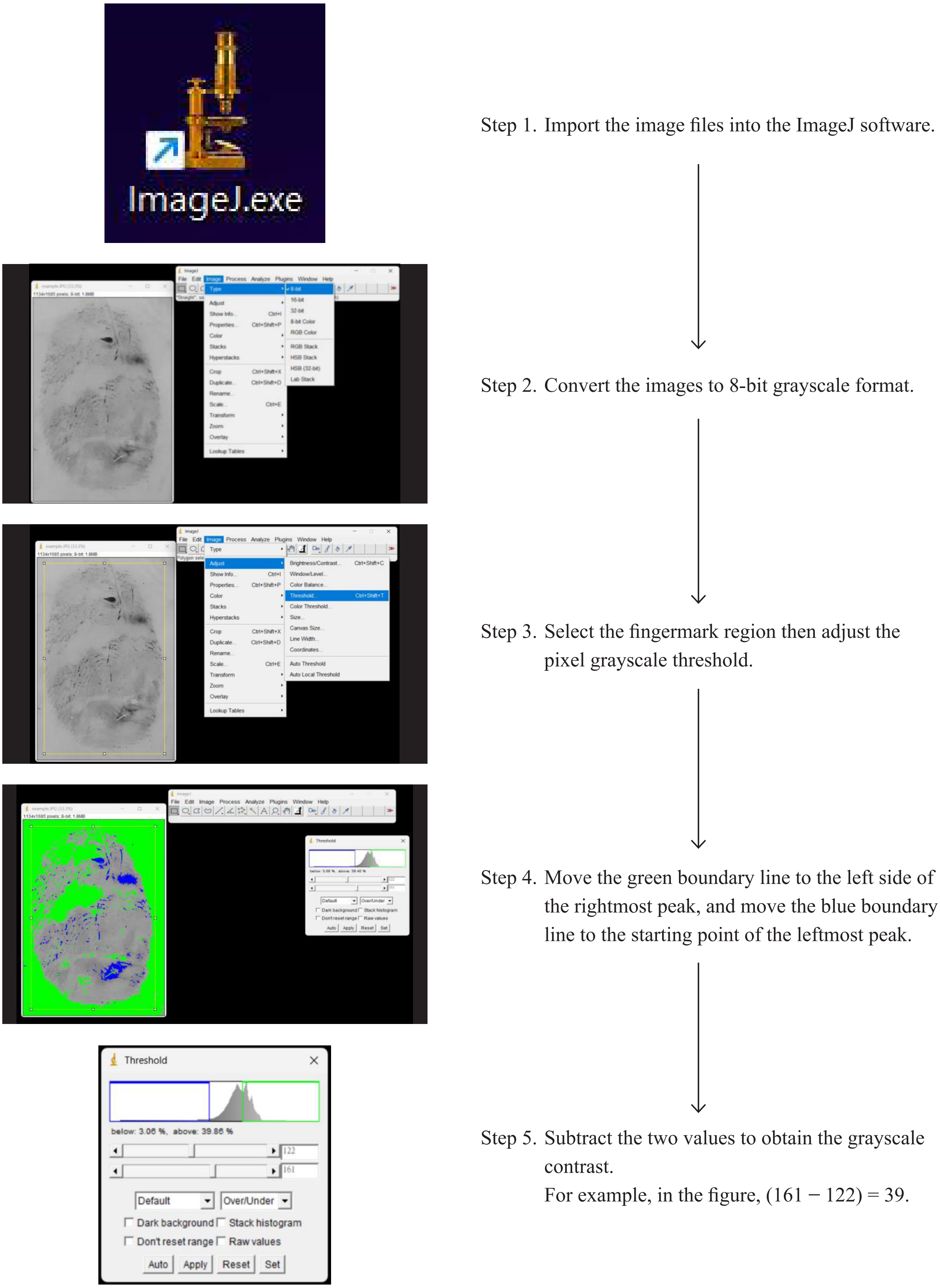


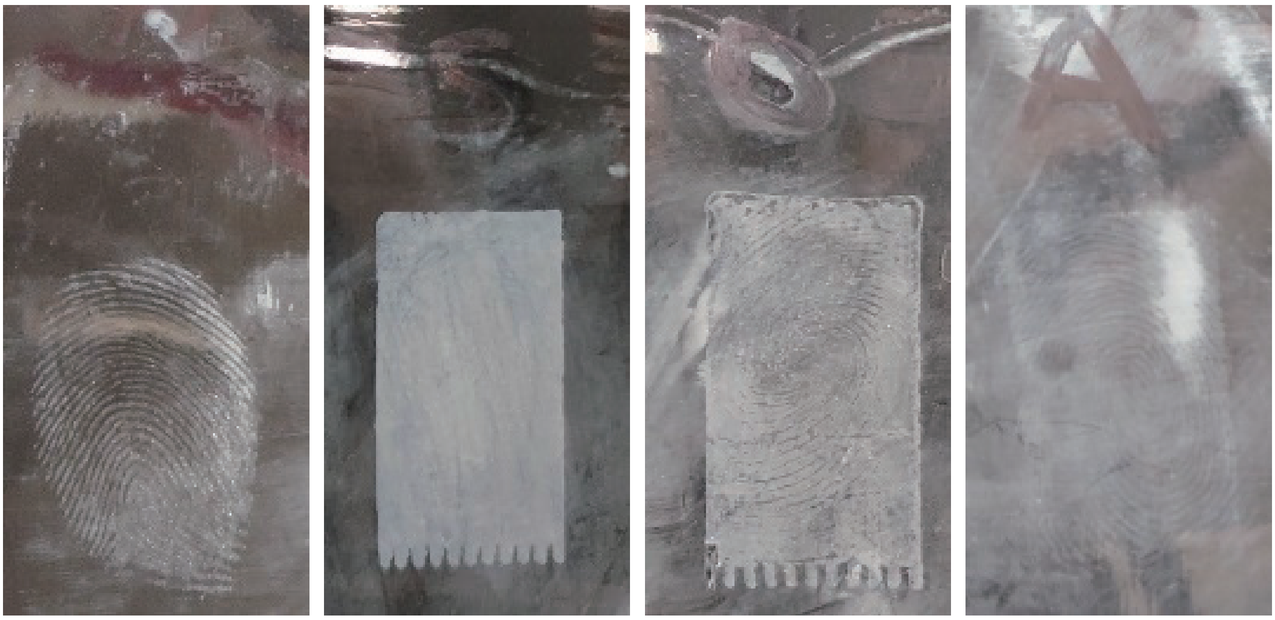
Fig 2. Example of an ImageJ grayscale contrast analysis.

Results and Discussion

Experiment I: Visualization of fingermarks with different compositions on various substrates

Visualization was first performed using Wet Powder™ reagents (black for light surfaces, white for dark surfaces). The same procedure was repeated for the Silver/Gray reagent on a separate but identical set of fingermark samples. The resulting images were assessed for completeness and contrast through visual inspection and ImageJ grayscale analysis. The total clarity score was obtained by summing the two parameters.

Figure 3 shows the fingermark visualization outcomes of Wet Powder™ (white) on Material 5 (rubber boot). The visualization results using Wet Powder™ (black/white) are shown in Figure 4, whereas those obtained using Silver/Gray are shown in Figure 5.



Natural (N) Standard (S) Sebaceous (O) Amino acid (A)

Fig 3. Visualization performance of Wet Powder™ (white) on Material 5 (rubber boot) across four fingermark compositions

