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A Forensic Study on Sequence of Strokes in Laser Printed Document and Stamp Pad Impressions

دراسة جنائية حول تتابع الضربات الخطية في المستندات المطبوعة بالليزر وبصمات الأختام

Kajal Sanyal* and Priya Sharma
Forensic Science Department, Chandigarh University, Mohali, Punjab, India

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Abstract

The analysis of overlapping of different ink strokes has always been an important factor in forensic document examination, as seen in cases of fraud and tampering of documents.

The objective of this study is to use microscopy to analyse the sequence of strokes of laser printer toner and stamp pad inks and evaluate its potential in identifying various characteristics that are found at the intersections. Samples prepared with different printer, ink brands and paper types, were examined by making two types of stroke intersections. At these intersections, features such as gloss variation, gaps in strokes, surface morphology and stroke narrowing were observed.

This study contributes in establishing that despite variations in paper, ink and toner, microscopy can be a reliable technique for the determination of sequence of strokes in laser printer toner and stamp pad inks. With the existing studies mainly focusing on the use of more sophisticated analyses, this study shows the importance of the use of stereomicroscopy on its own as a non-destructive and easily available method for stroke sequence determination. It is an adaptable and dependable method that can be effectively applied across laboratory setups with varying levels of technical infrastructure

Keywords: forensic sciences, forensic document examination, microscopy, stroke sequence determination, stereomicroscopy

المستخلص

يُعد تحليل تداخل الضربات الخطية للأحبار المختلفة عاملاً جوهرياً في الفحص الجنائي للمستندات،ولاسيما في حالات التزوير والعبث بالمحررات. تهدف هذه الدراسة إلى استخدام الفحص المجهري (Microscopy) لتحليل تتابع الضربات الخطية لكل من حبر طابعات الليزر (Toner) وحبر أختام البصمات، وتقييم قدرة هذه التقنية في تحديد الخصائص المختلفة التي تظهر عند نقاط التقاطع.

تم فحص عينات أُعدت باستخدام طابعات وأنواع أحبار وورق مختلفة، وذلك من خلال إنشاء نوعين من تقاطعات الضربات الخطية.

وعند نقاط التقاطع هذه، رُصدت عدة سمات مجهرية تشمل: التفاوت في اللمعان، والفجوات في الخطوط، ومورفولوجيا السطح (بنية السطح)، وتضيق الخطوط.

وتسهم هذه الدراسة في إثبات أنه على الرغم من اختلاف أنواع الورق والأحبار، يظل الفحص المجهري تقنية موثوقة لتحديد تتابع الضربات الخطية في مطبوعات الليزر وبصمات الأختام.

وفي حين تركز الدراسات الحالية بشكل أساسي على التحليلات الأكثر تعقيداً، تهدف هذه الدراسة بشكل رئيس إلى إبراز أهمية استخدام «المجهر المجسم» (Stereomicroscopy) كمنهجية مستقلة غير مدمرة للمستندات وسهلة التوفر لتحديد تتابع الخطوط.

وتُعد هذه الطريقة مرنة وموثوقة، ويمكن تطبيقها بفعالية في مختلف المختبرات بغض النظر عن مستوى بنيتها التحتية التقنية.

الكلمات المفتاحية: علوم الأدلة الجنائية، الفحص الجنائي للمستندات، الفحص المجهري، تحديد تتابع الضربات الخطية، المجهر المجسم

* Corresponding Author: Kajal Sanyal
Email: kajalsanyal3@gmail.com

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1. Introduction

Forensic document examination is one of the main domains in forensic science which deals with the examination of the authenticity, integrity and chronology of entries of any questioned document used in legal, administrative and financial settings [1,2]. One of the most critical aspects of examination is the determination of sequence of strokes. Sequence of strokes refers to the order in which the writing inks are placed onto a writing surface [3]. Establishing this stroke order is important in cases of fraud, tampering or backdating because the timing of any addition or alteration can significantly affect a document's legitimacy [1,4]. Whenever any two writing inks cross each other then they overlap and form an intersection. These intersections can be homogeneous, which means they are produced from the same writing ink like two ball pens, or heterogeneous, which means they are produced from two different writing materials such as a gel pen and ball pen or a printer toner and stamp ink impression. At these intersections various characteristics are found, like disturbances in surface texture, ink distribution and particle displacement depending on the order of the application and the writing instrument used. Features like interruption, compression and particle displacement can be seen in the underlying stroke or the stroke that is applied first, whereas in the overlaying stroke the continuity, spreading and surface coating might be affected. In case of pen strokes, the liquid ink may show changes in absorption and feathering, while in cases of dry materials like printer toner, features like gaps, toner disruption and edge modifications can be seen. Such characteristics can be observed and analysed to determine the order in which the particular strokes were applied [5].

