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Restoration of Stamp Marks on Steel Components

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Abstract

Stamp marks are used as a unique identification for a range of items, but these can be erased for criminal activities. Erased marks can sometimes be recovered by etching or magnetic means. The present study looked at the application of Fry's reagent to recover erased marks from steel. The investigation also demonstrated that Fry's reagent can deteriorate on storing and requires a longer etching time.

The effect of different applied forces of stamping was investigated, and the depth of the underlying deformation was determined by etching with varying degrees of metal removal. The amount of metal needing to be removed depends on the force applied to the die. Metal removal also affects the time needed for recovery. The underlying structural change remains as a hidden identification mark, and could potentially be used by manufacturers as an unseen identifier.

Keywords

Erased marks, recovery, etching, restoration of stamp marks

Introduction

Identification marks are imprinted on a range of components and items. However, the criminal fraternity will try to remove these identification marks either to avoid association with the item (e.g. firearms) or to produce a false identification mark for onward sale (e.g. VIN cloning of vehicles). The techniques used include filing, grinding, over-stamping, drilling, welding etc.[1] Forensic examination can, however, recover the erased mark in some circumstances, allowing the source of the item to be traced.

Recovery depends on a number of issues, not least being the material substrate and the technique originally used for imprinting. Die stamping is most common, although roll pressing and embossing can also be used to produce an imprint on the surface of the substrate. In recent times laser etching has been developed, and other methods such as hot stamping; engraving and adhesive labels are also used. Modern advances in labelling mean that micro-chipping or RFD implants may be used in the future for unique identification, but current and historic practice has predominantly been die stamping.

In die stamping plastic deformation occurs leaving a void or impression in the shape of the die. The forces required to deform the metal result in an underlying region of strain and modified crystal structure that can often be recovered by careful etching. A similar effect can occur in polymers and the strain can be revealed by localised swelling when a solvent is applied, or by dye penetration. [2] However, recovery is complicated as the polymer has little underlying crystallinity, and being softer it is easier to remove the original markings

Recovery of erased marks from metals depends on the metal substrate [3]. Steel alloys are commonly encountered materials in forensic cases due to the mechanical properties of steel, and Fry's reagent has been shown to be a good reagent for recovery [3]. Commercially, Fry's reagent is sold to forensic teams in the UK as a reagent for erased mark recovery.

In 1987 Turley [4] carried out an extensive study of the recovery of erased marks in steel and little further work has been published since then because` the technique is well established. However, Turley's experiments only considered the depth of penetration and did not consider the force required to produce plastic deformation. The present study was therefore carried out to look at the effect of the original stamp force on the ability to recover erased marks.

Method.

First Series. A series of mild steel discs were cut for the first set of experiments and a series of Charpy notch test specimens were used in a second series of tests. To ensure consistent imprints were obtained, the disc was imprinted by a single letter steel die using a press. Forces of 20, 30 and 40 kN (2, 3, and 4 tons) were applied. Below 20 kN little imprint was made and above 40 kN the letter was fully immersed in the metal and the shaft of the die started to contact the metal disc. Different letters were used to ensure there was no observer bias looking for a particular combination of letter strokes. This is important as partial recovery can lead to misjudgement of the letter involved.

The disc thickness was measured using vernier callipers and the disc was filed to erase the letter. The new depth was measured to determine the die penetration, and further filing continued until the pre-chosen depth below the imprinted letter was achieved. The disc was then polished on a series of silicon carbide grits to remove the file marks since it is well known that surface preparation is important in achieving good recovery. In the present study, though, we did not find that we needed to use diamond paste or a pre-etch in order to achieve good results.

The disc was etched with Fry's reagent (90g of Copper Chloride, 120ml of concentrated Hydrochloric Acid and 100ml of water) for a period of time. The sample was kept under a watch glass to avoid evaporation and periodically fresh reagent was added. Approximately every hour the specimen was rinsed with methanol (to avoid copper deposition) and observed. If no recovery was achieved after 9 hours the test was terminated.

Over-Stamped Items. In order to confirm that recovery can be achieved from over-stamped items, two tests were carried out where a chisel was used to deface the imprint. Whilst it is common for serial numbers to be filed off, it is becoming more common for the numbers to be obliterated in this destructive fashion. The criminal thinks that if the number is no longer legible then there is no chance of anyone else ever reading it. However the results from the tests in this section show that this is not necessarily the case. After removing 1.6 mm of metal (0.6 mm to remove the original imprint and a further 1 mm), the discs were etched as normal and the imprint was recovered. In practice, less metal would normally be removed during the sample preparation before etching.

Aging of Reagent. It was noticed that Fry's reagent appeared to be less reactive after storage, even though it was stored in a dark cupboard in a sealed container.. Precautions had been taken to prevent contamination, evaporation, crystallisation, photo-degradation or oxidation taking place, and it was decided to investigate this phenomenon. A series of discs were stamped at 30 kN (3 tons) and abraded to 0.5 mm below the imprint. A clean Pasteur pipette was used to extract etch reagent and a different disc was etched using the same batch of reagent after 1, 2, 3, and 4 weeks. The disc was regularly removed from the etch solution and it was noted whether any recovery was visible. A slight increase in etch time was required from 95 to 115 minutes. For this test the conditions were chosen so that recovery would be rapid in order to allow regular observation of the sample. The results appeared to confirm that some degradation can occur, but further study is required.

