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Determination of the Sequence of Non-intersecting Stamp Impressions and Laser-Printed Document



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تحديد أسبقية (ترتيب) طبقات الأختام غير المتقاطعة والوثائق المطبوعة بالليزر

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Abstract

Questioned document examiners come across various documents to establish their originality, authorship and authenticity. With technological advancement, documents are printed using different printing devices, of which laser printers are highly commercialised. However, the misuse of such technological advancements has also increased, so laser printers can be used to create forged documents. One class of forged documents is built-up documents, which contain authentic signatures, but the contents of the document are added after appending the signatures. These documents might be printed using a laser printer, and stamp impressions may also be present, which do not intersect each other. Thus, to address such cases, the present study has been conducted to establish the sequence of production of a laser-printed document containing a stamp impression. A total of 720 samples were prepared, of which 360 samples were first printed and then stamped, and the rest of the samples were first stamped and then printed. For the analysis, a NIKON SMZ800N stereo microscope with a magnification of $2 \times 10 \times 8X$ was used. The technique was non-destructive, reliable and inexpensive. Variables such as the colour of the stamp, substrate (paper), and printouts from different laser printers were also studied to analyse their effect on the determination of the sequence of document production. Micro-conformation features of toner particles, fibre distribution, and ink distribution were

المستخلص

يواجه فاحصو المستندات المشكوك فيها (المطعون بصحتها) وثائق مختلفة للتحقق من أصالتها، وهوية كاتبها، وموثوقيتها. ومع التقدم التكنولوجي، أصبحت المستندات تُطبع باستخدام أجهزة طباعة متنوعة، تُعد طباعات الليزر من أكثرها رواجاً واستخداماً في الأسواق. ومع ذلك، فقد ازداد أيضاً إساءة استخدام هذه التقنيات المتطورة، حيث يمكن استخدام طباعات الليزر لإنشاء مستندات مزورة. ويُعد «المستند التراكمي أو المركب» (Built-up document) أحد أنواع المستندات المزورة، وهو مستند يحتوي على توقيعات حقيقية وصحيحة، ولكن يُضاف محتوى المستند ونصه بعد وضع هذه التوقيعات. وقد تُطبع هذه المستندات باستخدام طباعة ليزر، كما قد تحتوي أيضاً على طبقات أختام لا تتقاطع بعضها مع بعض. ولذلك، ولعلاج مثل هذه الحالات، أُجريت هذه الدراسة لتحديد الأسبقية الزمنية لإنتاج مستند مطبوع بالليزر يحتوي على طبعة ختم. وتم إعداد ما مجموعه 720 عينة؛ حيث جرت طباعة 360 عينة أولاً ثم خُتمت لاحقاً، بينما خُتمت بقية العينات (360 عينة) أولاً ثم طبعت لاحقاً. ولغرض الفحص والتحليل، استُخدم مجهر مجسم (Stereo microscope) من نوع (NIKON SMZ800N) بقوة تكبير تبلغ $(2 \times 10 \times 8X)$. وتميزت هذه التقنية بأنها غير إتلافية (لا تلتف المستند)، وموثوقة، وغير مكلفة. كما دُرست متغيرات أخرى مثل لون الختم، والركازة (نوع الورق)، والمخرجات المطبوعة من طباعات ليزر مختلفة، وذلك لتحليل أثرها على تحديد الترتيب الزمني لإنتاج المستند. جرى تحليل السمات التشكيلية الدقيقة (Micro-conformation features) لجزيئات الحبر الجاف (التونر)، وتوزيع الألياف، وتوزيع الحبر السائل. وأظهرت

Keywords: forensic sciences, forged, documents, printing, stamp, analysis

الكلمات المفتاحية: علوم الأدلة الجنائية، تزوير، وثائق، طباعة، ختم، تحليل



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analysed. The results obtained showed that the sequence of non-intersecting laser printing and stamping could be established using micro-conformation features of fibre distribution and ink distribution. However, the micro-conformation features of toner particles do not help in establishing the sequence. The study also highlights the precautions that must be taken while forming an opinion on the sequence of non-intersecting strokes.

1. Introduction

Any document is usually questioned for its originality, authorship and authenticity. With technological advancements, illegitimate and unlawful activities have increased while producing documents of legal importance. Skilful alteration of documents by any means, like addition, substitution, interlineation, etc., has gained the attention of criminals [1, 2]. Forensic document examiners are usually asked to determine the sequence in which the document was produced, usually the written matter and the signature [3, 4, 5]. However, in rare cases, the sequence of the stamp application, which is used to authenticate a document, is also inquired about, or it acts as corroborative evidence to add further facts to establish the sequence of production of a document. Further, the stamp impression may or may not be intersected by the signature or the written matter.

Legal documents are usually printed, and primarily laser printers are used to print them because of their easy accessibility, affordability, clarity, and rapid printing [6, 7, 8]. Laser printers use microscopic toner particles instead of liquid ink and create images with the help of a laser beam [9]. Apart from the printed matter, these toner particles are scattered throughout the paper and may not be visible to the naked eye. These scattered toner particles are called stray toner particles [10, 11, 12]. Stamping has been common for authentication and legal purposes. Stamp pads are mainly used for stamping purposes, which are water-based and

النتائج التي تم التوصل إليها أنه يمكن تحديد الأسبقية الزمنية للطباعة بالليزر والختم غير المتقاطعين باستخدام السمات التشكيلية الدقيقة لتوزيع الألياف وتوزيع الحبر السائل. ومع ذلك، فإن السمات التشكيلية الدقيقة لجزيئات الحبر الجاف (التونر) لا تساعد في تحديد هذا الترتيب الزمني. كما تسلط الدراسة الضوء على الاحتياطات التي يجب اتخاذها عند إبداء الرأي الفني أو الجنائي بشأن الأسبقية الزمنية للخطوط (الضربات) غير المتقاطعة.

contain pigments, synthetic resins, vegetable or mineral oil, solvents, etc. [13]. Self-inking stamps are also commonly used and are oil- or water-based inks, depending on the manufacturer. Irrespective of the type of stamp used, it is essential to exert enough pressure to create a precise impression on a document.

