Article

The Recoverability of Fingerprints on Nonporous Surfaces Exposed to Elevated Temperatures

Ainsley J. Dominick [1]
Niamh Nic Daéid [1]
Stephen M. Bleay [2]

Abstract: Previous work by the authors compared the effectiveness of ninhydrin, 1,8-diazafluoren-9-one (DFO), and physical developer (PD) as enhancement reagents for fingerprints deposited on paper that had been exposed to elevated temperatures. This research extends the previous study and investigates the recoverability of fingerprints deposited onto glass and ceramic surfaces in order to mimic the environment these surfaces may be exposed to within a fire scene.

This research has shown that ridge detail is still retrievable from ceramic after exposure to 800 °C (1472 °F) for 20 minutes, although, at temperatures in excess of 350 °C (662 °F), ridge detail would only survive if the fingerprints had been protected from direct exposure to radiant heat and direct air flow across the surface. This investigation has shown that the most effective enhancement technique overall was found to be superglue followed by BY40 at all temperatures except 200 °C (392 °F) in which case, iron powder suspension was superior. However, superglue followed by BY40 may have to be excluded as a prospective enhancement technique for many situations because the nonporous surface may become wet during firefighting activity. The use of silver vacuum metal deposition has been demonstrated to develop fingerprints after exposure to higher temperatures and may have future potential for this application.

1 Centre for Forensic Science, University of Strathclyde, Glasgow, U.K.
2 Centre for Applied Science and Technology, Home Office Science, Sandridge, U.K.

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Introduction

At a cost to the economy of £53.8 million in England and Wales, the 2213 arson attacks that occur on average each week in the United Kingdom cause 2 fatalities and 53 injuries and damage or destroy 20 schools and colleges, 262 homes, 360 businesses and public buildings, and 1402 vehicles [1]. Once the origin and cause of a fire have been declared as arson, the next aim is to identify the arsonist. Fire is destructive in nature and will damage and obscure many types of evidence. However, many items, including fingerprints, may still survive [2–4]. If fingerprints have been deposited at the scene, this is one potential source of identification. However, their survivability and recovery from fire scenes have not been fully investigated. Although some studies have been carried out into fingerprint recovery from fire-affected articles since the late 1930s, few of these have used large numbers of fingerprints. The work of Deans [3] demonstrated that fingerprints could be repeatedly obtained from a wide variety of articles retrieved from fire scenes, and Bradshaw et al. [5] investigated the number of latent fingerprints that could survive high temperature exposure. However, none of the previous studies have used sufficient numbers of fingerprints to enable a full statistical analysis of the results to be comprehensively carried out. This study was undertaken to establish whether various ages of fingerprints deposited on glass and ceramic and exposed to various temperatures for different exposure times could survive, and, if so, to determine the most effective technique for their enhancement.

Previous work into the recoverability of fingerprints on ceramic tiles had considered a minimum exposure time of one hour [5]. However, many fires are extinguished before this period. For example, London Fire Brigade sets attendance time targets: the first fire appliance must reach the fire 65% of the time within five minutes and 90% within eight minutes [6]. Other fire services will have similar standards. Therefore, a more comprehensive study was required to investigate the survivability of fingerprints on nonporous surfaces exposed to elevated temperatures and to include exposure times of less than one hour. In addition, fingerprints of primary interest are likely to be one hour old or less, rather than the one-day minimum age used previously, and, therefore, this shorter time period between deposition and exposure was investigated.

Materials and Methods

Glass was supplied by Stevenage Glass (Stevenage, Hertfordshire) and cut to A4 size. It was cleaned using Fairy washing-up liquid (Proctor and Gamble, Brooklands, Weybridge, U.K.), air-dried, washed with ethanol (Hayman Limited, Witham, Essex, U.K.), and then air-dried once again. It was only handled while wearing gloves. A depletion grid was drawn on the glass surface as shown in Figure 1.

Fingerprint depletion samples (ten consecutive samples in each depletion series) were donated by five people from a mix of male and female donors over a wide age range to represent a cross-section of people. Only donors who had not washed their hands 30 minutes prior to deposition were allowed to deposit and, before donation, they rubbed their hands together to evenly distribute the sweat across all digits used for deposition. Each donor donated 840 depletion series in total – one for each variable tested in the study on both glass and ceramic.