Second Test Series. Finally, a series of tests were carried out using Charpy notch samples with aligned grains. Different forces were applied to four imprints on the same sample, all were filed or ground to the same degree, and each was etched for the same time period. The purpose of this experiment was to observe recovery from a different steel. This test does not indicate the maximum recovery depth, and multiple tests would be needed to achieve that. However, it did confirm observations made on the original discs, and demonstrated the effect of deformation of the metal grains.

Results

Depth of Impression. The depth of impression was recorded by measuring how much material had to be removed to obliterate the mark. It was, however, noticed under the optical microscope that burrs of metal from filing tended to infill the groove and weld together (Figures 2a, and 2b)

This appeared to be more of a problem with imprints made with low applied force, possibly because the metal burrs stay attached to the metal surface and a shallower depression is easier to in-fill, but this could not be confirmed. A consequence from a forensic point of view is the criminal is likely to believe the mark is obliterated, but during the etching stage liquid can penetrate and remove this infill and produce a sharper mark. Figure 3 shows the appearance of the letter V with etching of the strained area visible, but a much clearer mark where the in-filled impression was.

Figure 4 shows the measured depth of metal that needed to be removed in order to obliterate the imprint and corresponds with the imprint depth. From the graph it can be seen that there is a difference between the two series, probably due to the different yield strengths of the two materials.

Depth At Which Recovery Is Still Achievable. The results of the etching tests are shown in Table 1 and show that the greater the applied force the deeper the impression. As already noted, below 20 kN little impression was made and above 40 kN the main body of the die started to make an impression.

Applied Force kN	Imprint Depth mm	Additional Metal Removal mm						
		0.25	0.50	0.75	1.00	1.25	1.50	2.0
20	0.1	Yes (4)	Yes (2,7)	No (3)	Yes (5)	No (6)		No (1)
30	0.3		Yes (8)	Yes (9)	Yes (10)	Faint (11)	No (12)	
40	0.6			Yes (13)	Yes (14, 17)	Very faint (15)	No (16)	

Yes = successful recovery. No = no recovery. (a) indicates sample number

Table 1: Ability to Recover Erased Mark Under Different Conditions.

Effect of Storage Of Reagent. The results of etching time over a four-week period during which the reagent was stored in a cupboard are given Figure 5.

Discussion

Correlation of Penetration Depth And Applied Force. Turley's work showed a correlation between depth of stamp and the maximum depth at which restoration could be achieved, and found that the greater the initial penetration the greater the depth at which the stamp mark could be recovered. Furthermore, Turley showed that this was a decreasing correlation i.e. the doubling the stamp depth would not double the distance at which the mark could be recovered. From a forensic point of view this provides a useful guideline on the feasibility of recovering an erased mark: if the original depth is known and the degree of metal removed is known, then the feasibility of recovering a mark can be predicted.

However, Turley's work did not address the force initially applied to produce the stamp mark, although there is some hint of this in the differences he observed between different grades of steel. This issue is of relevance in forensic recovery since the greater the underlying deformation, the greater the possibility of recovering a mark. Indeed, the possibility exists of producing an invisible identification mark by stamping and erasing the surface mark, and having a second hidden mark if the original is defaced, though modern alternative tagging techniques are probably easier to apply. In the current study we used the applied force during stamping as our variable. Above a threshold value for the applied force, increasing the force increases the depth of the stamp mark. However, at higher forces the increase in stamp depth is limited because the main body of the die comes into contact with the sample.

Possible Model Of Deformation. In figure 6, A represents the depth of the imprint and B shows the depth of underlying distortion. Within the metal we have both plastic and elastic behaviour opposing the die. For simplicity in these diagrams the flow of the metal and subsequent distortion of the overall shape has been ignored. Instead curved lines are drawn to indicate the boundary between plastic and elastic behaviour in the metal. As the applied force increases this boundary is extended, and at this boundary the elastic behaviour of the metal is opposing the applied stress. Within this deformation zone of plastic behaviour there will be a change in crystallinity that can be revealed by etching.

In the present study the dimensions of the dies and imprints could not be determined directly due to the small size and complex shape, and photomicrographs were used to determine the imprint dimensions. Where the base of the die had made an imprint this was measured both by vernier callipers and on the photograph to confirm the validity of the measurements.. Typically the tip of the letter was 0.3 mm wide and slightly less than 10 mm long, and when the die made a full imprint the width was 1 mm wide. Alternative methods of imprint measurement were tried such as impressions in soft materials and ink printing, but these alternatives were unsuccessful.

Taking the die as a truncated pyramid, it is possible to calculate the pressure applied on the tip of the letter, and on the base of the die (the two limiting cases). At 10 kN (the lowest force used in this study) the tip of the letter this would experience 1000 MPa, which is well in excess of most steel yield strengths. Even when the force is applied over the surface area of the base of the die, it is still in excess for many steels. Plastic deformation will therefore occur, and deformation will result that can be revealed by etching: the region of elastic behaviour is unlikely to be revealed by etching.