A diminutive work related to determining the sequence of strokes involving stamp impressions can be encountered. The studies to determine the sequence of intersecting strokes involving stamp impressions include the works conducted by Li and Ouyang [13] and Wu et al. [14] that determined the sequence of crossing stamp/seal impressions and laser printing lines. Li [15] determined the sequence of crossing stamp/seal impression and various pen ink strokes. Li et al. [16] worked on the sequence of heterogeneous intersecting lines (including stamp impressions) using fluorescence. Zhang et al. [17] worked on the sequence of intersecting lines between gel pens and stamp/seal impressions using optical coherence tomography.

A few studies related to non-intersecting strokes have been conducted. The term non-intersecting refers to the elements where physical intersection between the two writing or printing media cannot be seen by the naked eye. In the absence of physical intersection, the findings are based on indirect microscopic substrate (stray toner particles) interactions rather than direct stroke sequence evidence. This terminology has been consistently used in the literature for determining the sequence



Table 1- *Different materials used for the preparation of samples.*

S. no.	Material	Specifications	
1.	Substrates	SATMED Trident	75 GSM, A4 Size, White colour
		Bilt Royal Executive	100 GSM, A4 Size, White colour
		Oddy Glossy Paper	130 GSM, A4 Size, White colour
2.	Stamp pads	Artline Stamp Pad	
		Ashoka Stamp Pad	Blue colour
		Kores Stamp Pad	
		Artline Stamp Pad	Red colour
		Ashoka Stamp Pad	
		Faber–Castell Stamp Pad	
3.	Laser Printer	Konica Minolta Bizhub C454e	Coloured Printers
		Brother (DCP-T310)	
		Canon (Image Runner) 2870	Black and White Printers
		Image Runner Advance 8295	

of production of documents in which laser printers have been used to produce the document. Aginsky [10], Wang et al. [18], Wang [11] and Gupta & Saini [12] focused on determining the sequence of non-intersecting strokes and analysed the micro-conformation features of pen inks, paper fibres, and toner particles. Micro-conformation features can be defined as subtle microscopic changes that occur while writings are executed using any writing instrument on paper. As the name says, these are microscopic and often require enlargement with the help of different types of microscopes. The stereomicroscope is the most preferred microscope due to its ability to give three-dimensional images [11, 12, 19].

As such, no study has been reported to determine the sequence of non-interesting strokes

between stamp impressions and laser-printed documents. Thus, the present study aimed to determine whether micro-conformation features can be helpful to analyse the sequence of non-intersecting stamp impressions and laser-printed documents. The analysis was performed using a stereo-microscope. Variables such as the substrate (paper), printouts from different laser printers and colour of the stamp were also studied to analyse their effect on the determination of the sequence of document production involving laser printing and stamp impressions. The methodology used for this study was non-destructive, reliable and inexpensive. This study would help to add to the knowledge of questioned document examiners and provide them with more facts to establish the sequence of production of the documents.



2. Materials and Methods

2.1. Collection of Materials

The following materials were collected/acquired for the preparation of the samples:

1. Rims of three types of substrates (Table 1).
2. Six soft rubber stamps (each rubber stamp was used for a different stamp pad).
3. Three stamp pads of red colour and three stamp pads of blue colour (Table 1).
4. Four different types of laser printers were acquired for printing (Table 1).

2.2. Sample Preparation

The samples were prepared in two sets. In the first set, printing was done before the stamping. For example, five sheets of Bilt Royal Executive paper were first printed using the Konica Minolta Bizhub printer, and then the Kores blue stamp was executed on the blank space of the paper so that the stamp impression and the printed matter do not intersect each other. The process was repeated using all types of paper, all six stamp pads and all four laser printers. Hence, 360 samples were prepared, in which the stamp impression was above and the printed matter was below. All the samples were assigned a unique sample ID.

Stamping was done before printing the second set of specimens. For example, first, the Kores blue stamp was executed on five sheets of Bilt Royal Executive paper, and then these sheets were printed using the Konica Minolta Bizhub printer in such a manner that the stamp impression and the printed matter do not intersect each other. The process was repeated using all types of paper, all six stamp pads and all four laser printers. Hence, 360 samples were prepared, in which the stamp impression was below and the printed matter was above.

Stamping was done by the same person to control the variables of pressure, and the matter for

printing was the same for each printer. The sheet of paper to be stamped was kept among 10 other sheets of paper to provide padding. Thus, a total of 720 samples were prepared. All the samples were stored in a controlled laboratory environment with a temperature of 27°C and 45% humidity.

Additionally, 10 samples were randomly prepared by the lead author using the same methodology for each sequence for the purpose of blind testing and a key was prepared. The lead author kept the key secret until these samples were analysed by other authors individually.

2.3. Analysis

The samples were analysed under a Nikon SMZ800N stereomicroscope (Tokyo, Japan) having a magnification of 2×10×8X. Images were captured by using a Nikon DIGITAL SIGHT DS-U3 camera head attached to the stereomicroscope. The whole system was connected to the NIS Elements software (Nikon, Tokyo, Japan) for the processing of the images. NIKON C- FLED2, a coaxial LED light source, was used to view the samples at a grazing angle (15° -20°). The photographs were recorded and stored in the computer attached to the stereomicroscope. Both sets of samples were compared based on the three micro-conformation features as observed by Wang [11] and Gupta and Saini [12] in their respective studies, and the results were noted.