Laser printing is a widely used technique due to its speed, quality and good output at low cost. The laser printers use a toner powder which usually consists of a polymer resin, colourant or pigment and various additives like waxes and charge control agents. This toner fuses onto the paper due to heat and pressure and forms a slightly raised layer which alters the surface topography [6]. Stamp pad inks are usually composed of dye or pigment, water, alcohol, glycerol and resins. They get absorbed into the cellulose structure of the paper when pressure is applied [7]. In forensic document examination, such laser printed documents bearing stamp pad impressions can be found in cases of legal documents, contracts, financial documents, certificates, office documents and administrative records. In such cases determining the sequence of strokes is important for evaluating the authenticity of the documents. When a stamp pad ink intersects with a fused toner layer then its ability to penetrate the paper surface or spread will be affected. Similarly if laser printing is done over a pre-existing stamp impression then the fusion of the toner particles to the paper surface will be affected and along with these other morphological alterations can also be observed [6].

These alterations found at the intersections can be analysed using instruments such as stereomicroscope, fluorescence microscope, scanning electron microscope (SEM) and other analytical techniques like microspectrophotometry [5,8,9]. Microscopic methods allow a detailed visualisation of all the surface disturbances such as gaps in strokes, difference in edge morphology and particle distribution of toner, specular reflection and narrowing, that occurred at the intersecting regions [10]. These observations can be used as reliable indicators for determining the sequence of strokes. Lee et al. [11] suggested the application of adhesive tape, together with Infinite Focus Microscopy to exfoliate layers at stroke intersections so that

the upper and lower strokes could be visually separated. Analytical instruments like Video Spectral Comparator (VSC) can reveal the spectral differences using absorption spectra in cases of printed and pen strokes [12]. Ozbek et al. [13] studied the combination of optical and microscopic methods to examine the colour, gloss, absorption and luminescence of ink strokes made by various pens. The study demonstrated that these methods are fast and destructive and give effective results.

Li [8] successfully determined the sequence of strokes between stamp pad ink and various pen inks using the technique of microspectrophotometry. Li & Ouyang [14] examined stamp pad ink and laser printer toner intersections using fluorescence analysis and scraping, finding that differences in fluorescence intensity and the exposure of toner defects after scraping could indicate the sequence of overlaps. Shraa et al. [15] studied several stamp brands, papers, and printers using digital microscopy and Raman spectroscopy to analyze heterogeneous overlaps between toner and stamp pad inks. Although some features were available under digital magnification, such as specular reflection, gloss differences, and ink-spreading, the study showed that the optical methods did not provide good, consistent results for all the materials analyzed whereas Raman spectroscopy was much more reliable. Esmaeili et al. [16] studied the effect of various factors like type of printer, paper, ink brand and colour of the ink, on determination of sequence of strokes of various pens and printers. Techniques like optical coherence tomography have also been used to determine the heterogeneous intersections between gel pens and stamp pad inks by analysing the depth and layering details [17].