These fingerprints were aged in the ambient environment for various times before being subjected to different temperatures for different exposure times. They were then enhanced by different methods (Table 1).

White ceramic tiles (20 cm x 25 cm) were purchased from Wickes (St. Albans, Hertfordshire, U.K.). They were washed, and depletion grids were drawn on them as previously described. The various ages of fingerprints on ceramic were also exposed to various temperatures for different exposure times. These experimental parameters are given in Table 2.

Two enhancement techniques for nonporous surfaces were employed: (1) iron powder suspension and (2) superglue followed by BY40. Superglue followed by BY40 was exercised in accordance with the Home Office's Manual of Fingerprint Development Techniques (MoFDT) [7]. Iron oxide-based powder suspension was formulated from 20 g of magnetic iron oxide (Fisher Scientific, Loughborough, Leicestershire, U.K.) suspended in a detergent solution consisting of 10 mL of Kodak Photo-Flo Wetting Agent (Kodak, Paris, France) and 10 mL of distilled water [8]. The iron powder suspension was applied to the glass and ceramic using a small brush. After the surface was coated, it was washed off using tap water before the iron powder suspension could dry on the surface. The treated glass and ceramic surfaces were left to dry overnight prior to examination.

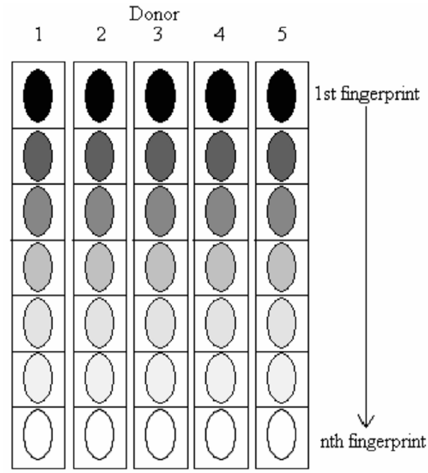

Figure 1

Example of a depletion grid.

Substrate	Aging Time	Temperature (°C)	Exposure Time (min)	Treatment
Glass	1 hour, 1 day, 1 week, 1 month	50	10, 20, 40, 80, 160, 320	1. Powder Suspension 2. Superglue - BY40
		100		
		150		
		200		
		250		
		300		
		350		
		400		
		450		
		500		

Table 1

Summary of exposure to heat experiments on glass.

Substrate	Aging Time	Temperature (°C)	Exposure Time (min)	Treatment
Ceramic	1 hour, 1 day, 1 week, 1 month	500	10, 20, 40, 80, 160, 320	1. Powder Suspension 2. Superglue - BY40
		550		
		600		
		650		
		700		
		750		
		800		

Table 2

Summary of exposure to heat experiments on ceramic.

A brief study into the effectiveness of vacuum metal deposition (VMD) was also undertaken at the higher temperatures. Bleay et al. [4] stated that vacuum metal deposition (VMD) was extremely effective for temperatures up to 900 °C. However, soot deposits and areas where water had dried would show up during treatment, making it difficult to resolve marks in practical situations. VMD is an expensive enhancement technique and not all laboratories have access to it. Therefore, the effectiveness of VMD was only briefly investigated in this work. These experimental parameters are given in Table 3.

Substrate	Aging Time	Temperature (°C)	Exposure Time (min)	Treatment
Ceramic	1 hour, 1 day	700	10, 20	1. Powder Suspension 2. Superglue - BY40 3. VMD
		750		
		800		

Table 3

Summary of exposure to heat experiments on ceramic (brief VMD study).

Vacuum metal deposition was carried out using a West Technology Systems Ltd metal deposition machine (WTSL, Yate, Gloucestershire, U.K.). The tiles were attached to the workholder using tape at the corners to minimize the amount of contact on the surface. The chamber was pumped down to a vacuum of 2×10^{-4} torr. Gold (Goodfellow, Cambridge, U.K.) and then zinc (Sigma-Aldrich, Gillingham, Dorset, U.K.) were evaporated before bringing the chamber back to atmospheric pressure for removal of the tile [7]. A limited VMD trial on a single tile was conducted using silver (Goodfellow, Cambridge, U.K.) as a single metal, according to the method of Philipson and Bleay [9].