Similarly, the blind samples were analysed based on the micro-conformation features. The results of the blind study were compared with the key to study the method's reproducibility and repeatability.

3. Results and Discussion

The three micro-conformation features, namely micro-conformation features of stamp inks, paper fibres, and toner particles, were analysed



to determine the sequence of non-intersecting strokes between a stamp impression and a laser-printed document using a stereo microscope. As the printing was done by using a laser printer, stray toner particles were scattered all over the document. These stray toner particles are not visible to the naked eye. Paper is made up of fibrous material that interlinks with each other to make the paper sturdy. These fibres are also microscopic and cannot be seen with the unaided eye. Each type of ink behaves independently and shows distinct characteristics when observed under a microscope. Thus, each micro-conformation feature is discussed in detail.

3.1. Micro-Conformation Features of Ink Distribution

3.1.1. Determination of Sequence in 75 and 100 GSM Papers

Stamp ink is a water-based ink and is susceptible to migration due to capillary forces. Due to the disturbance of fibres, the stamp ink moved along with the loose and distorted paper fibres. When the printing was above, and the stamp impression below, a uniform and regular distribution of ink at

the edges of the stroke was observed in the case of 75 and 100 GSM papers. This could be due to the force and heat applied by the rollers of the laser printer during the process of printing. However, in the opposite case, when the printing was below, and the stamp impression was above, the ink distribution was found to be irregular and non-uniform (Fig. 1) (Table 2). The results of the present study were in accordance with Gupta and Saini [12]. However, Wang *et al.* [18] and Wang [11] observed that when the toner was below and the pen ink was above, homogeneous and regular ink distribution was observed. These observations might be influenced by the type of ink and its behaviour with different types of paper.

3.1.2. Determination of Sequence in Glossy Paper

In the case of a glossy paper, a uniform and regular distribution of ink was observed in both sequences. However, certain voids were observed under a stereomicroscope (Fig. 1). The reason for these voids may be that the ink used in the stamp pads is water-based, and the glossy paper has a thin

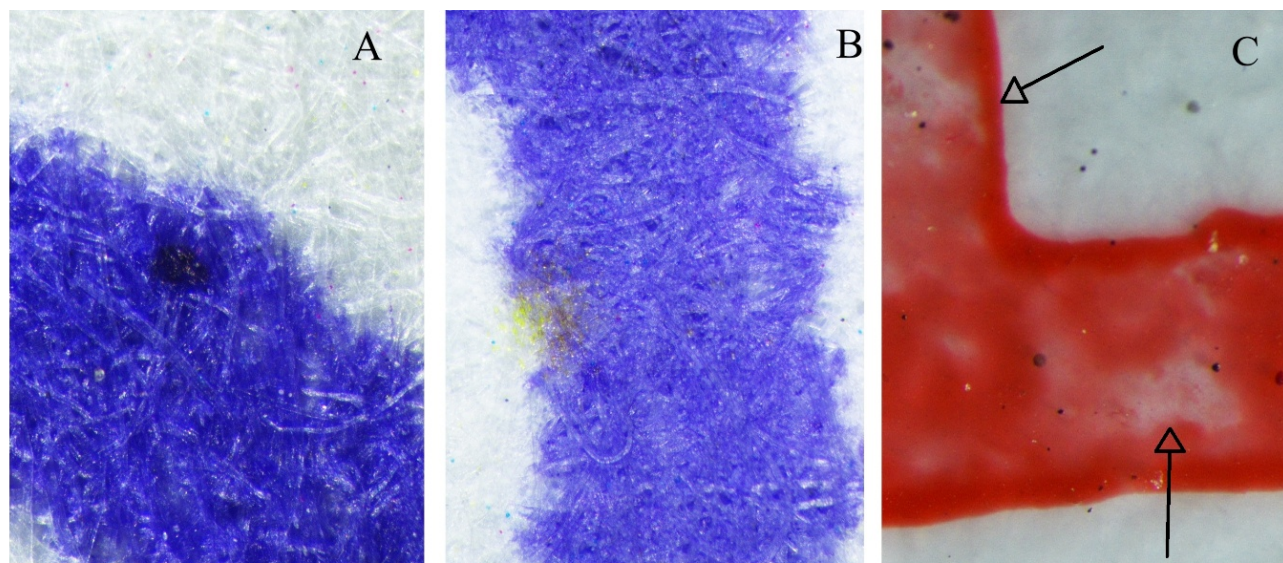


Figure 1- (A) Uniform and homogeneous deposition of ink on the edges of the stroke when stamping was done before printing. (B) Non-uniform and irregular deposition of ink when stamping was done after printing.



Table 2- *Micro-conformation features of ink distribution for determining the sequence of printing and stamping without intersections.*

Features	Stamp Above, Printing Below	Printing Above, Stamp Below
Ink distribution in the case of 75 and 100 GSM papers	Non-uniform and irregular edges in the case of 75 and 100 GSM papers. Uniform and regular edges and voids were observed in glossy paper.	Uniform and regular edges. Voids were observed in glossy paper.
Ink distribution in the case of glossy paper	Ink moved along the cracks	Ink folded along the polymer/resin film

polymer/resin layer on its surface, which repels the water-based ink, creating such voids. Further, the ink moved along the cracks of the polymer/resin film when the printing was done before stamping (Fig. 2). This could be due to the water-based nature of stamp inks. However, in the opposite case, when stamping was done before printing, the ink folded along the polymer/resin film (Fig. 2) (Table 2). This could be due to the fact that the ink was already on the glossy paper, and as it passed through the rollers of the printer, the heat and pressure curled the thin polymer/resin film along with the stamp ink. The colour of ink had no effect on the micro-conformation features of ink distribution. Thus, the sequence of stamping and printing could be determined based on the micro-conformation features of fibre distribution in the case of all types of paper.