Further, studies introducing techniques like Rutherford Backscattering Spectrometry and Particle Induced X-ray Emission have been used to establish the stroke sequence [18]. Other authors have developed other optical and physical techniques. Gupta and Nassruddin [19] examined homogeneous pen-stroke crossings by means of a Video Spectral Comparator (VSC 8000) and concluded that pressure continuity, stroke interruptions and 3-D topography under special lighting conditions all showed clear differences indicative of stroke order. Guo et al. [20] applied Raman spectral area scanning to analyze crossing points of red and blue seal inks with writing inks. Results successfully verified that Raman spectroscopy is a fast and non-destructive method to discriminate due to the characteristic spectra of carbon based pigments. Devaseelan et al. [21] studied printed documents from several laser, inkjet, and dot-matrix printers under a stereomicroscope. The work demonstrated how spur marks, edge contrast, feathering, smoothness, and resolution are among the features that allow differentiation among printer types, further strengthening the utility of stereomicroscopy for printer characteristics analyses, but not extending to stroke sequence determination. The use of fluorescence spectroscopic techniques has also been growing. In a large scale study various interactions were analysed using infrared luminescence and the stroke order was distinguished successfully in ink and print combinations [22]. Meneghetti et al. [23] studied the intersection points of different ink types of ball-point, gel, rollerball, fountain, fineliner and laser printer toner particles by means of a digital microscope. This research allowed them to confirm that differences in toner density, edge disruption, and microscopic voids at the sites of intersections are informative indicators of stroke order. Other advanced spectroscopic and imaging techniques have also been introduced. Confocal Raman Spectroscopy is a non-destructive and reliable

technique to determine order of intersection strokes of toner and stamp ink by analysing their distinct spectral signatures [24].

Recent studies focus toward digital and spectroscopic technologies for stroke sequence determination and along with it, techniques like hyperspectral imaging based research has also gained importance. Li and Gao [25] researched the crossing points of stamp impressions over laser-printed toner by applying Vis-NIR HSI (Visible Near Infrared Hyperspectral Imaging). Based on spectral differences at the crossing points, the authors successfully proved that HSI is effective in determining the stroke order in laser printed and stamp inks combinations. Khare et al. [26] applied fluorescence microscopy to distinguish 36 kinds of writing ink intersections which proved that fluorescence intensity, spreading, and specular reflection may give evidence of the order of heterogeneous pen strokes. Asicioglu et al. [27] investigated homogeneous and heterogeneous intersections developed using ballpoint pens of different colors with a 3D scanner. They showed that the second stroke applied had characteristic topographic fluctuations, showing that 3D surface mapping sensitively detects such micro-level distortions caused by overlapping strokes.

Even with such advances, challenges persist. The determination of stroke sequence can still be challenging due to various ink formations, toner density, fusion quality, paper porosity, environmental conditions and time gap between stamping and printing [28]. These studies, taken together, demonstrate that sophisticated tools like Raman spectroscopy, hyperspectral imaging, 3D scanners, fluorescence microscopy, VSC systems, and digital microscopes are indeed powerful ways of determining stroke order, but many studies rely on controlled environmental conditions that differ from variability seen in actual cases. There are few recent studies that have systematically investigated the capabilities and limitations of stereomicroscopy in analyzing intersections involving laser-printed toner and stamp-pad inks. Many of the existing optical studies supplement their observations either with spectroscopic data or by means of techniques that consume evidence or require specialized equipment not generally available in many forensic laboratories. Most of the studies also deal primarily either with pen over toner interactions, pen over pen interactions or stamp over pen interactions which make stamp pad ink over laser printer toner relatively less well represented.

One notable gap in the literature is the lack of uniform stereomicroscopic criteria that can be used for analysing features such as toner disruption, ink spreading, gloss variation, surface morphology and gap formation at intersections involving stamp pad inks. Also several of these studies were based on small or narrow samples, which may reduce their applicability to wide stamp ink, paper and laser printer model variability in casework. Although Shraa et al. [15] did sample several brands of stamp pad inks and printers, their findings revealed that digital microscopy alone was not enough to conclude the stroke order in every case; hence, optical methods require further thorough systematic exploration.

These gaps point to the need for studies that, using a large dataset and without reliance on advanced instrumentation, assess what observations can and cannot be made using a stereomicroscope, which is the most widely available tool in forensic document units. The aim of the present study is to determine the sequence of strokes of intersections formed by laser printed text and stamp pad impressions using different combinations of printer models, stamp pad inks and paper surfaces. For this purpose, a total of 324 samples of crossing strokes created by laser

Table 1- *List of printer brands/models*

Printer Brand	Printer Model
Canon	imageRUNNER ADVANCE 4545i
Canon	imageRUNNER ADVANCE 4245
Canon	imageRUNNER 3025N
HP	LaserJet Pro MFP M126nw
HP	LaserJet M1005 MFP
HP	LaserJet 1020
Kyocera	ECOSYS M2040dn

printed text and stamp pad ink impressions are examined with the aim of determining the diagnostic stereomicroscopic features that may assist in the determination of sequence of strokes under limited laboratory conditions.