Results and Discussion

Iron oxide-based powder suspension and superglue followed by BY40 were selected based on previous work, where they had both outperformed other techniques (with iron oxide-based powder suspension being the superior technique at exposure temperatures up to 200 °C and superglue followed by BY40 effective at temperatures from 200 °C to 500 °C) [4–5]. In practical terms, an advantage of using iron oxide-based powder suspension is that the detergent within the formulation can assist the soot removal on fire-exposed articles. The limitations with selecting superglue followed by BY40 as an enhancement technique for items exposed to fire is that the method of extinguishing the fire can exclude the use of superglue, because this technique cannot be used on items that have been wet [4].

It is important to note here that fingerprints that were exposed to direct heat and air flow over the glass and ceramic surfaces from within the furnace did not survive at temperatures of 350 °C and over. Once they were protected from these conditions, fingerprints did survive. Therefore, the results obtained from exposure to 350 °C and upwards are from fingerprints that were shielded from the direct heat and air flow in the furnace.

Also, when the study was being undertaken, it was clear that the fingerprints were still being enhanced at the maximum exposure time for glass of 500 °C for 320 min. Because it would become extremely difficult to expose the glass to temperatures exceeding 500 °C and still be able to remove the glass from the furnace unbroken, the surface was changed to ceramic. Results obtained at 500 °C for both glass and ceramic were analyzed statistically and demonstrated to have no significant difference. Therefore, when comparing the techniques, the results achieved for glass and ceramic have been combined and subsequently analyzed together.

Some of the fingerprint deposits appeared to "burn" as the temperature increased, leaving a visible black deposit with ridge detail on the ceramic at 500 °C prior to any fingerprint enhancement technique. An example of this is shown in Figure 2.

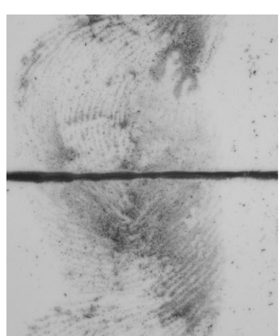

Figure 2

Example of "burnt" fingerprint on ceramic after exposure to 500 °C for 20 minutes.

Iron Oxide-based Powder Suspension

Powder suspension has many forms. There are the commercial products Wetwop (Armor Forensics, Jacksonville, Florida) and Wet Powder (Evident, Union Hall, Virginia), which are both carbon-based products, and Adhesive-Side Powder (Sirchie, Youngsville, North Carolina), which is iron oxide-based. The Centre for Applied Science and Technology (CAST) has also formulated its own powder suspension that is iron based [8], and the CAST recommends iron oxide-based formulations for nonporous surfaces [10].

In order to assess the quality of the enhancement technique, each fingerprint had to be assessed. The assessment method employed estimated the proportion of the developed fingerprint's clear ridge detail, with a score assigned to each fingerprint of 0 to 4. This was a much quicker and simpler method for a nonexpert to use rather than counting minutiae. Fingerprints were all graded as follows in Table 4:

Score	Level of Detail
0	No evidence of print
1	0–1/3 ridge detail
2	1/3–2/3 ridge detail
3	2/3–1 ridge detail
4	Ridge detail over every point of contact visible

Table 4

Fingerprint scoring system.

Finally, a resultant score was calculated by taking an average score for each finger's depletion series.

The fingerprint scores obtained were inputted into the Minitab 15 software package for statistical analysis. A Kolmogorov-Smirnov test for normality was undertaken to assess the distribution of the data for each enhancement technique. This resulted in P values of <0.010 for both techniques. This P value is compared to the α value of 0.05, with $P < 0.05$ indicating the variable has a significant effect on the response, or $P > 0.05$ indicating no significant effect on the response [11]. In this case, it showed that the data was not normally distributed for either technique. As such, a Kruskal-Wallis nonparametric test was undertaken that tests whether the medians of the data are equal or not. This P value is also compared to the α value of 0.05. A Kruskal-Wallis test was performed on the results obtained for both glass and ceramic at 500 °C to assess whether there was any difference in the fingerprint scores obtained from each substrate. The P value generated in this test was 0.726, indicating that there was no statistical difference in the scores at 500 °C obtained from glass and ceramic. Therefore, the scores obtained from each surface were combined and tested together. Kruskal-Wallis tests for each of the variables in this research (temperature, time, and age) were attained from Minitab. The *P* values from these tests are given in Table 5.