3.2. Micro-Conformation Features of Fibre Distribution

3.2.1. Determination of Sequence in 75 and 100 GSM Papers

The application of stamp impressions led to the disturbance or distortion of the paper fibres in the case of 75 and 100 GSM papers. Although the rubber stamp does not have much tendency to distort the fibres due to its soft nature, unlike pen

nibs, which are sharp and have a greater capacity to disturb the paper fibres.

In the case of 75 and 100 GSM papers, when the printing was above, and the stamp impression was below, the distorted fibres appeared on the same level as the fibres on the surface of the paper (Fig. 3). This could be due to the fact that the sheet of paper passes through the rollers of the printers, leading to the compression of distorted paper fibres. In the opposite case, when the printing was below, and the stamp impression was above, the distorted fibres were elevated above the level of the fibres on the surface of the paper (Fig. 4) (Table 3). Similar findings were reported by Wang [11] and Gupta and Saini [12] in their respective studies. The colour of ink did not affect the micro-conformation features of fibre distribution. Thus, the sequence of stamping and printing could be successfully determined based on the micro-conformation features of fibre distribution in the case of 75 and 100 GSM papers.

3.2.2. Determination of Sequence in Glossy Paper

In the case of glossy paper, the distortion of fibres was not observed because it had a thin polymer/resin layer on the paper surface, preventing the disturbance of fibres. However, due to the application of heat and pressure during the printing process, curling and cracking of this polymer/resin layer



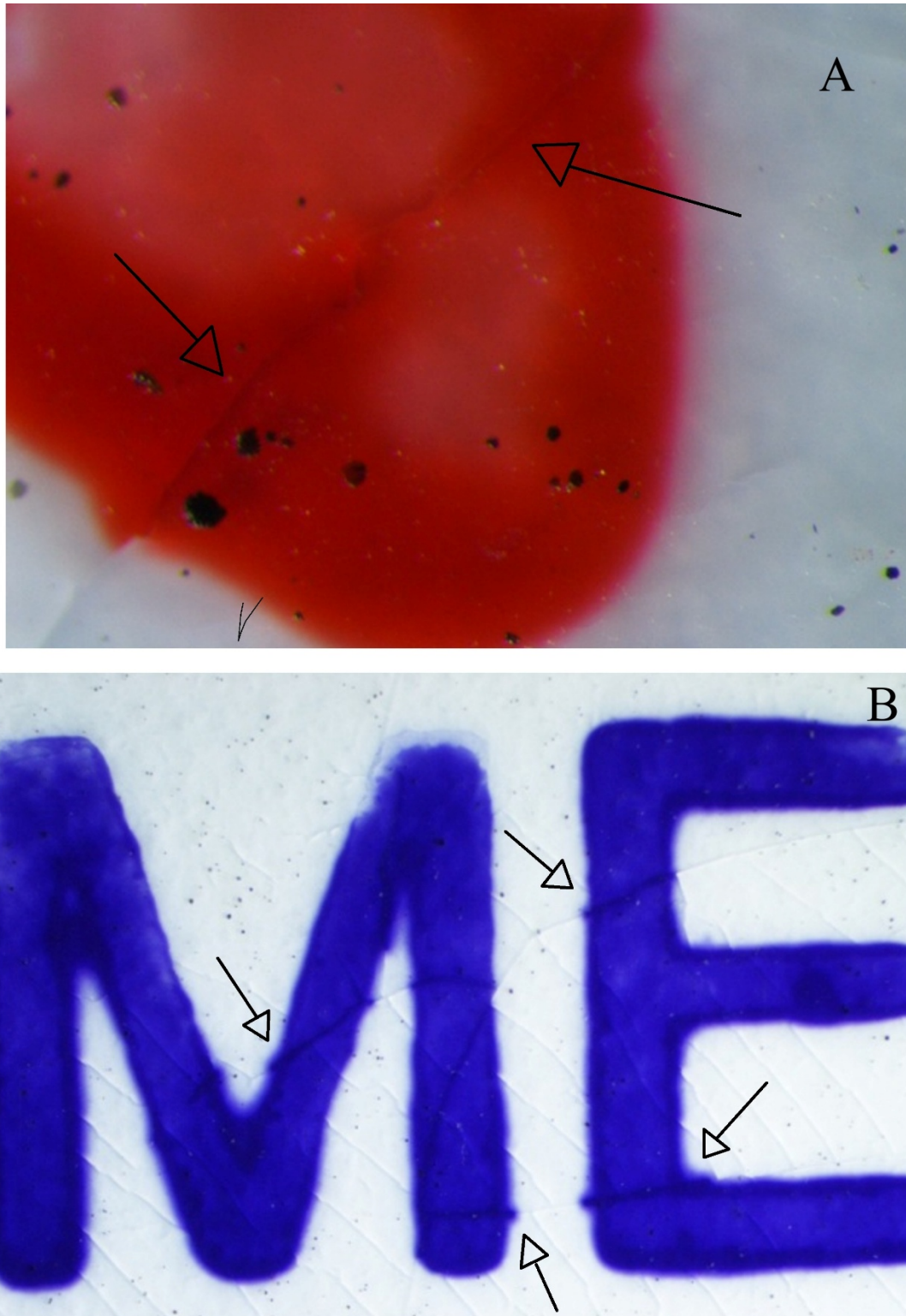


Figure 2- (A) Folding of ink along with the polymer/resin layer when the document was stamped before laser printing. (B) Movement of ink along with the cracks of the polymer/resin film when the laser printing was done before stamping.



