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Professional Practice Report

An assessment of a non-destructive magneto-optical imaging technique for the recovery of laser engraved marks from steel plates and firearm components

Bailey Henwood [a,*], Aimée Helliker [b], Rachael Hazael [a], Katherine Hewins [a]

[a] Cranfield Forensic Institute, Cranfield University, Defence Academy of the United Kingdom, Shrivenham SN6 8LA, United Kingdom
[b] Centre for Defence Engineering, Cranfield University, Defence Academy of the United Kingdom, Shrivenham SN6 8LA, United Kingdom

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ABSTRACT

The International Tracing Instrument (ITI) is a document adopted by United Nations Member States in 2005, which outlines challenges faced in the tracing of illicit weapons and offers suggestions to increase the success of tracing operations. A key provision of the ITI states that serial numbers must be recoverable if obliterated. This research, therefore, investigates two methods of recovering laser engraved marks on steel, due to the increase in firearms manufacturing relying on lasers to apply critical markings. This work uses 20 steel plates (CR4 grade), 6 AK-pattern rifle top covers, and a steel pistol slide to investigate the potential for visualising laser engraved marks. All samples had marks applied using a BWM-30F Fibre laser marking machine, in addition to any original manufacture's stamped marks on the pistol. All marks were removed using a grinding belt (plates) and a Dremel® rotary tool (slide and top covers) to average depths of 1200 μm (stamped) and 240 μm (laser engraved). Recovery of the marks was attempted using two techniques to compare the two techniques in their ability to recover laser engraved marks; Regula Forensics® Eddy Current Recovery kit, followed by traditional Fry's reagent. Both recovery techniques recovered 100 % (n = 6) of the stamped characters on the pistol slide, and 0 % (n = 509) of the laser engraved characters on the pistol, top covers and steel plates. Recommendations are made for forensic firearms examiners to avoid attempting the recovery of laser engraved marks using Fry's reagent to preserve the integrity of evidence. It is also suggested that manufacturers avoid laser engraving unique identifying marks on firearms, and to use more permanent methods, such as stamping, to remain compliant with politically binding documents such as the ITI.

1. Introduction

Firearm manufacturers apply a unique serial number to firearms to support their identification during production, onward shipping, and subsequent transfers to end users and owners throughout their lifecycle [1]. Serial numbers ensure effective record keeping methods by the manufacturers during sales to customers, such as government forces and resellers. When a weapon reaches the end user such as a police force or military, serial numbers may be used to assign personnel with individual weapons and ensure adequate stockpile management. In the civilian market, local gunsmiths and other registered firearm traders in many countries are required by law to record the serial numbers of the firearms they service, store, and sell [2].

The International Tracing Instrument (ITI) [3] is a document adopted by United Nations (UN) Member States in 2005. It is a politically binding agreement and outlines the challenges faced in the tracing of illicit weapons and offers suggestions and measures to increase the success of tracing operations. A key provision of the ITI states that serial numbers must be "recognizable, readable, durable, and as far as technically possible, *recoverable*" [3]. "Marking of Imported Firearms Under the UN Firearms Protocol" [4], authored by the South Eastern and Eastern Europe Clearinghouse for the Control of Small Arms and Light Weapons (SEESAC), claims that unlike marks that have been stamped into the firearms, marks applied by laser engraving cannot be recovered if obliterated. As such, the UN also recommend stamping identifying marks where possible [2]; however, this guideline is increasingly not being followed by manufacturers due to the low cost and rapid manufacturing involved with laser engraving these same marks. It is

* Corresponding author.
E-mail address: bailey.henwood@cranfield.ac.uk (B. Henwood).

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important to understand the limitations of current and emerging manufacturing methods and the likelihood of successful recovery if marks are removed, to optimise both forensic examinations and policy changes.

Stamping, a method of cold working used on steel, is historically one of the most common methods of mark application due to the simplicity of the machinery required and the low costs associated [4,5]. The stamp does not remove material but forces it away from the tool, affecting the underlying microstructure of the firearm [5]. Stamped marks result in material build-up around the edges of the mark and exhibit the highest level of compression to the underlying crystalline layers [6]. This compression of the microstructure in the lower layers of the metal allows the recovery of obliterated markings. The top layers of the steel are affected by the obliteration tool, but the integrity of the lower layers is maintained [6]. The lower layers of the material can then be exposed through the use of etchants to visualise the original markings [7–10].