Variable	Kruskal-Wallis P value
Temperature	0.000
Time	0.000
Age	0.684

Table 5

Kruskal-Wallis P values for iron powder suspension-enhanced fingerprints.

The *P* values indicate that two of the variables (temperature and time) are significant to the resulting fingerprint score. Age is not significant to the score. This implies that varying the temperature and the time that fingerprints are exposed to the temperature, no matter what age they are, will significantly change the enhancement score of the fingerprint. A main effects plot shows this visually, by comparing the mean of the scores for each variable. This is shown in Figure 3.

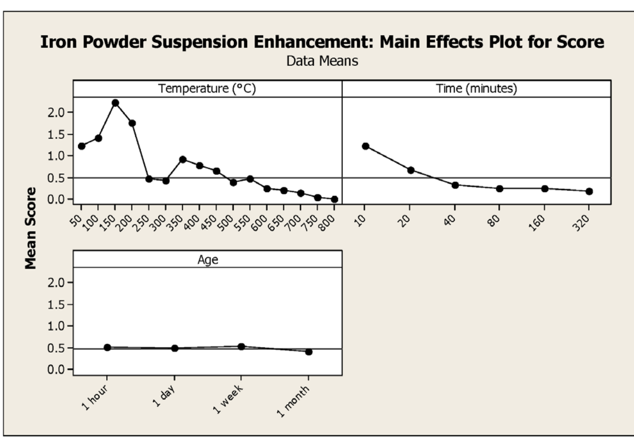

Figure 3

Main effects plot for iron oxide-based powder suspension-enhanced fingerprints.

The main effects plot shows that (generally) as the temperature increases, the mean fingerprint score decreases. There is an increase in score observed at 350 °C and this is explained by the fingerprints being shielded from direct heat and air flow by covering with a metal tray. Also, iron powder suspension appears to enhance more detail in the fingerprints exposed to 150 °C than at lower temperatures. Because the fingerprint component that iron oxide-based powder suspension reacts with is unknown, it is not possible to explain this increase in score. As exposure time increases, the score decreases, too. These plots show that there is a difference in the results between each temperature and each exposure time because the results are divergent from the mean response line of 0.483 on the plot, whereas the scores for age stay close to the mean response line, indicating no difference in the scores with increased age.

Superglue Followed by BY40

Superglue vapor (ethyl cyanoacrylate) reacts with certain eccrine and sebaceous deposits of the latent fingerprint. The vapor selectively polymerizes on the fingerprint to form polycyanoacrylate, which appears as a white deposit [12]. This can be subsequently dyed with fluorescent stains such as basic yellow 40 to increase contrast with the background. Photographs of superglue-enhanced fingerprints are shown in Figure 4.

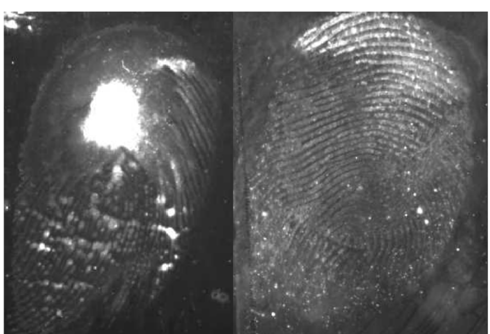

Figure 4

Fingerprints developed using superglue followed by dyeing with BY40 on glass after exposure to 150 °C for 40 minutes.

The superglue enhancement scores were also not normally distributed. A Kruskal-Wallis test was undertaken to check whether the scores obtained at 500 °C for each substrate were statistically the same. This test resulted in a *P* value of 0.375. When compared to the α value, this revealed that there was no significant difference in the scores for each substrate at 500 °C. The scores for glass and ceramic were combined and analyzed together.

Kruskal-Wallis tests for each variable were also undertaken for superglue followed by BY40 enhancement. The results of these tests are given in Table 6.