2. Materials and Methods

2. 1. Materials Used

For the present study, first a survey was conducted in the local shops of Punjab region and the most commonly used printer brands were identified. Out of those three most commonly used printer brands are selected which are Canon, HP and Kyocera. Further from these, three different printer models from each brand are used to make the sample, which resulted in a total of nine printers as listed in Table 1. This variability ensures to capture the potential variations that can affect the morphology at the intersections, due to the differences in the toner composition, particle size and printing resolution.

Paper type can also affect the characteristics at the intersections. From each printer two different types of samples were made, on two different papers. A standard A4 office paper which is a regular office copier paper, of the brand JK Copier and bond paper which is a high quality, thick paper usually used for official documents, of the brands

Table 2- *List of stamp pad ink brands and colours*

Stamp Pad Brand	Ink Colour
Camlin	Red
Artline	Blue
Artline	Black

JK excel bond and Star bond papers were used. Due to their varying surface texture, porosity and fibre density, the absorption, spreading and the depth of the penetration of stamp pad ink could vary accordingly. For the stamp pad inks, three colours, which are red, blue and black were chosen from two different brands as listed in Table 2.The differences in ink composition and their saturation level were considered as the important factors, that could affect the interaction of laser printer and stamp pad ink.

2. 2. Sample Preparation

For the sample preparation two ways were used; in the first method the stamp was applied first and then the document was printed by using a laser printer which helped to assess how toner particles deposit over pre-existing stamp pad ink and in the second method the stamp was applied onto the printed document which allowed to observe that how the stamp pad ink behaves when it is applied over toner particles on the printed surface, as illustrated in Figure-1. Thus, a total of 324 samples were made using various combinations of nine printers, two types of paper, three colours of stamp pad inks, two orders of application and triplicate repetitions for each sample, as depicted in Figure-2.

In these samples various characteristics were observed at the intersections made by laser toner particles and stamp pad ink to determine the stroke sequence. Characteristics like toner particle displacement, gaps in strokes, specular reflection, narrowing, ink diffusion patterns and surface