Laser engraving is a process where a light beam passes over the material resulting in extremely clear marks while not compromising the underlying layers of the material [11–13]. Laser engraving can be used on various materials that stamping cannot, such as polymers and aluminium, and the machinery requires no re-tooling maintenance as there is no physical contact between the machine and the material [5]. A heat affected zone is generated by the laser beam which results in a build up of tensile residual strength, shown through the changes observed in the shallow layers of the microstructure [13]. The downside to this method of application lies in forensic applications; laser engraved marks produce the smallest area of localized deformation (seen in the heat affected zone) in the surrounding material, resulting in low recoverability [5]. There have been limited successful recoveries of marks applied using a laser by relief polishing [14] and etchants [7], however, the success is highly dependent on the depth of obliteration and is very time-consuming due to difficulty in controlling the parameters of the individual methodologies.

The recovery of identifying marks is undertaken in forensic laboratories where it is suspected that they have been removed from firearms involved in criminal proceedings. Recovery is currently conducted using chemical etchants, namely Fry's Reagent, to physically strip layers of the surface to expose deeper layers of the material to visualise the original markings [15]. Fry's reagent is a mixture of deionized water and cupric chloride, combined with hydrochloric acid [16]. While Fry's reagent can assist in the recovery of obliterated markings, it does so by causing irreprible damage to the surface of the material; both through the surface preparation and the chemical application [15]. This leads to the destruction of forensic evidence and renders the evidence impossible to re-examine if necessary. Therefore, if it is deemed the evidential value of the physical evidence outweighs the potential intelligence gained through recovery, Fry's reagent may not be used at the risk of damaging evidence. Other methodologies for recovering obliterated marks have been investigated in existing literature, and may be used and/or adapted in forensic practice around the world, such as relief polishing [14] or magnetic partical inspection [17], however are not considered as part of this pilot study. This paper, therefore, presents the potential for laser engraved marks to be recovered using an emerging technique which uses eddy currents[1] and magnetic fields to non-destructively visualise the markings post-obliteration. This is acheieved through visualising the microstructure of steel to detect any remaining material stresses in the material beneath the marks of the sample. The use of Regula Forensics® Eddy Current Recovery kit (ECK) [18,19] has previously been shown to be an effective method for the recovery of obliterated stamped marks on firearms [20].

[1] Eddy currents, also known as Foucault's currents [26], circulate within conductors, and are produced by alternating magnetic fields in closed loops perpendicular to the magnetic field plane produced by the magnetic stand of the ECK.

Based on the comparison of the two techniques, Fry's reagent and the ECK, recommendations for international policy makers, manufacturers, and forensic firearms examiners and practitioners will be made to reflect the potential of recovering laser engraved obliterated marks using the current standard (Fry's reagent) and the magneto-optical imaging technique.

2. Materials and methods

2.1. Steel plates

20 CR4 grade mild steel plates, with a mean Vickers hardness of 135 HV, had a microstructure composed of ferrite and pearlite. Each 60 mm × 100 mm × 2 mm plate was laser engraved using a 30-watt BWM-30F Fibre laser marking machine. These plates were used to simulate firearms with a laser engraved serial number, while maintaining consistent and known material properties. For the purposes of this study, a "character" is any single letter, number, or symbol. Each steel plate was engraved with twenty marks of ten characters (1234567890) to allow for increased recovery areas for sampling. The average depth of the engraving on the steel plate was obtained by cross-sectioning an engraved area and measured using a calibrated Olympus SC50 microscope at 50x magnification to 230 μm ± 10 μm. One of the 20 sample plates is shown in Fig. 1, showing an aerial view of the engraving, as well as a cross section of a laser engraved digit. In total, two characters from each steel plate were sampled to obtain the average depth. Fig. 1 also shows cross section of a single digit, mounted in a black polymer mounting medium. At the edges of the engraved digit, material can be seen lipping up and outward on both edges of the engraving, and the uneven surface at the bottom of the digit.