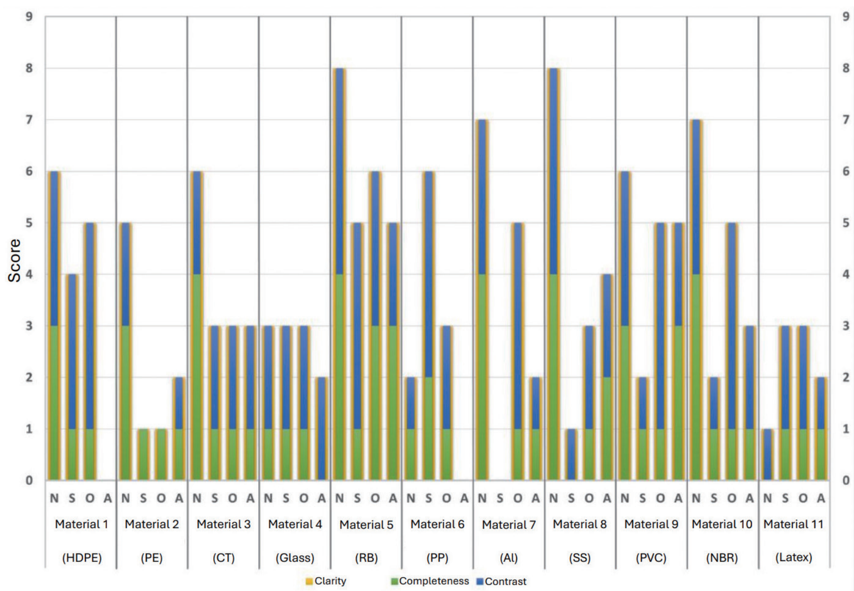


Fig 4. Visualization results of Wet Powder™ (black/white) on 11 various substrates

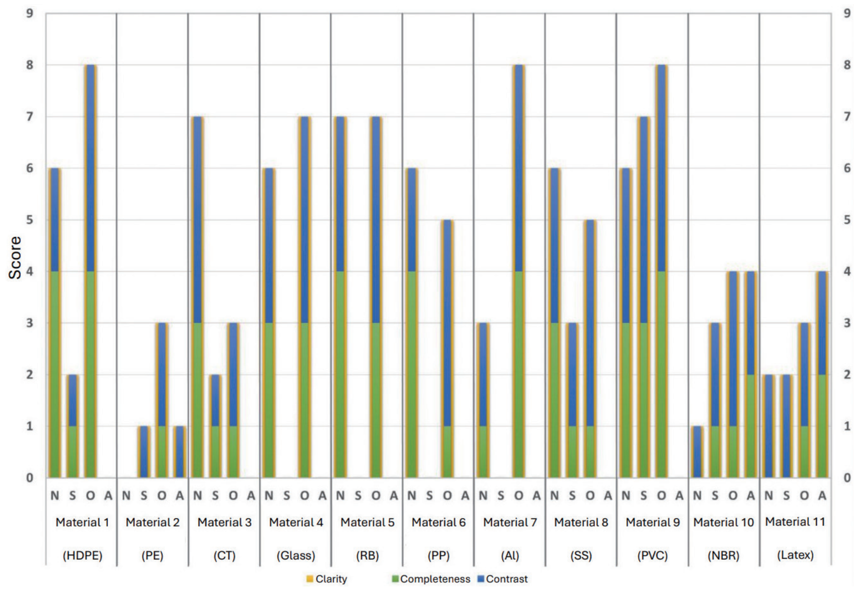


Fig 5. Visualization results of Silver/Gray on 11 various substrates

The Wet Powder™ (black/white) reagents exhibited superior visualization performance compared to Silver/Gray, possibly due to their higher visual contrast or greater powder deposition efficiency. The Silver/Gray reagent, conversely, demonstrated greater sensitivity toward purely sebaceous fingermarks.

Among the fingermark compositions, natural fingermarks consistently yielded more stable and distinct results, suggesting that, beyond lipid residues, additional natural components within real fingermarks contribute to effective WPS deposition. The standard formulation fingermarks showed less satisfactory visualization, warranting further investigation.

Surface characteristics such as scratches, wrinkles or microtexture, will considerably influence the WPS powder adherence and eventually affects the visualization integrity. On metallic substrates, inherent metallographic patterns sometimes interfered with ridge interpretation. Smooth surfaces tended to yield poorer adhesion of artificial fingermark inks, whereas natural fingermarks were less affected by this factor.