The transmission of stress will be in various directions depending on grain boundary alignments etc and the shape of this boundary will be complex, but for an initial assessment it was considered as a sphere. If the yield stress (elastic/plastic boundary) is at the surface of this sphere, then an estimate can be made of the size of this boundary by equating the force applied, the yield stress and the surface area of the sphere of plastic behaviour.

$$\text{Force Applied}/(4\pi r^2) = \text{Yield Stress},$$

or $$r^2=\text{Force Applied}/(4\pi\text{Yield Stress})$$

Substituting for 20 kN force and 500 MPa yield stress gives r of 1.8 mm., which would suggest that plastic deformation occurs up to a depth of 1.8 mm below the impression. This value is consistent with the observed recovery depths, though it is slightly higher. This is because at the boundary no recovery would be possible and deformation will be small when close to this boundary and may not be recoverable. In the present study at 20 kN recovery was achieved at 1.0 mm.

From this model it can be seen that a larger applied force will result in a greater depth at which recovery may be possible, whilst a steel with a higher yield stress (greater elasticity) will result in a reduced depth of recovery. This is a simplistic model and would require a further study or finite element analysis for validation, but it offers an explanation of why force has an increasing effect but eventually reaches a limit. It also explains the reduced potential for mark recovery with a steel with a higher yield strength.

The effect of applied force is an important addition to the work of Turley since the depth of penetration depends partly on the size of the die and partly on the applied force. It also suggests that the degree of distortion will be dependent on the metal used. In the model proposed above, a metal with a higher plastic/elastic limit may be expected to have a smaller volume of material of changed crystallinity. This appears to concur with Turley's results where increasing carbon content results in a lower depth of restoration/stamp mark ratio (B/A in the Figure 6). It should be noted, though, that Turley reports only two samples for each composition, so this observation needs further confirmation. However, the evidence suggests that manufacturers stamping a component should consider higher applied forces to maximise the chance of recovery of erased marks.

Grain Realignment. The effect of stamping and distorting the crystal structure is shown with specimens of Charpy samples that had aligned grain structures. Etching with Fry's reagent revealed the aligned grain structure and how this is re-orientated at the stamp mark. Figure 7 indicates the realignment of the grains at the stamp mark.

In-Filling Of Imprints. In Turley's work the imprint was to a maximum of 0.37 mm, but was more typically 0.1-0.2 mm. The present study typically used impressions of greater depth. However, it was noticed during filing that imprints produced at low applied force did not require full removal of the metal before the mark was obliterated and microscopic examination revealed the cause. During the filing operation the burrs that are removed from the surface are also forced into the depression of the stamp mark. Whilst a lot of these are separate iron filings that easily tip out of the groove, some adhere to the base metal and weld together to fill the void. Consequently the imprint is obliterated more easily than expected. However, during etching the corollary is true and the imprint reappears more easily than expected as this extraneous material is leached away. This imprint has a much clearer edge than etching of the re-orientated grain structure, as seen in Figure 3

Over-Stamping and Grinding. To obliterate the stamp mark and the underlying structure requires determination. For a criminal, over-stamping with a cold chisel appears to make the imprinted letter unreadable, but the chisel damage is much more localised and a letter may still be recovered. This is due to the localised deformation caused by the chisel in comparison with the die.

Grinding on a grinding wheel may be easier for a criminal than filing, and in this study it removed the lettering easily but it caused limited underlying damage and recovery was relatively easy. In fact, no further polishing of the sample was required when grinding was used.

Filing was most effective at obliteration and required more sample preparation for recovery. However, to be truly effective it requires the manual removal of at least 2 mm of metal to be effective.

Possible Aging of Fry's Reagent. In this study, aging of Fry’s reagent appeared to occur and to give a decrease in performance and take longer to etch. Over a four-week period it took noticeably longer for recovery to occur and this needs to be considered in recovery activities. The cause was not identified, but in the test carried out to quantify the observation, a 20% increase in etching time was observed over a four-week period.

Conclusion

This study has confirmed that Fry’s reagent is an effective etch for recovering erased identification marks in steel. A test to examine its performance over a period of four weeks demonstrated an increase in etching time from 95 minutes to 115 minutes for mild steel stamped at 45 MPa and with the metal removed to a depth 0.5 mm below the impression. The study also confirmed that over-stamping obliterates the original mark, but this can still be recovered by polishing and etching.

Surface preparation is important and file marks need to be removed by polishing with silicon carbide paper. However, grinding of the surface did not require any further preparation and could be etched directly.

The applied force used to form the imprint is important since this controls the degree of underlying deformation as well as the depth of penetration. Recovery of erased marks is difficult where low applied force has occurred (less than 20 kN in this study). At higher forces there is a limit due to stress also being transmitted by the die shaft in contact with the specimen. In the present study marks could still be recovered 1.25 mm below the impression.

The possibility exists of producing an invisible identification mark by stamping and erasing the surface mark, and thus leaving a second hidden mark if the original is defaced

A model has been proposed based on yield stress to explain the depth at which recovery is possible.

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