2.2. Firearm & components

To compare the results of standardised steel plates, true firearm components were also used in this work. A steel Glock pistol slide (18.6 cm × 2.55 cm × 2.55 cm) was also laser engraved using the same BWM-30F Fibre laser marking machine. This was in addition to the pre-existing manufacturer stamped marks. The average depth of the marks applied post-manufacturing with the laser were 550 μm ± 10 μm, while the stamped manufacturing marks was 840 μm ± 10 μm. The depth of these marks was measured using a Vernier caliper, sampled in six locations on each item. Fig. 2 shows both the marks stamped during manufacturing and those added for the purpose of this study. In total, there were six original stamped marks, and seven applied laser engraved marks.

Six AK-pattern rifle top covers (24 cm × 3.5 cm × 3.5 cm) were also laser engraved, using the same standards and equipment. These top covers each had 17 marks of 10 characters (1234567890) applied

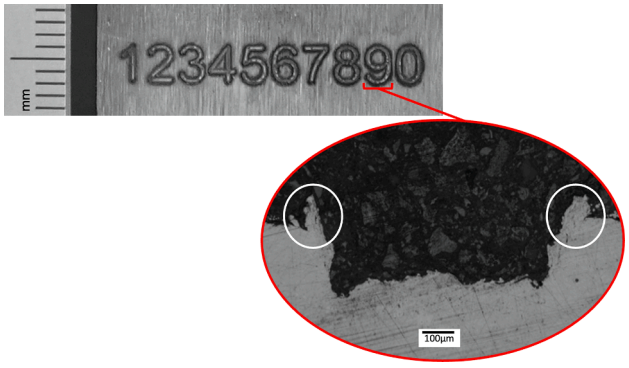


Fig. 1. One laser engraved serial number on a steel plate (left) and a cross section of the highlighted character (×50 magnification), showing the depth of the laser engraving (230 μm) (right). The lipping of the metal is circled.

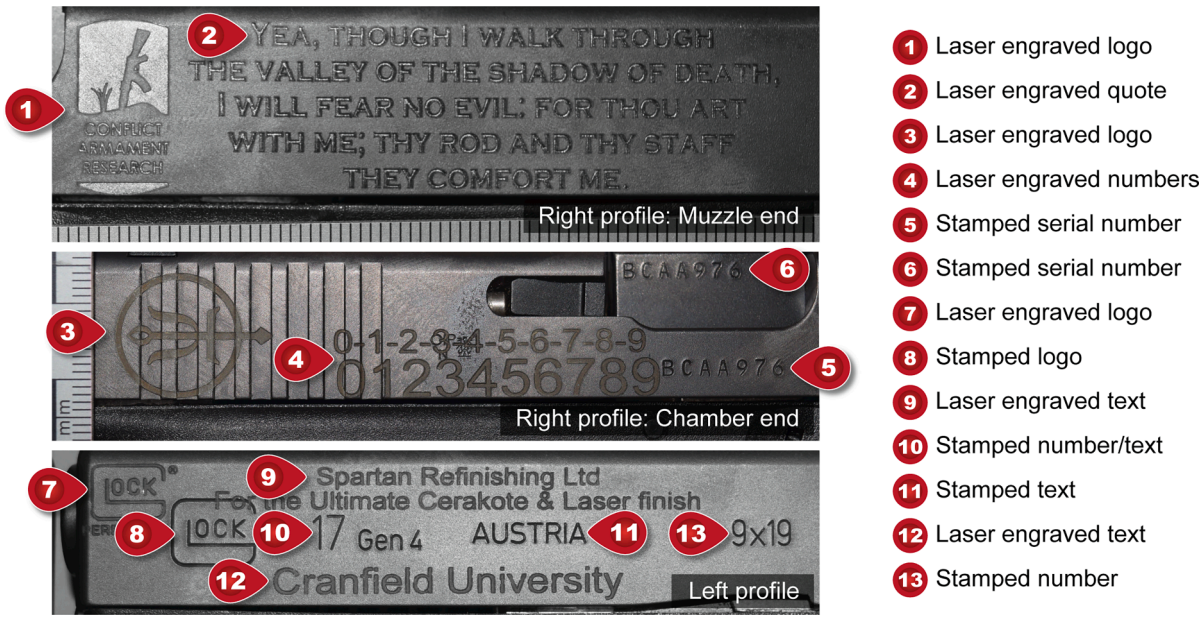


Fig. 2. The laser engraved and stamped marks removed from the right profile (top, middle) and left profile (bottom) sides of the pistol slide. Image authors own.