Experiment II: Visualization performance under simulated environmental conditions

Selection of substrates

From Experiment I, the following five substrates with total clarity scores of ≥6 when visualized with natural fingermarks using both Wet Powder™ (black/white) and Silver/Gray reagents were selected for the environmental simulation study: (A)garbage bags (HDPE); (B) ceramic tiles; (C) rubber boots; (D) stainless-steel (SS) boxes; and (E) PVC gloves.

Simulated arson environments

Before the fingermarks were deposited, the surfaces were cleaned using a detergent and then air dried. Latent fingermarks were placed on garbage bags (HDPE), ceramic tiles, rubber boots, SS boxes, and PVC gloves. Two destructive environmental conditions were simulated to assess visualization robustness, which were show in Figure 6.

- Water immersion
  Fingermark samples were immersed in tap water for 24 hours before visualization.
- Smoke and soot exposures
  Samples deposited with fingermarks were placed in a SS container covered with a glass plate. Several wads of tissue paper and incense sticks were ignited inside. Initially, a small opening was left opened to allow for partial combustion. Shortly after, the glass was sealed off completely to allow smoke and light soot deposition on the substrates. After 1 hour, the samples were processed for visualization. In our arson/fire scene simulation, soot removal was not needed.

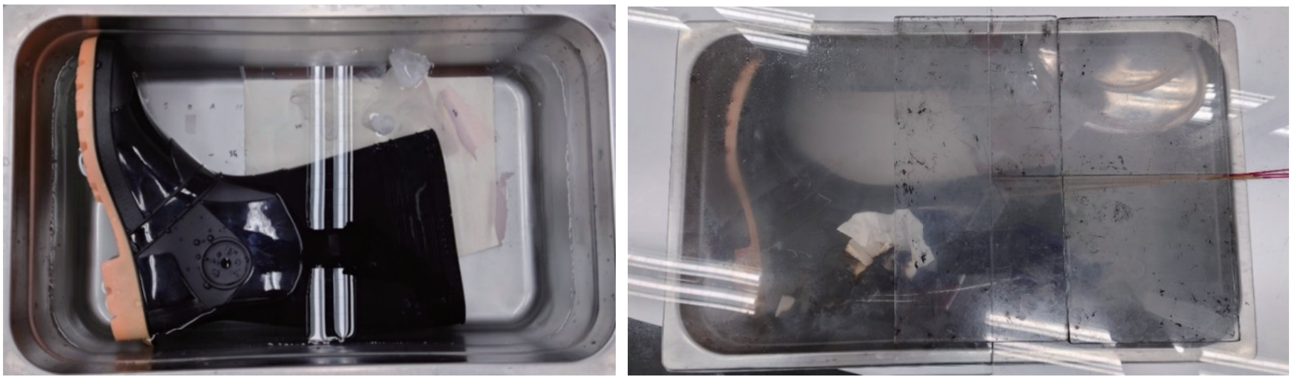


Fig 6. The simulated arson environmental conditions utilized in the present study, including water immersion (left side), and smoke/soot exposure (right side).

Development procedure

Each fingermark deposited on the substrates were divided into two halves. If the substrate could be physically cut, it was divided along the central fingermark ridge axis. For materials difficult to cut, the central ridge was marked and separated using a fine string, creating two zones for different reagent applications. The cutting and separation method is shown in Figure 7.