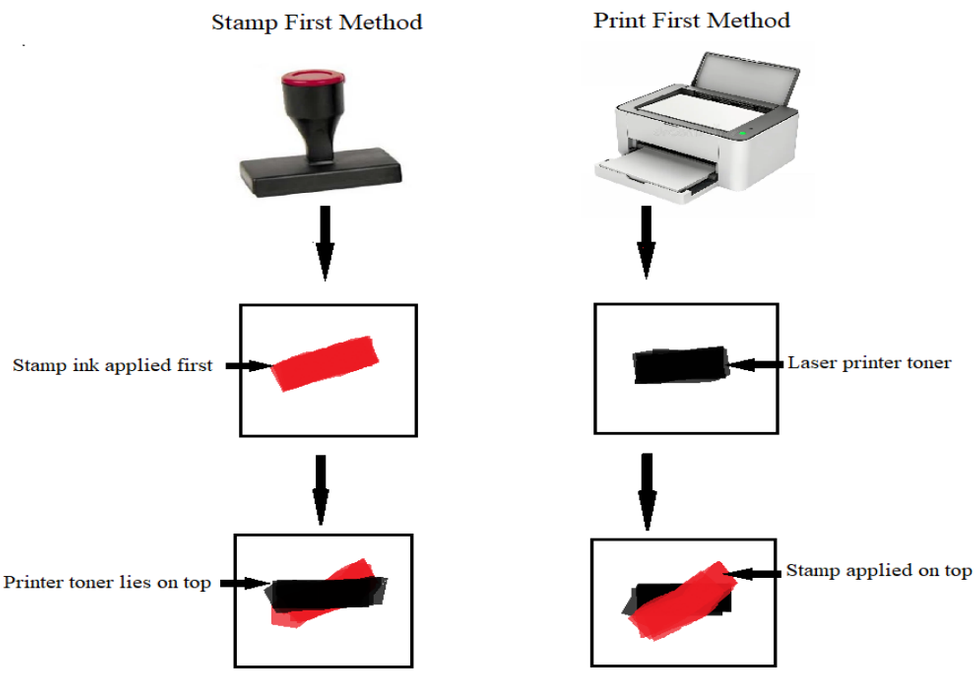

Figure1- *Illustration depicting methods used for sample preparation*

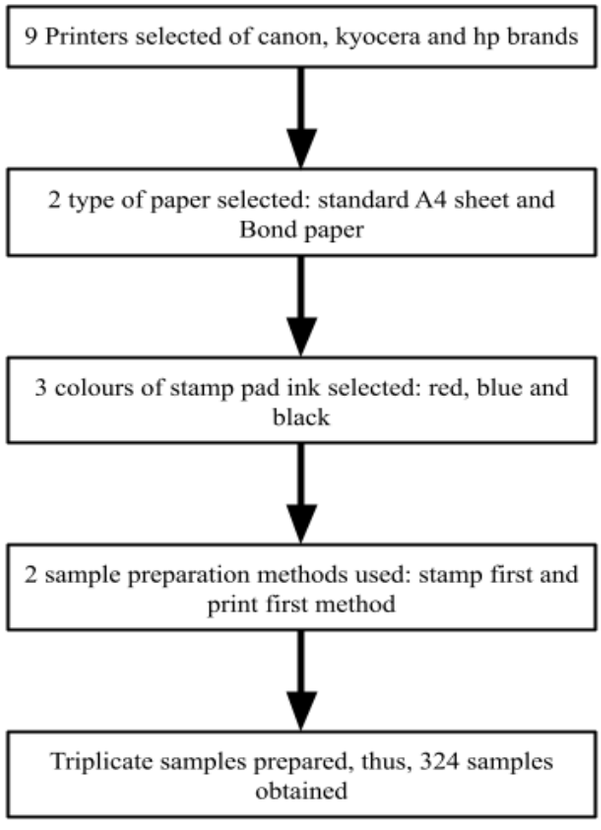

Figure2- *Flowchart depicting sample preparation*

morphology were observed, as included in Table 3, and the noticeable features were documented. While observing, the impact of paper porosity and ink colour was also assessed to understand better on how these variables might be helpful or can hinder the visualisation of sequence of stroke under the microscope.

2. 3. Microscopic Examination

The instrument used for analysis was a stereomicroscope, an Olympus SZX7 equipped with a DF PLAPO 1x objective which was coupled with an external display for monitoring the sample being observed in real time. A stereomicroscope is an optical instrument which is also called a dissecting microscope that is helpful to analyse the morphological features of objects. It has two separate optical paths for each eye, therefore, provides a three-dimensional and erect image of the sample being visualised [29]. All the samples were observed under an appropriate zoom range and light source that allowed the detailed visualisation

Table 3- *List of characteristics used for stroke determination*

Feature	Description
Gaps in Toner	These are the discontinuities or interruptions that are usually found in the toner due to the presence of an already existing stroke, like any pen ink or stamp pad ink.
Narrowing of strokes	It is a reduction in the width of the stroke when it crosses over another stroke, at an intersection. This happens due to interaction between stamp pad ink and laser printer toner.
Specular reflection	It is a mirror-like reflection of light that is caused by a smooth surface. In case of toner printers and stamp pad ink the specular reflection can be seen less or more in certain areas.
Toner particle displacement or edge disruption	It is the movement or disturbance of toner particles that can occur due to interaction with stamp pad ink.
Surface morphology	Any microscopic feature present at the intersection or any change in surface topography that can be seen under a microscope.

Table 4- *Discriminative power of the microscopic features observed to determine the sequence of strokes*

Feature Observed	Occurrence of Feature in Laser Over Stamp Samples (%)	Occurrence of Feature in Stamp Over Laser Samples (%)	Discriminative Power (%)
Narrowing	2%	76%	74%
Specular reflection	4%	60%	56%
Gaps	73%	18%	55%

of surface morphology. A proper background light source, an oblique light source and an external light source was used which ensured uniform lighting and then the images were captured.

