2008 SPIE Annual Optics & Technology Conference – San Diego, CA
Optical Technologies for Arming, Safing, Fuzing, and Firing IV Conference
Presented by Todd E Lizotte, Conference Committee / Session Chair (Proc. SPIE, Vol. 7070)

Forensic Firearm Identification of Semiautomatic Handguns Using Laser Formed Microstamping Elements

Todd E. Lizotte, Orest Ohar
Microstamping Technology Transfer Center
Pivotal Development Company
Londonderry, NH 03053, USA

ABSTRACT

For well over one hundred years the science of Firearm and Tool Mark Identification has relied on the theory that unintentional random tooling marks generated during the manufacture of a firearm onto its interior surfaces are unique to each individual firearm.[1][2] Forensic Firearm and Tool Mark Examiners have had to rely on the analysis of these randomly formed unintentional striations, or scratches and dings, transferred onto ammunition components from firearms used to commit crimes, as a way of developing clues and evidence. Such transfers take place during the cycle of fire and ejection of the cartridge from the firearm during the commission of a crime.

The typical striations on the cartridge casings are caused by tooling marks that are randomly formed during the machining of interior surfaces of the manufactured firearm and by other firearm components that come in contact with the cycling ammunition. Components like the firing pin, extractor and ejector, impact the surfaces of the cartridges as they are fed, fired and ejected from the firearm. When found at a crime scene, these striae constitute ballistic evidence when effectively analyzed by a Forensic Firearm and Tool Mark Examiner. Examiners categorize these striations looking for matches to be made between the components that created the marks and the recovered firearm. Reality is that nearly 50% of firearms used in violent crimes are not recovered at a crime scene, requiring the analysis to be processed and logged into evidence files or imaged into reference image databases for future comparison whenever a firearm might be recovered.

This paper will present a unique law enforcement technology, embedded into firearms for tracking the sources of illegally trafficked firearms, called Microstamping. Microstamping is a laser based micromachining process that forms microscopic "intentional structures and marks" on components within a firearm. Thus when the firearm is fired, these microstamp structures transfer an identifying tracking code onto the expended cartridge ejected from the firearm. Microstamped structures are laser micromachined alpha numeric and encoded geometric tracking numbers, linked to the serial number of the firearm.

Ballistic testing data will be presented covering microstamp transfer quality, transfer rates and survivability/durability. Further information will provide an overview on how microstamping information can be utilized by law enforcement to combat illegal firearm trafficking.

Keywords: Microstamping, Trace Evidence, Trafficking, Pattern Crime, Firearms, Ballistic, Law enforcement, Forensic, Tool Mark Analysis, Cycle of Fire Analysis, Intentional Tool Mark Structures.

INTRODUCTION

For well over one hundred years the science of Firearm and Tool Mark Identification has relied on the theory that unintentional random tooling marks formed onto the firearms interior surfaces during its manufacture are unique to each individual firearm produced.[1][2] With the recent publication of a report commissioned by the National Research Council and the US department of Justice, the science of firearm and tool mark analysis has come under even closer scrutiny. The National Academy of Sciences report states in no uncertain terms that, "…*the statement commonly made by firearms examiners that "matches" of ballistic evidence identify a particular source gun, "to the exclusion of all other firearms" should be avoided. There is currently no statistical justification for such a statement, and it is inconsistent with the element of subjectivity inherent in any firearms examiner's assessment of a match*." The report further states, "*If firearms identification is to rest on firmer scientific ground, more research would need to assess the fundamental assumption that toolmarks are unique and remain recognizable over time, despite repeated firings. Such research should include a program of experiments covering a full range of factors that may degrade a gun's toolmarks, as well as factors that might cause different guns to generate similar toolmarks. Intensive work is also needed on the underlying physics, engineering, and metallurgy of firearms, in order to better understand the mechanisms that form toolmarks as a weapon is fired.* " [3]

Why is the fundamental science of Firearm and Tool Mark Identification being challenged? This question is hard to answer, however the authors of this paper believe the issue has more to do with the inadequacy of imaging technology. When automation is created to replicate the judgment power of the human brain combined with the expertise of a Firearm and Tool Mark Examiner, problems are bound to surface. The judgments of a trained Examiner far outperform matches made by computers utilizing "Digital Virtual Evidence."