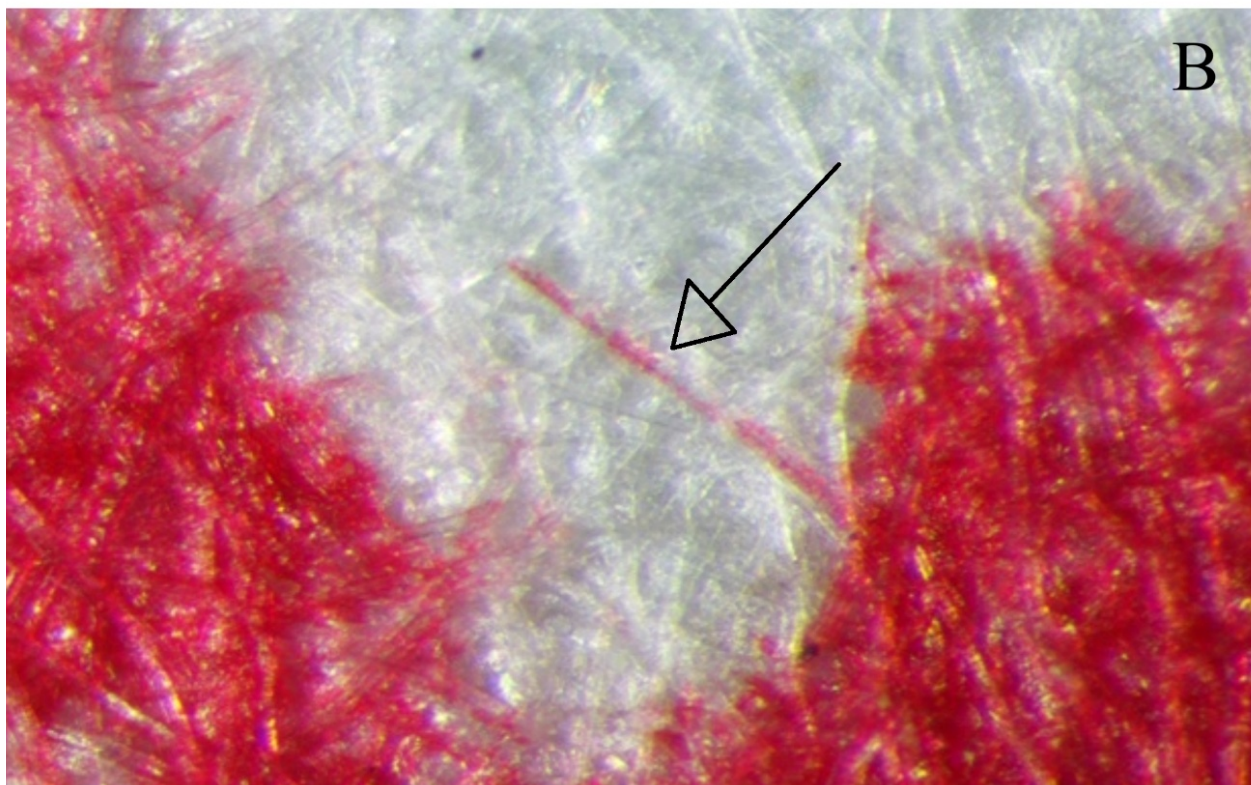
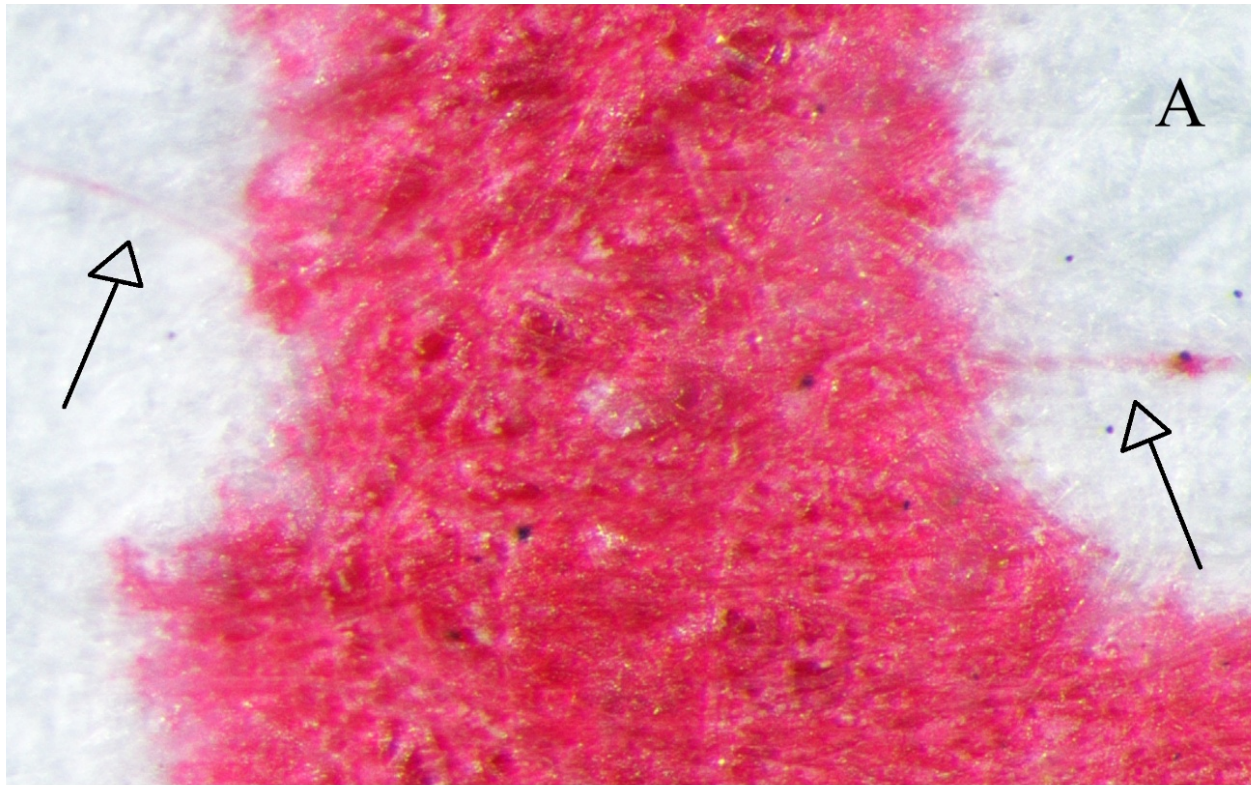


Figure 3- Loose-inked fibre resting along the paper surface when stamping was done before printing.