Fig. 3. The left side of an AK-pattern rifle top cover, with ten laser engraved marks ("1234567890").

(Fig. 3). In addition to the ten pictured on the left side, one was applied to the backface of the cover, and an additional six marks were engraved on the right side. There were no original stamped marks on these items.

The application of laser engraved marks using the same fibre laser engraver and settings ensured consistent conditions were held across all samples. The depth of the markings applied on different samples (plate vs slide vs top cover) differed only due to the material properties of each specific sample.

2.3. Obliteration

The steel plates were each obliterated using a grinding belt to a depth of 240 μm ± 5 μm. This depth was established by measuring the depth of engraving and removing material to 10 μm below the depth of the measured marks. This method of obliteration ensured the depth of obliteration remained consistent to a depth where the marks were no longer visible, whilst the material under the original mark was not disturbed, allowing the best chance of recovery.

Due to the size of the weapon components (pistol slide and AK covers), a Dremel® rotary tool with a grinding bit was used to remove the manufacturer stamped marks and additional laser engraved marks. This was conducted by one operator to a depth where the marks were no longer visible to the naked eye. The original surface was maintained to ensure a datum point remained for measuring the obliteration depth. Fig. 4 shows the pistol slide and a top cover post-obliteration, where the obliteration depth was measured at 1200 μm ± 10 μm (n = 10 measurements across all samples). To ensure the orientation of the recovery scans some features (small amounts of laser engraved text) left unobliterated, which can also be seen in the figure.

2.4. Recovery

Two recovery techniques were used in this study: firstly, the non-destructive technique employing the ECK, and secondly the current forensic standard of Fry's reagent. The ECK technique was used to demonstrate any potential benefits of using a non-destructive technique to recover laser engraved marks, and has been used by the authors of this work in previous studies on dot-peened and stamped samples [20]. The kit utilises eddy currents and magnetic fields to visualise the substructure of metals, in turn showing the crystalline deformation within the material where serial numbers and other marks are applied. The electromagnetic image is captured by magnetic tape placed on the surface of the obliteration and visualised using specialised hardware as provided with the kit. Fry's reagent technique was selected as a current industry standard for serial number recovery in forensic firearms laboratories that are accreditated to ISO 17025 [21]. In addition, it was used on each sample after the non-destructive method.

The settings on the eddy current machine were adjusted for each sample to obtain the clearest magneto-optical image. To adjust the strength of the magnetic field, additional magnets from the ECK are