What is clear from the National Academy Assessment of Ballistic Imaging is that the science of "firearm tool mark analysis" has merit and should be strengthened by further fundamental research. This same report offered an alternative to Ballistic Imaging called Microstamping which is the basis of this paper. The report specifically states that Microstamping is a promising alternative to providing links between crime-scene evidence and the original firearm.[3] For over fourteen years, the authors of this paper have incrementally developed this technique called Microstamping, with the mission of providing law enforcement with fresh data to target firearms trafficking.

Microstamping technology specifically allows the firearm to be identified the first time it is used in a crime, without needing to be recovered by law enforcement. That becomes the shortest "time to crime" data point that can be achieved by law enforcement and by any other firearms identification technology in use today.

What is so critical about such data? From a law enforcement perspective, capturing this data allows firearm trafficking teams to produce traffic pattern maps or routes as close to real time as possible. When patterns emerge, hotspots can be quickly identified. Specific areas or regions where firearm theft rings operate can get quick attention by police. Straw purchase patterns as well as interstate trafficking patterns can be mapped, possibly identifying rouge distributors or out of state straw gun traffic flows.[4] By overlaying and comparing these types of firearm trafficking maps with other data from various law enforcement groups: such as data on known criminal associates; drug trafficking maps; criminal network maps; and reports of stolen firearms, information can be brought together to map trends, determine patterns and provide opportunities to efficiently apply police resources to more targeted areas. This is a common approach used by large city police departments like LAPD and NYPD who employ COMPSTAT. COMPSTAT is a crime analysis and police management process developed by the New York City Police Department. Effective crime-fighting requires accurate and timely intelligence, COMPSTAT allows law enforcement the ability to collect, analyze and map crime data so that they can effectively deploy resources to disrupt these crime gun source locations.

MICROSTAMPING TECHNOLOGY

Microstamping is a method of placing intentional codes linked to the serial number of a firearm by means of an "optimized laser micromachining" process. These codes are formed as micro-embossing structures, which come into contact with a cartridge that is cycled through the firearm and ejected when it is fired. The goal is to provide an improved piece of trace evidence for forensic investigators, so that they can track a firearm without having to recover it. Figure 1 depicts how a typical cartridge is commonly identified at a crime scene.

Figure 1 – Depicts a cartridge at a crime scene

Transferring of unique markings such as letters and numbers has been around for many centuries. The Gutenberg press could be considered the first instance where a formed or molded set of alpha-numeric characters was used repeatedly to transfer unique marks from one medium to another. In this case, ink laden molds of characters were pressed onto paper. Preceding the printing press by hundreds and even thousands of years, artisans have been embossing metal surfaces as well as many other materials. One of the best known embossing tools was used by the Ancient Greeks to wax seal envelopes, which had finely detailed feature sizes down to 200 µm.

As for Microstamping, the mechanics or physics of transfer have not changed. We are still dealing with uniquely formed characters, such as letters, numbers or encoded geometric codes, which require a force or pressure to achieve the transfer to a material softer than the formed characters themselves. Most people can relate to a child's ink stamp where raised rubber features in the shape of cartoon characters are stamped into an inkpad and then pressed onto a piece of paper, replicating the cartoon in all its detail. The principle of stamping and Microstamping is simple.

Just like the Gutenberg press, Microstamping is not new, all firearms currently microstamp unintentionally, as they have for hundreds of years. Today's Microstamping is just an enhanced version of this well understood process, optimized and developed for application to firearms with intentional micro-code structures. Figure 2 shows a typical microstamp mark on a primer.

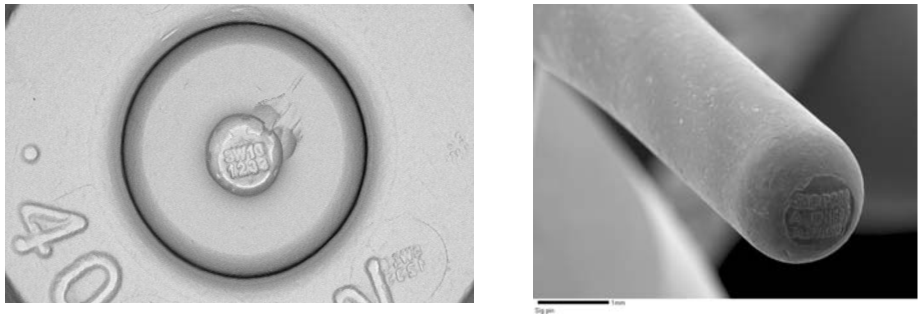

Figure 2 – Microstamp on a cartridge primer after cycling through an optimized firearm (Cartridge ~2500+ Round) and a microstamping firing pin (Circa 1998)