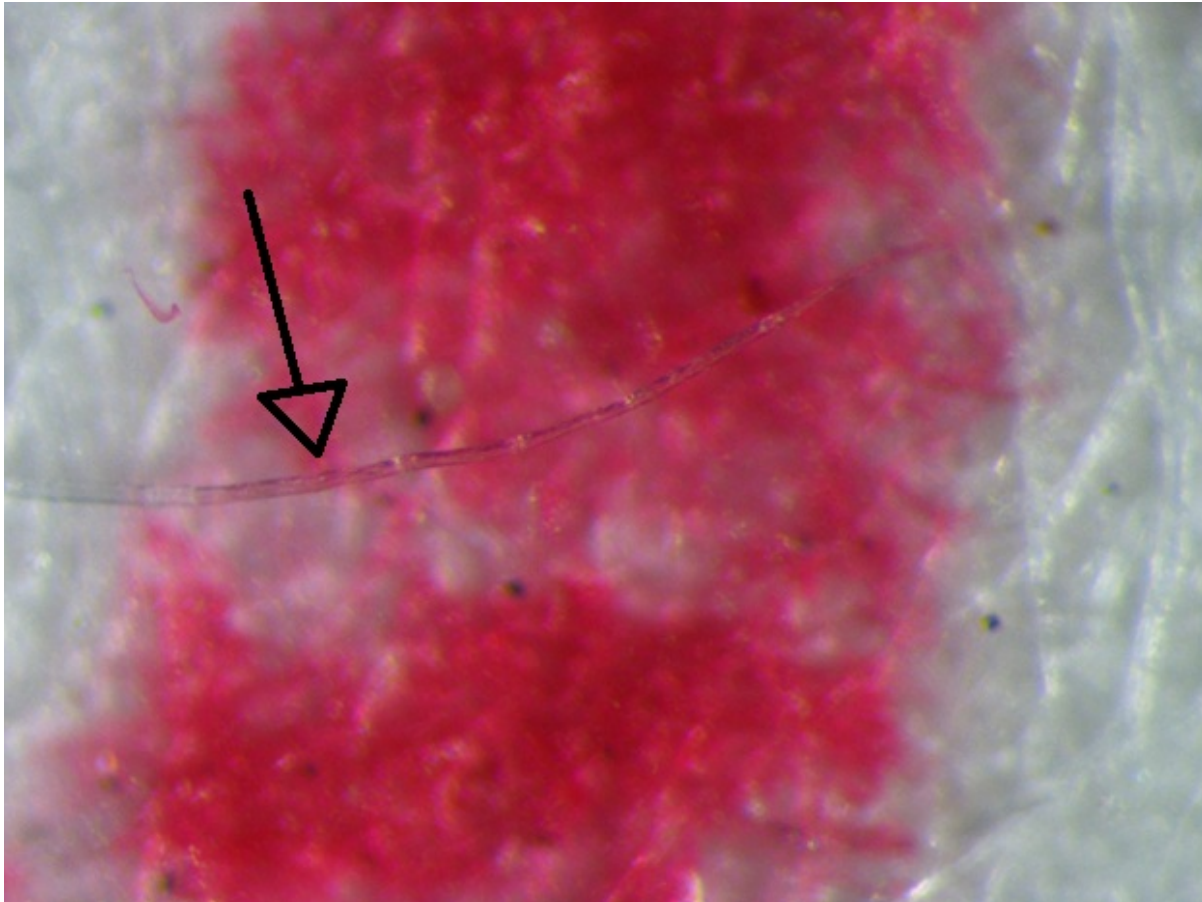


Figure 4- Raised fibre due to the disturbance in the paper fibres of 75 GSM paper when the stamp is executed after laser printing.

were observed, irrespective of the sequence of the document production (Fig. 2). Thus, the sequence of stamping and printing could not be determined based on the micro-conformation features of fibre distribution in the case of glossy papers.

Further, indentations/grooves were not observed (less prominent) in both the sequences of printing and stamping. This could be due to the fact that the rubber stamp was soft, and the pressure applied to make the stamp impression was not enough to create indentations. Gupta and Saini [12] observed prominent indentations when the pen writing was made after printing. However, in the opposite case, these indentations disappeared. Thus, the sequence of stamping and printing could not be

determined based on the indentations on any type of substrate (paper).

3.3. Micro-Conformation Features of Toner-Particle Distribution

3.3.1. Determination of Sequence in 75 GSM, 100 GSM and Glossy Papers

In all the types of paper, in both cases, when the printing was above or below the stamp impression, the toner particles were found to be round and raised. A slight flattening of toner particles was observed in some instances when the stamp was above. However, the presence of round toner particles was dominating. Additionally, sheen (a white colour dot) was observed on the toner particles at a grazing



Table 3- Micro-conformation features of paper fibres for determining the sequence of printing and stamping without intersections.