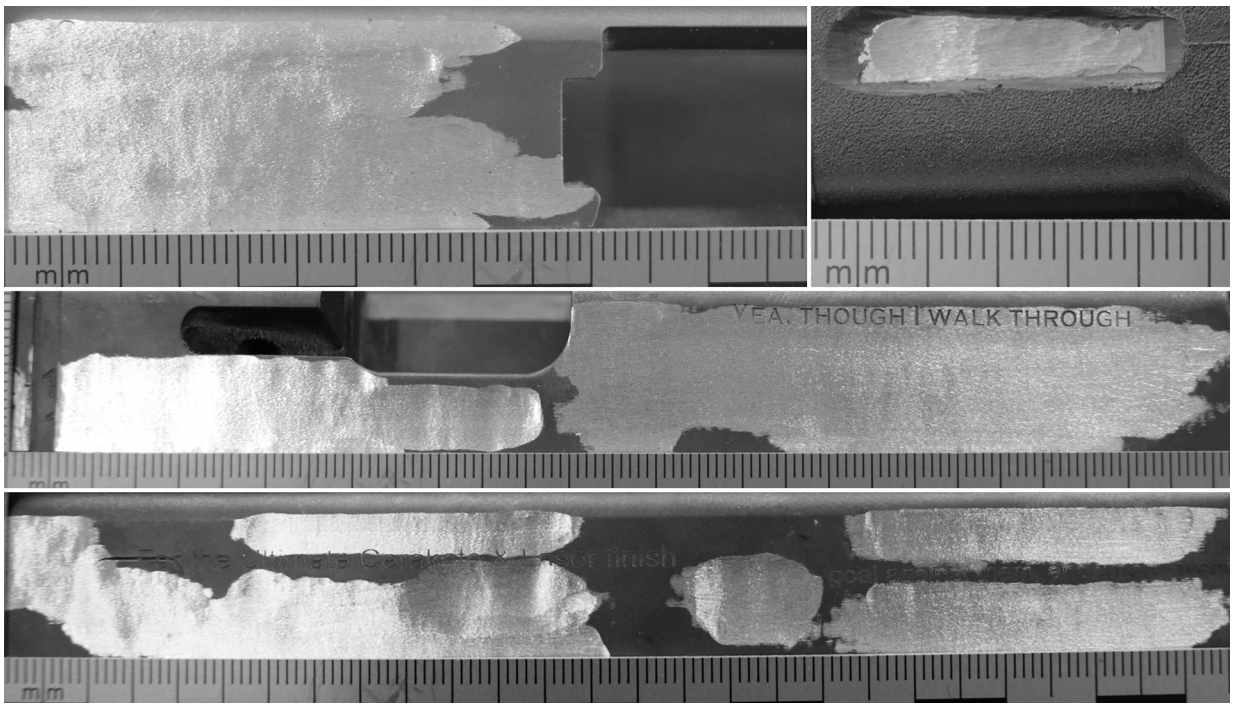


Fig. 4. Each side of the pistol slide (top, middle) and the backface of a top cover (bottom) after the marks were removed with a Dremel®.

added to the area around the obliteration. The steel plate, AK-pattern top covers, and the top slide of the Glock were positioned on the ECK magnetic firearm base, no additional magnets were used to manipulate the magnetic field. The eddy current pulse amplitude was set to the lowest level (on a scale of 1–12) in the first instance and increased until optically favourable (to the trained user) to obtain the clearest scan possible.

Fry's reagent was made using 5 g of copper chloride in 25 ml of ethanol and 40 ml of hydrochloric acid in 30 ml of distilled water [22]. The solution was heated to 30 °C and brushed on to the surface of each sample using cotton buds inside a fume hood. This process was repeated until a mark was revealed, or depth of material removed exceeded the depth of the laser engraved markings observed in the cross-section of Fig. 1.

3. Results

3.1. Steel plates

0 % (n = 400) of the laser engraved marks were recovered from the steel plates using the ECK technique. From this method the clearest magneto-optical image was obtained at an amplitude level 8 (Fig. 5), showing the microstructure of the steel without any residual markings from the laser engraving. There are shadows on the image, however those are attributed to the magnetic tape.

Additionally, Fry's reagent did not successfully recover any of the laser engraved marks from the steel plates.

3.2. Pistol slide

Using the ECK, the attempted recovery on the slide showed the clearest result at level 8 of 12 on the pulse control unit. The results showed that while faint, the stamped manufactured marks were visible, and the laser engraved marks were not. The stamped manufactured marks "9 × 19" and "Austria" are circled in Fig. 6, while the blank spaces (rectangles) are where the laser engraved text should have been recovered. The visible marks in Fig. 6 are the laser engraved marks that were not removed, allowing the orientation of the scan.

Fry's reagent successfully recovered all (n = 6)of the stamped marks from the slide, and did not recover any of the seven laser engraved marks. Fig. 7 shows an example of the Fry's reagent recovery of a stamped mark and highlights one area where the laser engraved marks were removed, but not recovered. Also included in Fig. 7 are the marks before removal, for visual comparison.

External consultation of the resulting magneto-optical image was conducted by third party examiners to ensure the marks could be identified by those who had no pre-existing knowledge of the location of identity of the marks. The results of these consultations can be found in the supplementary information.