Variable	Kruskal-Wallis P value
Temperature	0.000
Time	0.000
Age	0.888

Table 6

Kruskal-Wallis P values for superglue followed by BY40-enhanced fingerprints.

The results for enhancement by superglue gave the same outcomes as the results given for iron oxide-based powder suspension. This implies that temperature and time are significant to the fingerprint score, but age does not influence the result. A main effects plot for superglue followed by BY40 enhancement is shown in Figure 5.

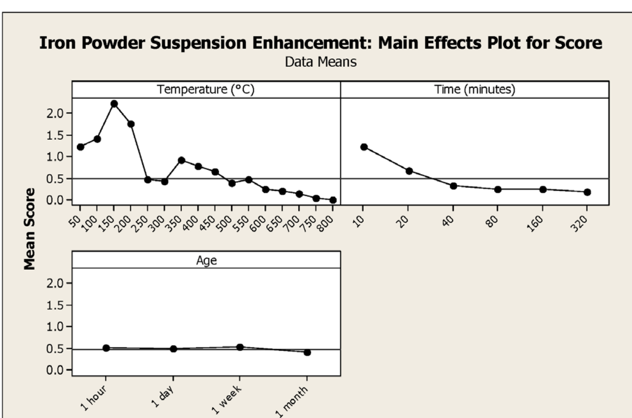

Figure 5

Main effects plot for superglue followed by BY40-enhanced fingerprints.

The main effects plot shows similar trends to the plot for iron oxide-based powder suspension, with scores decreasing with increased exposure time and no difference in the score observed with increased age. When examining temperature, an increase is observed at 100 °C, 50 °C lower than the increase with iron oxide-based powder suspension. There is another increase at 300 °C that does not coincide with the shielding effect. There appears to be a dip in the scores for 400 °C, also. The mean response line is higher at 1.182, showing increased scores with superglue followed by BY40 enhancement than iron oxide-based powder suspension.

Enhancement Technique Comparison

The scores obtained for both fingerprint enhancement techniques were combined for further analysis. To check whether there was a significant difference between the scores for each enhancement technique, a Kruskal-Wallis test was used. This gave a *P* value of 0.000, indicating that there is a difference in the scores for the enhancement techniques. This was evaluated further using a main effects plot, which is given in Figure 6.

The main effects plot clearly shows that the scores for superglue followed by BY40 are higher than the iron oxide-based powder suspension scores. The Kruskal-Wallis test implies that the higher scores for superglue followed by BY40 are significantly higher than iron oxide-based powder suspension.

An interaction plot examines the interaction between the variables tested and is presented in Figure 7.

The interaction plot shows (generally) that as the temperature increased, the effectiveness of both techniques decreased. Superglue followed by BY40 produced better scores at all temperatures (except at 200 °C) than powder suspension. This differs from the work of Bradshaw et al. [5], who undertook a series of tests similar to the ones explored in this work where samples were exposed to regulated temperatures for specific periods of time.

The interaction plot also shows that as the exposure time is increased, the resultant score is lower. Superglue again outperforms iron oxide-based powder suspension. There is very little difference observed in the scores as the age of the fingerprints increases. The interaction between temperature and time shows a general trend that the fingerprint scores decrease with increased exposure to the heat. Scores are greater for samples exposed to lower temperatures. This is mirrored in the interaction between

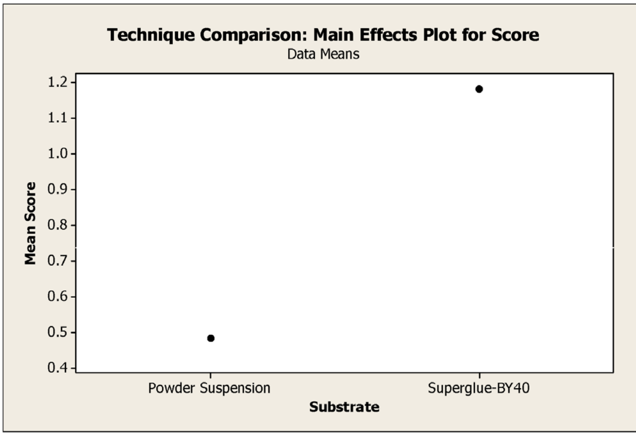

Figure 6

Main effects plot comparing enhancement technique scores.