Features	Stamp Above, Printing Below	Printing Above, Stamp Below
Fibres of 75 and 100 GSM paper	Distorted paper fibres elevated above the level of the paper surface	Distorted paper fibres on the same level of the paper surface
Grooves on paper	Less prominent	Less prominent
Curling/cracking of the polymer/resin film of glossy paper	Present	Present

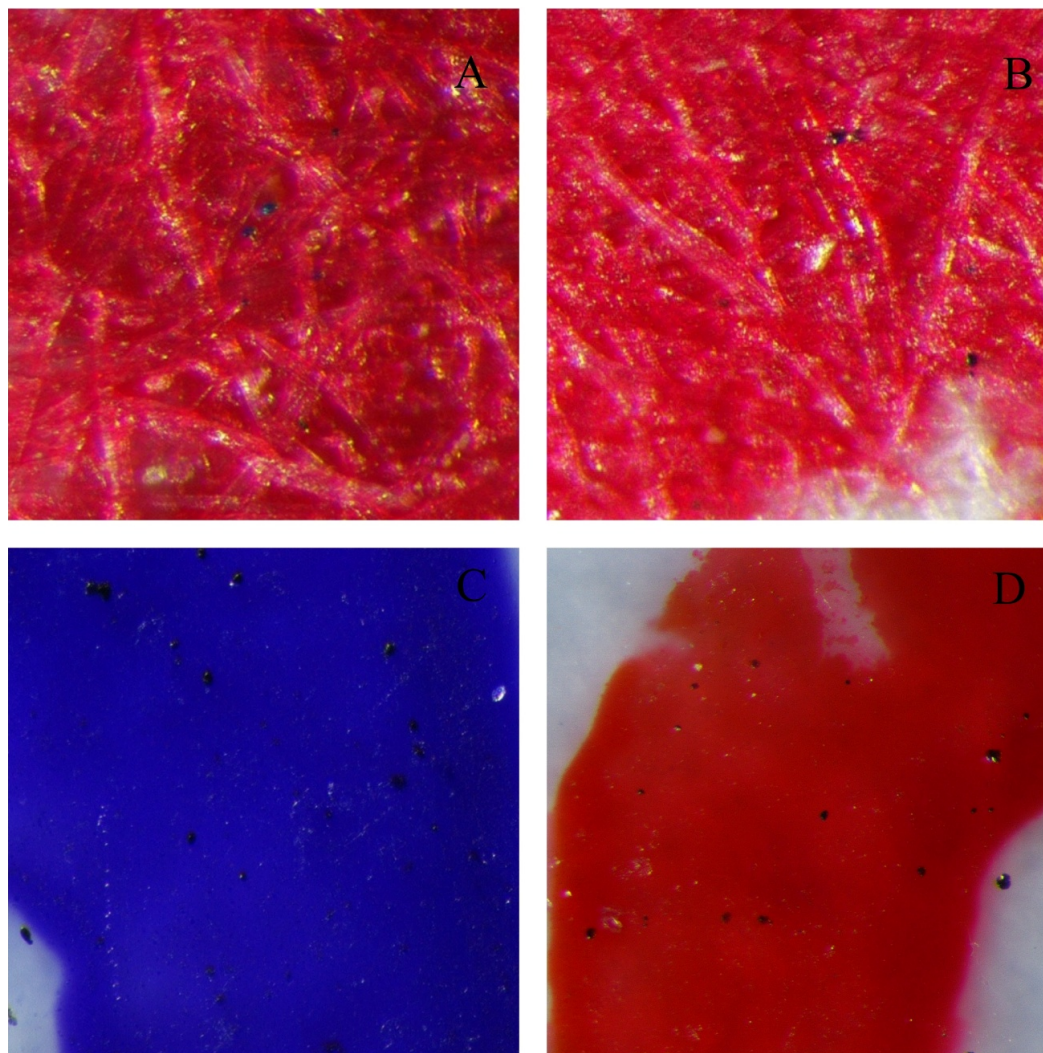


Figure 5- (A) Presence of sheen on round toner particles on 75 GSM paper when printing was done after stamping. (B) Presence of sheen on toner particles (at places) and round toner particles on 75 GSM paper when the stamping was done after laser printing. (C) Presence of sheen in the glossy paper when the stamping was done after laser printing. (D) Presence of sheen in the glossy paper when the stamping was done before laser printing.



Table 4- *Micro-conformation features of toner particles for determining the sequence of printing and stamping without intersections.*

Features	Stamp Above, Printing Below	Printing Above, Stamp Below
Shape of toner particles	Mostly Round and raised	Round and raised
Appearance of toner particles	Dull	Dull
Sheen on toner particles	Diminished sheen is present in the case of 75 and 100 GSM paper. Present in the case of Glossy paper.	Present

angle of illumination for all three types of paper (Fig. 5). This could be due to the fact that the rubber stamp was soft, and when the stamp was applied to the paper, the pressure exerted on the toner particles was not enough to squeeze them. In the case of glossy paper, in addition to the low pressure, a sheen may be observed on the toner particles because the glossy paper has its own shine, which appears as a sheen on the toner particles (Fig. 6) (Table 4). The aforementioned observations introduce uncertainty when attempting to establish the sequence.

The results of the studies conducted by Seitz [20], Aginsky [10], Wang *et al.* [18], Wang [11], and Gupta and Saini [12] to determine sequence of writing using different types of pens and laser printing without any intersecting stroke presented different results in the case of samples where the toner particles were below, and the pen ink was above. The reason behind these observations was that the tip of the pen is hard (mostly metallic) and has less surface area. Thus, when writing is executed, enough pressure is generated to rupture the toner particles. Contrarily, rubber stamps are soft and have more surface area than the tip of a pen. Thus, enough pressure is not generated to rupture the toner particles. Hence, the sequence of printing and stamping could not be ascertained based on the micro-conformation features of toner particles.