3. Results and Discussion

The sequence of strokes for laser printer toner and stamp pad ink impressions was determined using a stereomicroscope for all the samples including different paper thicknesses, stamp pad ink colours and laser printer toner combinations. Observations were recorded where features like gaps in strokes, narrowing, specular reflection, varying edge morphology and any other surface disruption, if present, was seen.

The following observations were recorded:

3. 1. Gaps in Strokes

The first feature observed was gaps in toner particles. The toner particles fuse onto the surface of the paper, therefore if an ink layer is already present on the surface then it will disrupt the fusion process of the toner particles, thus creating gaps in strokes. This feature was seen when stamp was applied prior to printing, therefore, when printing was done on a pre-existing stamp impression then the toner particles could not fuse properly to the paper surface due to the presence of ink layer regardless of its colour and the paper type as seen in Figure-3 to 6. The gaps were easily visible when

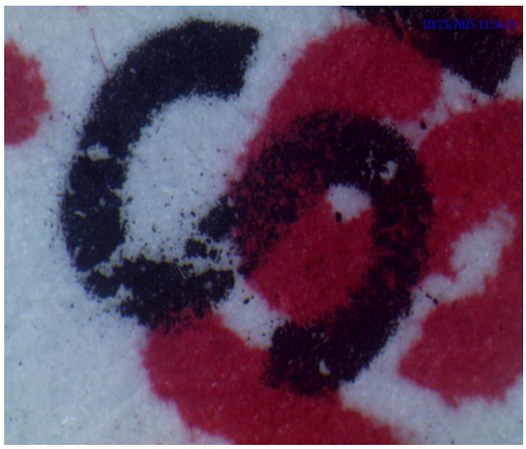

Figure 3- *Gaps and defects seen in the toner layer when present above the stamp pad ink on a bond paper (magnification 1.6x)*

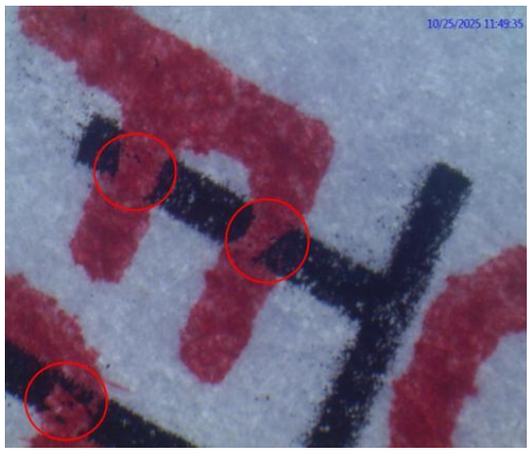

Figure 4- *Gaps seen in toner layer when present above the stamp impression on standard A4 paper (magnification 1.25x)*

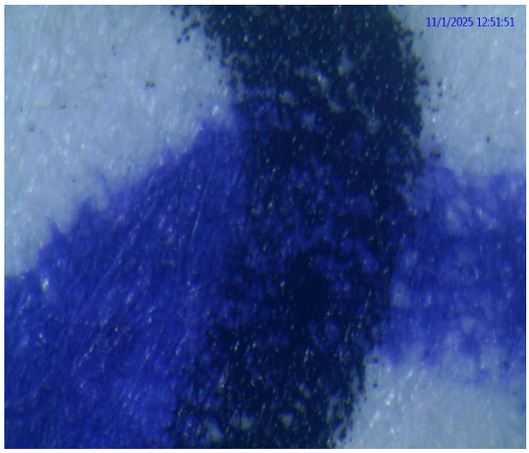

Figure 5- *Gaps in the toner layer present when it is above the stamp pad ink layer on a bond paper (magnification 4x)*