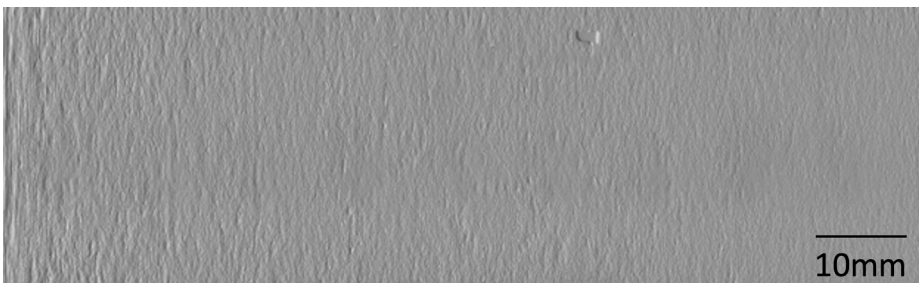


Fig. 5. The clearest magneto-optical image of the obliterated steel plate microstructure.



Fig. 6. The left side of the pistol slide, where all stamped manufactured marks (highlighted in rectangles and annotated) are visible on the ECK scan after obliteration, at level 8. The applied laser engraved marks are not visible (dotted rectangles).

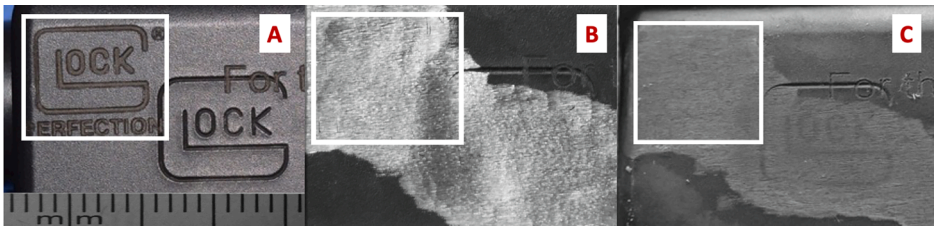


Fig. 7. The front left side of the pistol slide. (A) the marks before obliteration, (B) the marks after obliteration, and (C) the stamped "Glock" logo was recovered using Fry's reagent, and the laser engraved logo was not recovered (boxes). Note; additional laser engraved text was not obliterated and can be seen overlapping the Glock logo.

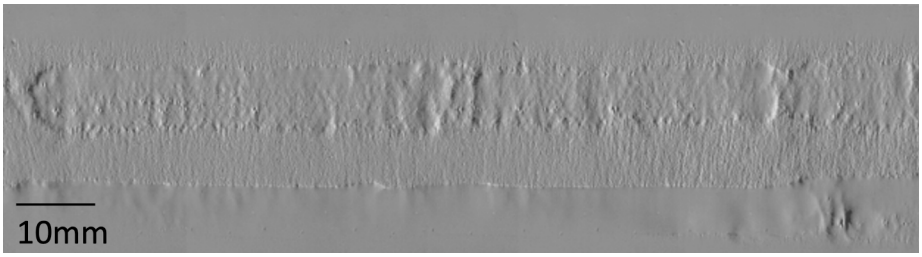


Fig. 8. The electromagnetic recovery image showing the microstructure of the AK-pattern rifle top cover, where the laser engraved marks were removed by hand using a Dremel® rotary tool.

3.3. AK- pattern rifle top covers

None of the 102 characters were visible in the electromagnetic image following recovery from the ECK, or when using the Fry's reagent. Fig. 8 shows the electromagnetic image of the eddy current scan, where the microstructure disturbance is clear, however, no characters are discernable.

3.4. Results summary

The number of both stamped and laser engraved marks on each sample type are reported in Table 1. The table also lists the number of marks that were successfully recovered by each method.

Table 1
Results summary of the marks recovered from each sample type using ECK and Fry's reagent. As the steel plates and AK top covers did not have any stamped marks, they have been greyed out in the table.