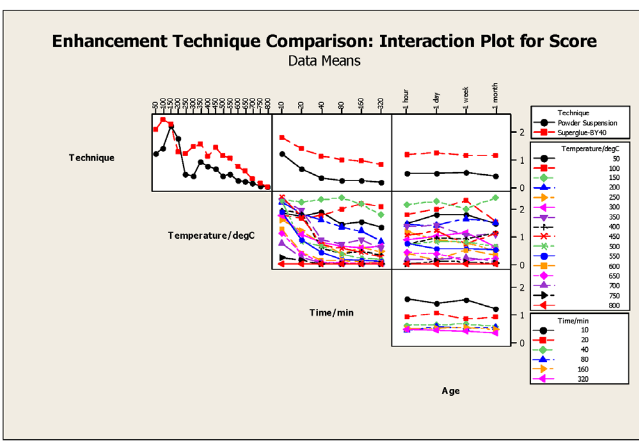

Figure 7

Interaction plot for fingerprints deposited on glass and ceramic.

temperature and age. In the interaction between time and age, scores are greater for fingerprints exposed for shorter periods of time.

From the results of the Kruskal-Wallis test and the main effects and interaction plots, superglue followed by BY40 is the superior technique in terms of laboratory controlled experiments. The practicality of selecting this technique is unknown because superglue can only be used on dry surfaces, and the firefighting activity involved in suppressing a fire could inadvertently wet the surface. This could exclude the possible selection of the superglue followed by BY40 technique. However, Bradshaw et al. [5] also placed samples directly into fire environments and found that iron oxide-based powder suspension was more effective than superglue on ceramic tiles because it enhanced fingerprints placed on the surface that had been placed "face up" into the fire environment and exposed to temperatures briefly between 600 °C and 900 °C. Superglue followed by BY40 did not enhance any "face up" fingerprints. In their study, glass was not tested. Deans [3] also placed numerous items within fire compartments. His results, specifically for glass, were unsuccessful. Either the glass yielded no fingerprint ridge detail or the fingerprints were unrecoverable after the fire exposure. The method of fingerprint enhancement employed on the recovered glass was not discussed in the paper. Ceramic was not used in any of his tests.

VMD Study

VMD was only briefly examined in order to investigate its effectiveness at 10-minute and 20-minute exposure times, at 700 °C, 750 °C, and 800 °C, and after 1 hour and 1 day of aging, in comparison with iron oxide-based powder suspension and superglue followed by BY40. The Kolmogorov-Smirnov normality test was undertaken for this new data set and showed that the data was not normally distributed. A Kruskal-Wallis test was undertaken also to assess the differences in scores for each of the enhancement techniques. This provided a P value of 0.071, indicating no significant difference in the scores obtained from the different enhancement techniques. The main effects plot is given in Figure 8.

The main effects plot shows that even though there is not a significant difference in the scores (according to the Kruskal-Wallis test interpretation), superglue followed by BY40 scores are higher than the other two scores, with VMD third. The interaction plot is given in Figure 9.

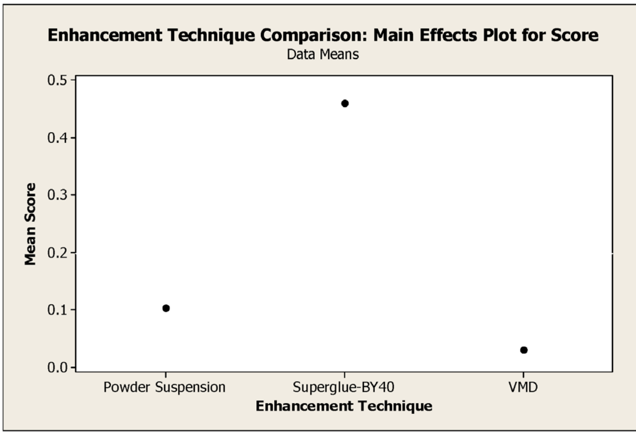

Figure 8

Main effects plot comparing enhancement technique scores.