UNINTENTIONAL MICROSTAMPING

Since the early 1900's firearm and tool mark examination techniques have been based on the analysis of unintentional or randomly formed marking surfaces which transfer to the surfaces of ammunition components. These unintentional transferred marks on the surfaces of the cartridge and the projectile take the form of striations (scratches and indentations). Because they are randomly formed by the machining processes that are used to manufacture the firearm, these unintentional marking surfaces are not optimized to produce resolvable striae specific to the dynamics of the firearms mechanism. Such unintentional microstamped features are nondescript, have little readily resolvable repeatability and rely on the recovery of the matching firearm. However, such unintentional tool marks have been accepted as reliable for identification of firearms associated with crimes.

INTENTIONAL MICROSTAMPING

Intentional Microstamping creates an opportunity for the evolution of traditional firearm and tool mark analysis. How intentional Microstamping differs from unintentional microstamping is that micron level features are actually optimized to the multivariate and dynamic behavior of the firearm being outfitted.

Through a highly evolved optimization protocol developed over the last fourteen years, a firearm model is tested to determine its specific intentional Microstamping geometries, such as character height, width, separation, surface finish, depth, draft angle and their arrangement within the firearm for optimum transferability and durability. Specific font structures have been created to allow for enhanced optical character recognition with Microstamped cartridges. The optimization routine delivers a higher level of transfer in comparison to unintentional microstamping, which in most firearms has been observed to not be repeatable down to the last striae over repetitive firings.[5]

Intentional Microstamping features are truly intentional and tested against the specific behavior of each model of firearm. They naturally provide a higher level of transfer performance, survivability and repeatability. The optimization routine takes into consideration the explosive impact forces, extreme pressure, intense heat, caustic gases, violent shear and mechanical stresses that all converge simultaneously to affect the ability of Microstamping features to replicate characters or encoded geometries into the targeted cartridge surfaces.

MICROSTAMPING IMPLEMENTATION WITHIN A FIREARM

Dynamic behavior of a firearm mechanism must be understood to successfully apply intentional Microstamping within a firearm. Using a firearm examination technique called "cycle of fire analysis," the firearm is tested and its ejected cartridges are analyzed. Each cartridge provides an insight into the best surfaces within a firearm to place small intentional Microstamping elements. Cycle of fire analysis maps the locations where the firearm surfaces actually come in contact with the cartridge. These firearm surfaces shown in figure 3 include the breech face, firing pin, ejector, magazine and extractor to name a few.[6] The primary surface utilized is the firing pin tip. The firing pin tip is used because it is propelled by the hammer during firing and embosses the primer which sets off the main charge of the bullet. Since the firing pin hits with great force, it is the best place for the primary code. A second surface is the breech face of the firearm, shown in figure 3. These two locations have the highest levels of reliability, however various other surfaces can be used and have been tested.

Once the surfaces within the firearm are identified, a series of optimization tests are conducted. The firearm is outfitted with a matrix of Microstamping features of different geometries and resolutions. As each of these test character sets are cycled through the firearm, a quality level is attached to the resulting features produced into the cartridge casing surfaces. The data is tabulated and an optimized character set developed. Once the optimized character and feature geometries are chosen they are outfitted into the firearm and the firearm is tested for repeatability of character transfer.