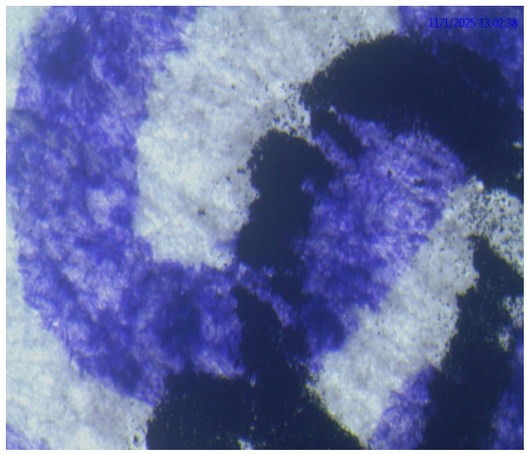

Figure 6- *Gaps in the toner layer when present above the stamp impression on standard A4 paper (magnification 2.5x)*

better colour contrast was present as seen with red and blue stamp pad inks as compared to black stamp pad ink and black laser printer toner [16]. In other cases when the stamp was applied on top of the toner, then the gaps were seen in very few samples, in the majority of the samples the toner layer appeared as a clean and sharp stroke.

3. 2. Narrowing of Strokes

This was another feature observed prominently in the ink strokes when the stamp ink was present on top of the toner as shown in Figure-7. Because of the presence of a non-absorbent toner particle layer the stamp pad ink cannot spread evenly at the intersections. In case the ink is water based, the toner particles will repel it and the stroke will appear narrower at the intersection. In the other case where the stamp was below the toner, no such phenomenon is seen as shown in Figure-8.

3. 3. Specular Reflection

The third feature observed was specular reflection. It is a phenomenon that occurs when light reflects off a smooth surface at a definitive angle. This feature was

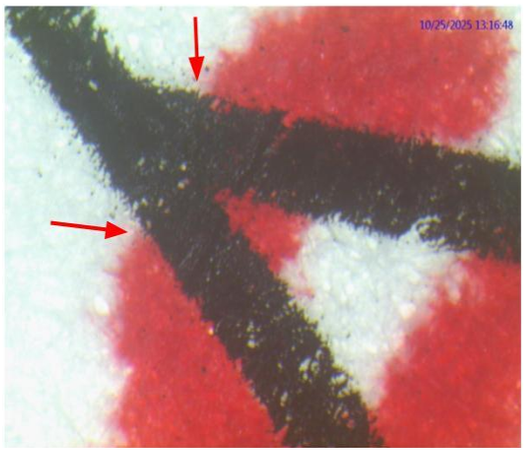

Figure 7- *Narrowing of the stamp pad ink stroke when it is applied on top of the toner (magnification 2.5x)*

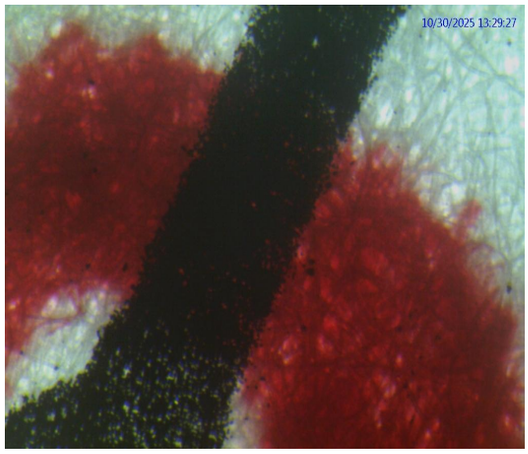

Figure 8- *No such narrowing or disruption is seen when stamp pad impression was applied prior to laser printing (magnification 4x)*

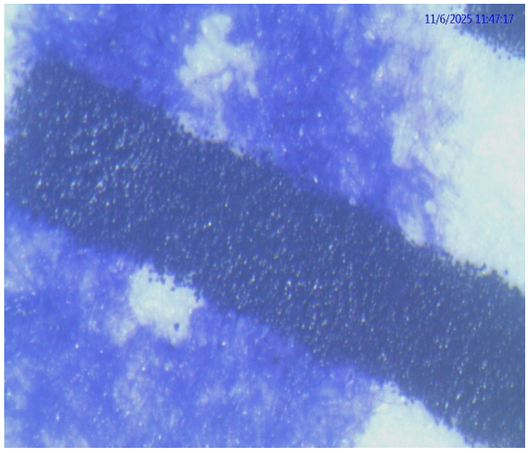

Figure 9- *Enhanced specular reflection seen at intersections when stamp impression present on top of the toner (magnification 4x)*