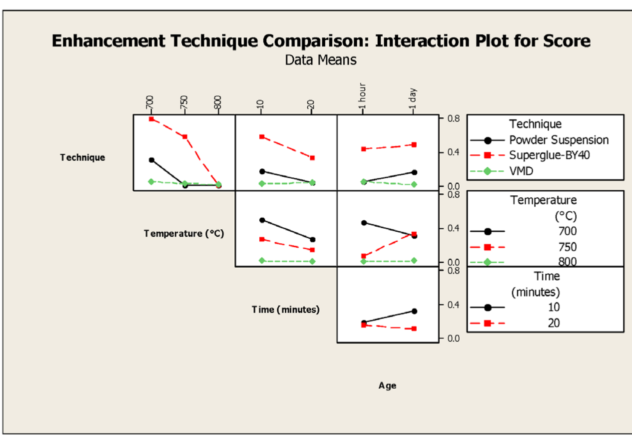

Figure 9

Interaction plot for fingerprints deposited on ceramic.

The interaction plot for enhancement technique and temperature shows that VMD performs poorly compared to the other techniques. Superglue followed by BY40 scores for 700 °C and 750 °C are higher than the others, but the Kruskal-Wallis test illustrated that this difference was not significant. Scores decreased with increased exposure time and appear to increase slightly from one- hour to one-day-old fingerprints (except for VMD, which shows a slight decrease with age). The interaction between temperature and time shows that scores decrease with increased temperature and exposure time, although an increase in score with increased age is observed for 750 °C, but decreases for the other two temperatures. A lower exposure time provides a higher score across the ages because the conventional VMD process coats the heat-exposed surfaces very rapidly with a coating of zinc, and there is little, if any, definition between ridges and background.

In their work, Bleay et al. [4] suggested that VMD was an extremely effective enhancement technique and could even enhance fingerprints up to 900 °C, but they also suggested that VMD will expose soot deposits or areas where water has dried. This brief study showed that both superglue followed by BY40 and iron oxide-based powder suspension were more effective than the conventional gold–zinc VMD process at the temperatures tested here; however, a more complete study would need to be undertaken to provide any definite conclusions.

A further experiment carried out on a single ceramic tile using the silver VMD process demonstrated that this VMD has far greater potential to detect fingerprints on marks exposed to this higher temperature regime. Good-quality marks were developed from a range of donors, and some of these were improved by allowing the silver coating to age and change color. Examples of marks developed using silver VMD on a tile exposed to 800 °C for 20 minutes are shown in Figure 10.

The short experiment reported here shows that the technique has potential for use on exhibits exposed to this higher temperature range, but further work would be required to confirm this.

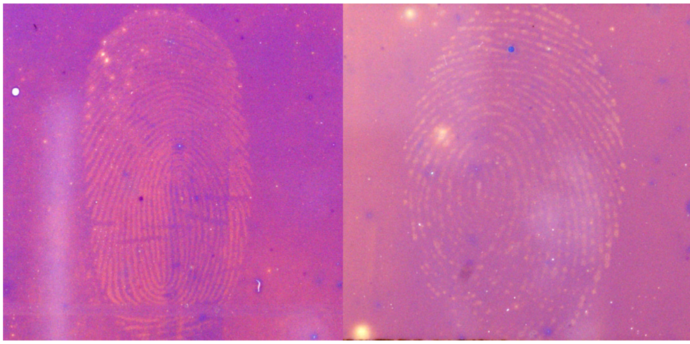

Figure 10

Fingerprints developed using silver VMD on ceramic after exposure to 800 °C for 20 minutes (brightness and contrast adjusted using photo editing software).

Conclusion

All fingerprint enhancement techniques tested did enhance deposited fingerprints to some degree. The technique that produced the best results overall was superglue followed by BY40.

Therefore, when undertaking fingerprint analysis on nonporous surfaces recovered from a fire scene, superglue followed by BY40 should be the first technique to be considered although it would be dependent on whether the surfaces remained dry or wet during the extinguishing of the fire. If the surface was wet, then iron powder suspension would still be effective at developing fingerprints, but to a lesser extent. VMD is an option but may not be the most effective technique in operational scenarios, with further work being required to evaluate the silver VMD technique.

For further information, please contact:

Ainsley J. Dominick
Centre for Forensic Science
University of Strathclyde
Royal College 204 George Street
Glasgow G1 1XW
United Kingdom
ainsley.dominick@strath.ac.uk

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