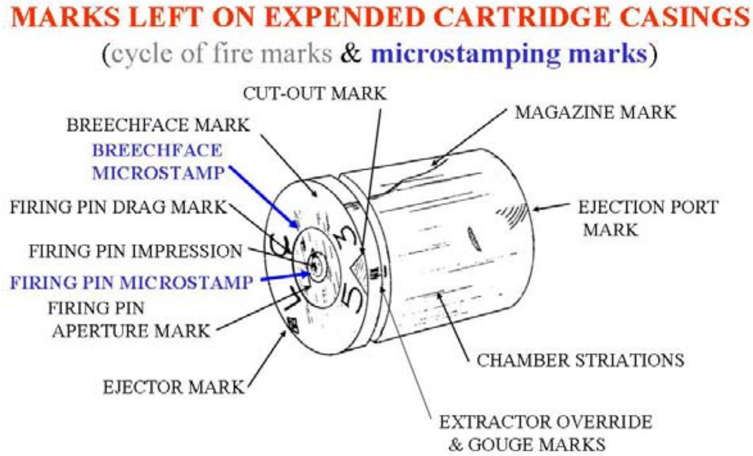

Figure 3 – "Cycle of Fire" markings

It should be noted that a firearm is not a mechanism where one pull of the trigger guarantees a single mark. It has been unexpectedly observed and noted by other researchers when testing intentional Microstamping that seeing as many as five multiple impacts of the firing pin for a single pull of the trigger is not uncommon. [5] What is significant about this discovery is that with traditional firearms examination it has always been assumed that a single strike takes place and that not every striae transfers. However, intentional Microstamping research has shown that multiple hits of firing pin and breech face are prevalent in most semi-auto pistols. Multiple strikes impact the reliability of an actual match using traditional firearms examination but without repeatable and highly resolvable structures, it can not be detected.

In terms of intentional Microstamping, multiple strikes often means shifting to higher quality microscopy, such as scanning electron microscopy (SEM), a technique that eliminates issues such as short depth of field and scattered light encountered with optical microscopy. Not a new technology for forensic scientists, scanning electron microscopy was explained and used to examine projectiles and cartridge casing firing pin impressions in articles dating back to as far as 1970. The SEM can be utilized to an investigators advantage during the direct examination of surface topography on physical evidence of forensic interest. The large depth of focus and very high resolutions produced by the various modes available in a SEM tool can reveal important micro-structural detail not readily obtained by other microscopic means.[7]

To overcome hindrances encountered in analyzing multiple-hit pin impressions encountered during traditional cartridge examination of unintentional markings, it is often necessary to test fire the recovered firearm a minimum of four (more are preferable) rounds of ammunition, of exactly the same make and type to be able to compare against the recovered cartridge evidence found at a crime scene.[8] To date, the authors have yet to find research papers or references detailing the criteria used by trained firearms examiners or automated ballistic imaging systems, to make the determination that a multiple firing pin strike has occurred and/or how such cartridges are to be segregated when found.

BENCHMARKING: FIREARMS IDENTIFICATION TECHNOLOGIES

Intentional Microstamping has shown to have significant benefits when compared to existing methods of firearm identification. The two common approaches are traditional firearms examination as detailed in "Cycle of Fire Analysis" and Ballistic Imaging. As can be seen in Figure 4, neither of the existing forensic techniques can identify a firearm, unless the firearm is first recovered.

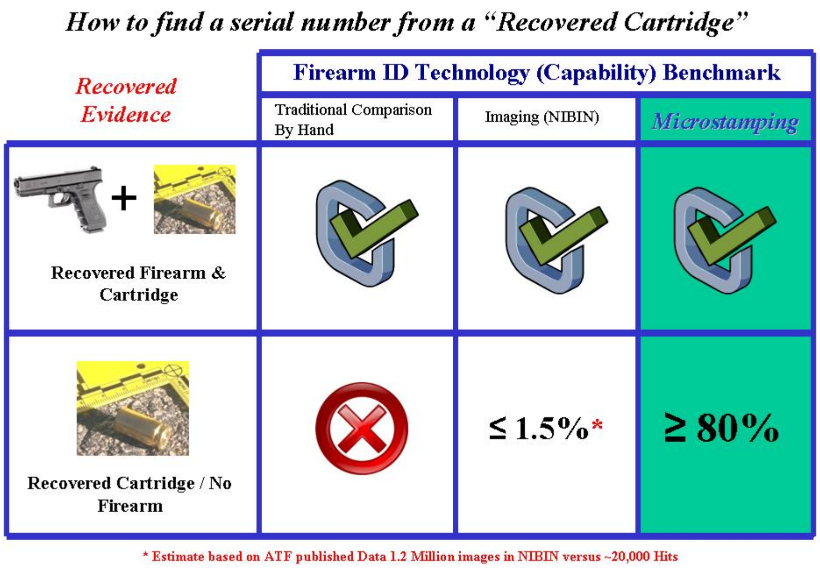

Figure 4 – Benchmarking existing firearm identification technologies

Many critics of intentional Microstamping attempt to discredit the idea by simply stating that the technology can be thwarted by physical tampering or outright replacement of firearm components. The reality is that all three of the methods of firearm identification described above are subject to exactly the same limitations when tampered with. For instance, a simple change of a barrel and magazine as shown in Figure 5 can change a 0.40 caliber handgun into a 9 mm handgun and render a ballistic imaging database ineffective. However if the same firearm retained the intentional Microstamped firing pin and second surface such as the breech face, the firearm would be identified, no matter what ammunition conversion was implemented.