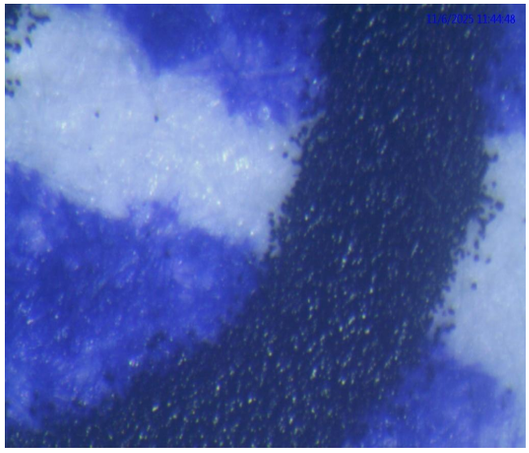

Figure 10- *Enhanced specular Reflection seen when stamp impression present on top of the toner (magnification 5.6x)*

seen when stamp pad ink was applied on top of the toner particles. The ink creates a smooth, reflective layer over the surface of rough toner particles. When light falls on the intersection, then a glare is formed, this tells that the stamp was applied on top of the printer toner. This feature was seen with all the colours of stamp pad ink, with more prominence in blue and red inks as shown in Figure-9 and 10.

The variations in thickness of different types of paper, which is a standard A4 office paper and bond paper did not significantly influence the visibility and definition of the distinguishing features to determine the stroke sequence. The varying ink color and compositions did affect the visualisation of samples. The black stamp pad ink made it difficult to distinguish features between black ink and black laser printer toner.

Although, stereomicroscopy has its own limitations. Extremely fine details and uncommon combinations of ink and toner could have difficulty in determining the sequence of strokes. But taking all the findings together, stereomicroscopy emerges as a nondestructive, easily accessible, efficient and reliable method for determining the sequence

of strokes for laser printed documents and stamp pad ink impressions. These results add to the current forensic document examination practices by providing confirmation that using stereomicroscopy, the associated visual features of the toner and ink interactions can support determination of sequence in absence of advanced analytical methods.

The Discriminative Power (DP) is calculated for all the features observed, as shown in Table 4. It is the probability of discriminating between distinct samples at random by identifying their unique features, from a population [30]. Here it is calculated as the difference between the percentages of the features observed in laser over stamp and stamp over laser samples.

$$DP\ (\%) = |P_{L/S} - P_{S/L}|$$

Where,

$P_{L/S}$ = Percentage of feature observed in laser over stamp samples

$P_{S/L}$ = Percentage of feature observed in stamp over laser samples

The discriminative power obtained for all the features show their effectiveness for distinguishing between laser over stamp and stamp over laser sequences. The features with higher discriminative power show greater reliability to determine the sequence of strokes. These findings enable a comparative assessment of the features that are examined and support their relevance in determination of sequence of strokes.

4. Conclusion

These results illustrated the efficiency of stereomicroscopy for determining the sequence of strokes for laser printed document and stamp pad ink impressions. The key features like gaps in toner, narrowing and specular reflection can be seen that can help to know order of stroke. In cases where toner was on top of the stamp ink, features like gaps in strokes and increased toner disruption were evident. In case of stamp over toner, features like narrowing and enhanced specular reflection were more evident. The analysis revealed the significance of the features to determine the stroke sequence. Among all the features observed, narrowing of the strokes demonstrated higher discriminative power as compared to specular reflection and gaps in toner particles. The visualization of the characteristics can be affected due to the factors like ink hue and complexity of intersecting strokes, but overall the findings of the present study demonstrated that stereomicroscopy is a non-destructive, reliable and easily accessible method that can provide distinct visual indicators for determination of sequence of strokes. Future studies may focus on diverse document conditions, expanding the sample size and using varied combinations of intersecting strokes that may aid in more standardised protocols for sequence of strokes determination.

Conflict of Interest

The authors declare no conflicts of interest.

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