Sample Type	Number of Stamped Marks	Recovered by ECK	Recovered by Fry's Reagent	Number of Laser Engraved Marks	Recovered by ECK	Recovered by Fry's Reagent
Steel Plate				400	0	0
Pistol Slide	6	6	6	7	0	0
AK Top Cover				102	0	0

4. Discussion

The recovery of obliterated serial numbers and markings from firearms is an important capability for both forensic investigations and weapon tracing operations. Due to the destructive nature of chemical etchants like Fry's reagent, the investigative value of the potential results in a forensic examination needs to be weighed against the destruction of evidence. To offer a potential solution for the loss of future evidence on steel firearms and components, a non-destructive methodology of ECK was used to determine the efficacy of this novel technique for recovering laser engraved marks. In addition, Fry's reagent was utilised to attempt the recovery of obliterated laser engraved marks to provide a baseline comparison of results.

The non-destructive ECK was employed first, to preserve the integrity of the samples for later testing. As previously described, the ECK detects structural differences in the microstructure of the steel and visualises it through magneto-optical digital images. As shown in the example (Fig. 7 above), all stamped marks (n = 6) were recoverable with clear results. This is an expected result for stamped marks based on continuous, proven use in forensic laboratories, relying on the plastic deformation to the microstructure of the steel below the original mark. The total laser engraved characters (n = 509), were not recovered via ECK (also pictured in Fig. 8), demonstrating that the microstructural alteration in the steel by laser engraving are insufficient to allow for recovery using this technique.

Fry's reagent was used to attempt the recovery of all applications after the ECK due to its destructive method of recovery and irreversible damage to the steel. Of the 8 stamped marks, limited to the pistol slide, all were recovered. This was an expected result, as Fry's reagent is used globally to recover obliterated marks from firearms with good success. The obliterated laser engraved marks, however, did not obtain the same results with the application of the etchant, with 0 % of the characters recovered (n = 509).

It was determined that neither Fry's reagent, nor the Regula Forensics® Eddy Current Recovery kit were successful in the recovery of laser engraved marks from steel plates or steel firearm components. This study has, therefore, shown that marks applied with a laser are not recoverable from steel using two methods that are reliably used in forensic and tracing investigations. This study, in addition to previously published work [7,8,23], supports the conclusion that to maintain the recoverability of obliterated marks, manufactures of firearms should continue applying serial numbers and other identifying marks using cold-working methods such stamping.

4.1. Limitations

The CR4-grade steel is not commonly used in firearms, the cost and availability of more appropriate steel restricted acquisition. However, it does have similar carbon content, tensile strength, and yield stress to that used in weapons-grade steel [24,25]. The use of true firearm components for comparison permitted the most accurate way of comparing the potential for recovery to real-life forensic and tracing cases. As the depth of the laser engraved markings on the plates did not penetrate as deep into the material compared to those measured on the firearm components, and the marks were still unrecoverable, it is unlikely that the type of steel used would significantly impact the potential for recovery.

Due to the shape of the slide and top cover components, the belt grinder could not be used to remove the marks, instead a Dremel® was used. In an effort to reduce the inherent inconsistency in this method of obliteration, one operator conducted all obliterations, and carefully and consistently removed minimal material until the mark was no longer visible to the naked eye. This was done in shallow layers with little pressure applied to the surface.

Finally, the ECK has only been shown in this study on ferromagnetic steel. The manufacturer includes tools for the examination of aluminium, however the effectiveness of recovery from aluminium was not examined in this work.

5. Conclusions

This pilot study has shown that Fry's reagent, an industry-standard chemical etchant, and Regula Forensics® Eddy Current Recovery kit, a proven non-destructive method, were unsuccessful in recovering any of the applied laser marks. The authors suggest future work be conducted to expand the types of samples used with varied materials, depth of marking, and methods of marking to validate these findings further.

From these results, forensic practitioners are recommended to establish the method of application of the marks they are attempting to recover, primarily to avoid attempting the recovery of laser engraved marks using a strong chemical etchant. This will preserve the integrity of forensic evidence in case of potential failure to recover the mark as shown in this study. Additionally, to maintain compliance with the ITI and other international legislation, firearm manufacturers in countries subscribing to these political agreements should use more permanent cold working methods (eg stamping) when applying unique identifying marks. This highlights the need for further refinement of politically binding agreements to clarify the requirements for the marking of firearms by manufacturers to ensure full traceability.

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Previous Presentation

This work has not been presented previously, in whole or in part.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scijus.2023.10.007.

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