Figure 5 – Same firearm two different rounds fired (Same Breech Face Marks)

All technology is susceptible to tampering as documented by ATF trace reports. Many such recovered firearms are found with defaced serial numbers on the side of the handgun.[9] With this trend of serial number defacement, the solution implemented by the state of Massachusetts was to produce hidden micro-sized serial numbers under the handgun grips. Smith & Wesson implemented micro-serial numbering to their manufacturing process even before it became law in Massachusetts.[10]

FIREARMS TESTING

Over the years, numerous firearms have been tested. Firearms such as 0.40 Cal SIG P229, 0.40 Cal S&W 4006, 0.22 Cal Ruger Mark III, AR-15, AK-47 and other makes and models have been tested. Figure 6 shows various cartridge firing pin impression examples, including samples from the .22LR Cal Ruger Mark III, Code S12/R34 (500+ rounds, Lizotte) and a Glock 9mm, Code GLCK/8463 – Firing Pin Shown, (~1400 Rounds, Haag).

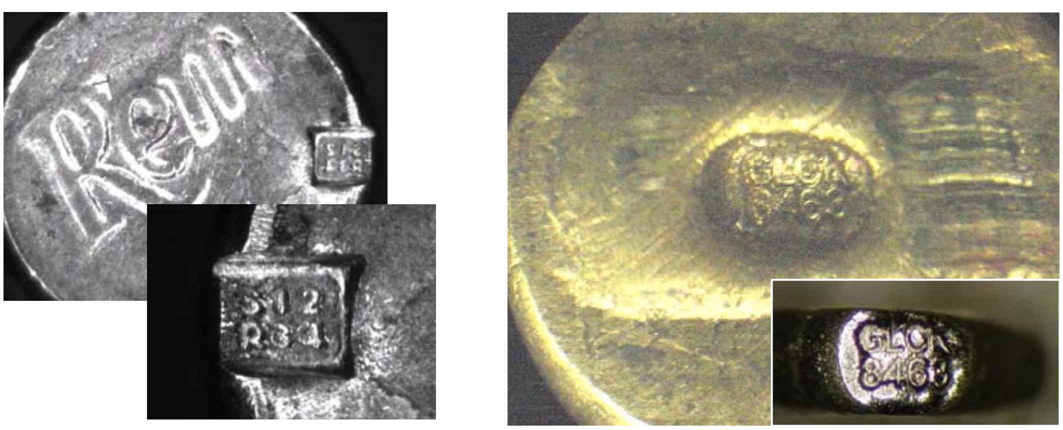

Figure 6 – Example cartridges fired from semiautomatic handguns

The objective of this paper is to provide recent results of a 3500 round durability and microstamp transfer reliability test of a .45 Cal Colt 1991 A1 Commander (1911 Model) semiautomatic handgun. Phase one presented here, consisted of 1500 rounds fired with the cartridges captured and cataloged in sequential order

The firearm was purchased as a used model and outfitted with new stock recoil and firing pin springs as well as new firing pin to bring the mechanism up to nearly new specifications. The Colt 1991 A1 was optimized and outfitted with microstamping microstructures and prepared for testing. Figure 7 is an image of the Colt 1991 A1 used for testing.

Figure 7 – Colt 1991 A1 Commander Model (1911)

To thoroughly test the durability and verify the transfer and extractability of the a microstamped code, the ammunition chosen was a high quality 45 Auto ACP, 230 Grain FMJ, Lawman Ammunition Produced by CCI/Speer . Several other rounds were tested including, Winchester FMJ, MAGTECH FMJ, Aguila FMJ, Fiocchi FMJ, Wolf Steel Case FMJ, and Lellier & Bellot FMJ which confirmed that over various ammunition the markings are still produced repeatedly. However, the first 1500+ Round testing exclusively used the Speer Lawman ammunition. Since firing 1500+ rounds in consecutive order takes time, several new magazines were purchased to allow quicker cycling of the firearm. The testing used three magazines, one was the original sold with the firearm and two were Kimber 1911 after market products.

1500+ rounds were fired consecutively. Each cartridge was sequentially captured and consecutively cataloged in a numbered pallet as they cycled through the firearm. Three easy-to-clear ammunition cycling jams were encountered during testing, but one resulted in an unfired bullet that was cleared by hand cycling. The archived cartridge set represents cartridge number 0143 as missing, since it was not fired. The gun was not cleaned or oiled during this test.