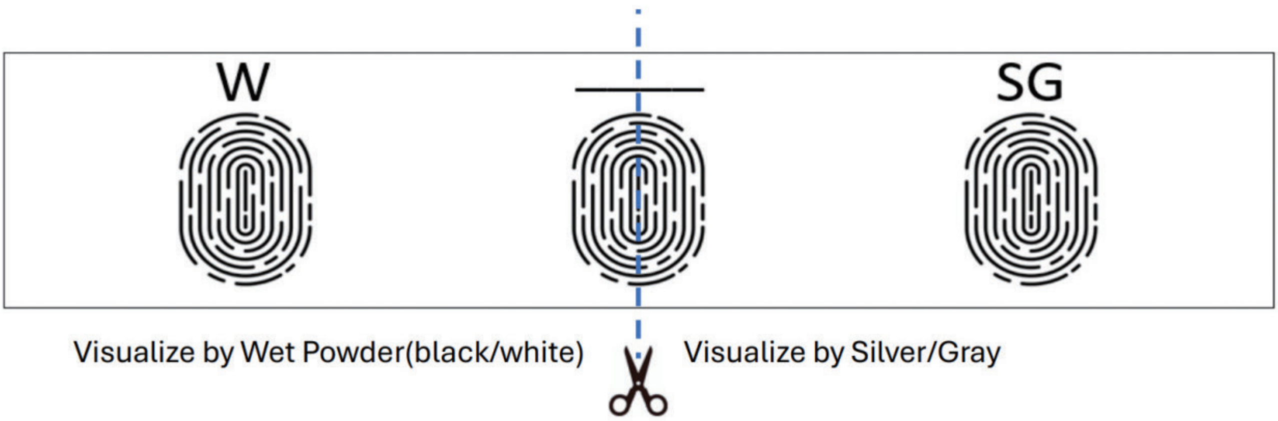


Fig 7. Method for dividing the fingermark samples in Experiment II for simultaneous reagent comparison

Both Wet Powder™ (black/white) and Silver/Gray reagents were applied to the respective halves by brushing to cover the fingermark area, followed by a 30-minute reaction time, as determined from the preliminary tests. The substrates were then gently rinsed with running water, photographed, and analyzed using both visual scoring and ImageJ contrast quantification. The total clarity score was obtained by summing the completeness and contrast scores.

Table 3 shows the visualization outcomes of the latent fingermarks deposited on the surface of a SS box (Material D) after smoke and heat exposures and subsequently treated with different reagents. The visualization results of the water-immersed samples are shown in Figure 8, whereas those of the samples exposed to smoke and heat are shown in Figure 9.

Table 3. Visualization results of fingermarks deposited on stainless-steel surface (Material D) following smoke and heat exposure

Reagent	Wet Powder™	Wet Powder™/ Silver/Gray	Silver/Gray
Visualization Result			

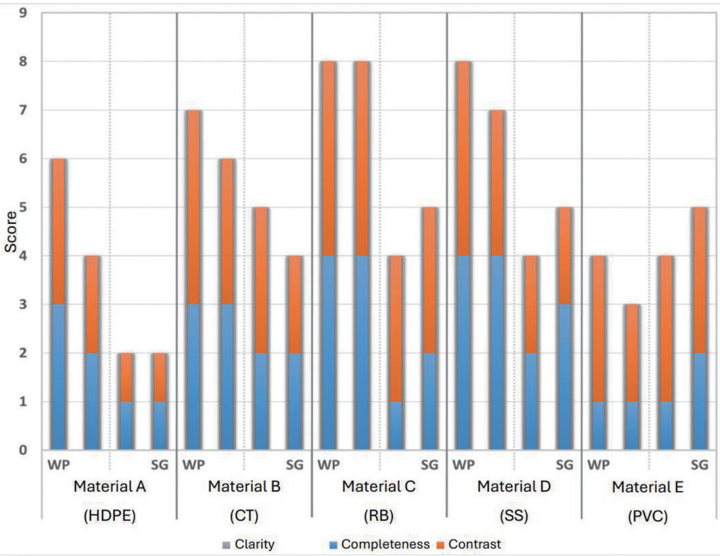


Fig 8. Results of five materials obtained after water immersion using each WP/SG reagent.