3.4. Effect of Paper, Stamp and Printers

The stamps used in the study were soft rubber stamps. Stamping pressure is an important factor that may influence fibre disturbance, ink distribution, and surface morphology. Although all stamp impressions were produced by the same individual to maintain procedural consistency, minor variations in manually applied pressure could not be completely eliminated. These unavoidable differences may have introduced slight variability in the observed microscopic characteristics. Future studies may employ pressure-controlled or automated stamping devices to achieve greater standardisation and improve reproducibility of results. The colour of stamp ink does not affect the study in the case of coloured printers. However, it might affect the results in the case of black-and-white laser printers with black-coloured stamp impressions.

Further, different types of laser printers use different types of toner particles, and their size and distribution cannot be controlled. The best results are obtained with coloured laser printers, as they print using 4 colours of toner particles (CMYK), which helps to create a contrast between different colours of stamp impressions. The examiner must be well aware of these factors that might affect the observations, and it is advised that any opinion must be given only if the examiner is satisfied and confident with the observations.



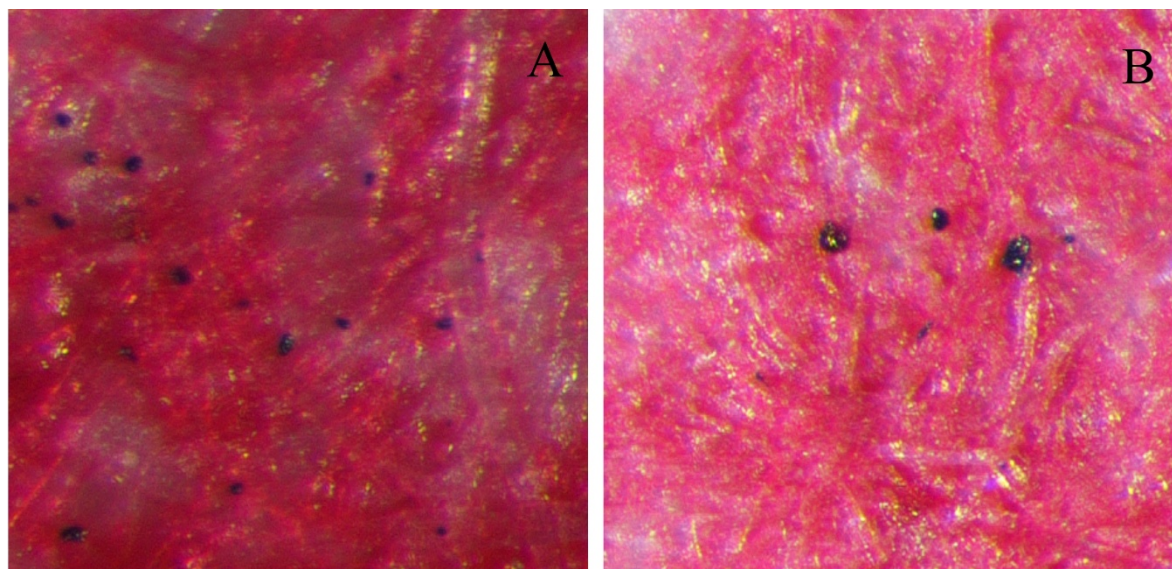


Figure 4- (A) Mostly round and dull toner particles with diminished sheen on 75 GSM paper when the stamping was done after laser printing. (B) Round and dull toner particles with sheen on 75 GSM paper when the stamping was done before laser printing.

3.5. Blind Study

The blind test samples were examined using the methodology used in this study. After careful examination of all 20 blind samples, the correct interpretation was made for 85% of the samples only. The three samples that were not correctly identified included documents where glossy paper was used. The shine on the glossy paper sometimes overpowered other micro confirmation features. The misinterpretation in the 15% samples is justified by the results obtained in the study, which are tabularised in Tables 3-4, because of similar observations in both the sequences of stamping and printing. Although this validated the methodology that was followed and the results obtained in this study. However, it also raises a concern about the correct interpretation of the sequence of samples that might have been stored in a variety of conditions and might have gone through a lot of wear and tear over time. Thus, this can be considered a limitation of the study. Further, this study aimed to add scientific evidence in the case of documents in which stamp impressions are

used along with the signature. However, with this blind study, it is advisable for the examiners to be highly cautious before forming any definite opinion about the sequence of non-intersecting strokes of laser-printed documents and stamp impressions.

4. Conclusion

The study was performed to determine the sequence of non-intersecting strokes between stamp impressions and laser-printed documents. The analysis was performed using a NIKON SMZ800N stereomicroscope having a magnification of $2\times 10\times 8X$. The observations were made by the analysis of micro-conformation features of ink deposition, paper fibres, and toner particles. The results obtained showed that the sequence of non-intersecting laser printing and stamping could be established using micro-conformation features of fibre distribution and ink distribution. Best results were obtained with 75 GSM paper due to its loose fibres and coloured laser printers, which used coloured toners that created contrast with stamp ink to give better results. No effect of the colour



of the stamp impression was observed. However, the micro-conformation features of toner particles do not help in establishing the sequence. This is attributed to the insufficient pressure applied by the stamp on the toner particles during the stamping process. The results were conclusive, reproducible and repeatable for 75 and 100 GSM paper. Although certain difficulties may hinder a conclusive opinion in the case of glossy paper. Glossy paper posed greater interpretive difficulty due to its reflective surface characteristics, where the shine of the glossy paper hindered the observation of other micro-conformation features. Nevertheless, it is important for the scientific community to exercise caution when forming an opinion on the sequence of non-intersecting strokes of laser-printed documents and stamp impressions.

Conflict of Interest

The authors declare no conflicts of interest.

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