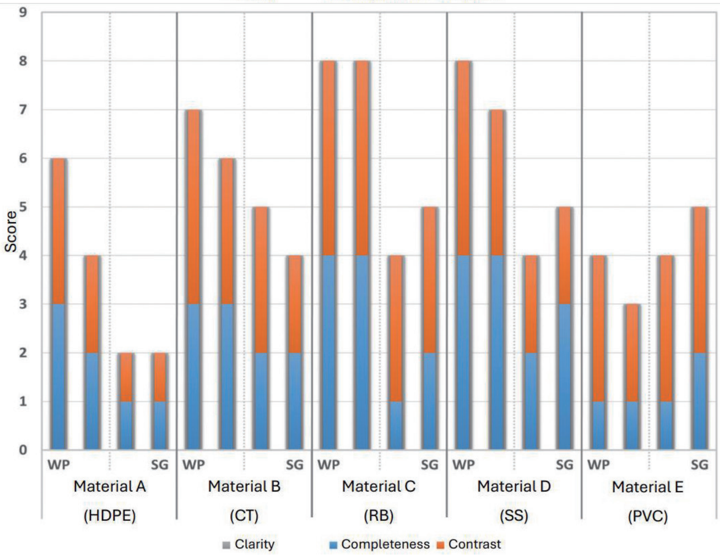


Fig 9. Results of five materials obtained after smoke and heat exposure using each WP/SG reagent.

Environmental factors predominantly influence the performance of the WPS through their effects on fingermark completeness. Although all tested substrates were non-porous, variations in surface smoothness, macrotextures, and absorption potential led to varying visualization outcomes under destructive conditions. After water immersion, smoother surfaces with lower adhesion capability, including HDPE, ceramic tiles and PVC, tended to exhibit partial ridge loss, reducing fingermark completeness. Conversely, rougher surfaces, including rubber boots and stainless-steel, tend to retain ridge details better, resulting in higher clarity scores.

After smoke and heat exposures, substrates susceptible to deformation or damage under high temperatures exhibited severe ridge distortion. For example, HDPE and PVC deformed or burned, whereas heat-resistant materials, including metals, ceramic tiles, and coated rubber boots, remained complete and maintained better fingermark completeness. Smoke deposition also affected contrast—sometimes enhancing it by darkening the ridge regions or reducing it when large soot particles adhered unevenly, such as when a developed fingermark became more visible/clear on light-colored ceramic tiles.

The reagent type also influences the visualization results. In our study, Wet Powder™ (black/white) consistently produced superior visualization performance over Silver/Gray reagents, likely due to their higher inherent contrast from darker carbon-based pigments or their more efficient powder deposition. Alternatively, Silver/Gray reagents may require a longer deposition time or higher concentration for optimal results, which is an issue warranting further investigation.

Conclusions

Visualization performance of WPS reagents varies considerably depending on the substrate characteristics. Softer substrates, including HDPE garbage bags and gloves, tend to have wrinkles or indentations that cause powder accumulation, whereas metallic surfaces, including aluminum foils, may exhibit a reduced contrast due to their color similarity with the powder. Factors including surface smoothness, microstructure, and unique textural patterns on metallic surfaces, as well as environmental damage, such as scratches or creases, may influence the powder deposition degree and distribution during identical visualization durations, ultimately affecting fingermark completeness, contrast, and overall clarity. Among different fingermark residue compositions, natural fingermarks generally yielded better results compared to synthetic or single-component prints, suggesting that WPS powder adhesion is facilitated not only by lipid components but also by additional naturally occurring constituents, which may promote stronger interaction with the reagent and substrate.

Environmental conditions further impact the visualization outcomes primarily through modifications of the physical properties of the surface. Latent fingermarks on rougher surfaces, including rubber boots and SS boxes, were less affected by water immersion, whereas HDPE and PVC were prone to deformation under high temperatures. After water immersion, rougher substrates demonstrated clearer ridge visualization compared to smoother ones. Following smoke and heat exposures, substrates resistant to deformation or heat damage retained higher clarity, whereas smoke particle deposition could either improve or obscure contrast, depending on soot density and particle size. Reagent composition also played a decisive role. Between the two commercial products evaluated—Wet Powder™ (black/white) (carbon/titanium dioxide-based) and Silver/Gray (iron oxide–based)—the darker carbon-based reagent possessed an inherent contrast advantage and achieved better visualization under identical conditions.

Overall, these findings underscore the influence of substrate, residue composition, environmental factors, and reagent formulation on the fingermark visualization effectiveness of WPS. The results provide practical insights for optimizing fingermark recovery in destructive environments, contributing to improved success rates and reliability in forensic applications.

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