After returning from the firing range, all the cartridge casings were permanently laser marked, as shown in figure 8, with the date fired and a consecutive serial number used for tracking the data while it is stored in its archiving pallet, ready for future retrieval.

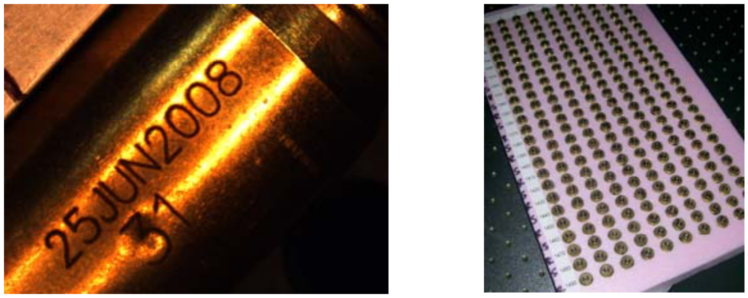

Figure 8 – Laser marked cartridges and archive tray

RESULTS

Once the first phase of firing 1500+ rounds was completed and the cartridges cataloged, the head stamps and primers where inspected using an optical microscope system.

<u>Cartridge Inspection and Documentation Hardware</u>

Microscope:	Optem 125, 1X Video Tube / Industrial Tube Scope, 0.6X Zoom Optic Setting, 1.5 X Auxiliary Lens – ~1.25 mm x ~1.42 mm Digital Field of View, Free working distance ~52 mm
Camera:	Q-Image 5 Mega Pixel Camera (3.42 micron Square Pixels) Firewire
Lighting:	Cross Polarization Fiber Ring Illumination Schott EKE Fiber Optic Light Source, 150 Watt
Software:	Media Cybernetics Image Pro Express 6.0
Standard:	NIST Microscope Calibration Standard

Each cartridge was photographed using a custom microscope built by the authors and staff. Figure 9, shows the microscope configuration and illumination. Each cartridge had four images taken: the cartridge head stamp illuminated with both polarized and non-polarized metallurgical lighting techniques; and the firing pin impression illuminated with polarized and non-polarized lighting. Figure 9, shows the four types of images taken for each cartridge. As demonstrate by the images, direct reflections and glare make it impossible to observe the specimen with a high degree of resolution, due to the high light intensity from the various reflecting surfaces and structures. The two polarized images show that by illuminating the surface with linear polarized light and by turning an analyzer into a crossed position most of the direct reflections / glare will be attenuated or extinct.

Figure 9 – Four images (Same cartridge) taken for each position one (1) cartridge
(Head Stamp non-polarized lighting, Head Stamp with polarized light, Firing Pin Impression non-polarized lighting and Firing Pin Impression with polarized light)

Since Microstamping is a forensic tool, the criterion for success was being able to extract the code from the mark produced. The firing pin impression resides in the primer of the cartridge and there are two codes from two surfaces of the pin which are transferred to the cartridge when fired. The first mark is produced by the tip of the pin and can be found in the center of the primer impression. It takes the form of an alpha numeric eight digit code. The second mark is produced further down the firing pin shaft, away from the tip. It is represented as an encoded ring -- a gear code that is made by the cylindrical shaft of the pin. It appears in the firing pin impression of the cartridge as a ring which surrounds the alpha numeric code. This circular gear code is a redundant code that backs up the primary eight digit code in case of mechanically induced permanent or temporary firing pin tip failures.

If the eight digit code has an illegible digit, the circular gear code can be utilized to provide the missing digit. Figure 10 shows an enhanced image highlighting the gear code in support of extracting the multi-hit alpha numeric code. In nearly all of the transferred marks, the gear code can provide the entire code.

Figure 10 – gear code and multi-hit alpha numeric code (C129 / A3HJ) Images
(Simple image enhancement techniques used to improved code extraction)

The analysis was conducted using levels of microscopy available to any highly trained forensic firearms examiner skilled in metallurgical microscopy. The criterion for a successful extraction of the code was based on the ability to reconstitute the entire eight digit code, based only on observation and the digital image taken, stored and archived representing the cartridge pin impression.

The resulting code extraction data is shown in figure 11. It should be noted that these cartridges were not inspected using scanning electron microscopy, which has been demonstrated to increase legibility significantly by eliminating depth of field limitations found in optical microscopy, as well as metallurgical surface glare issues common with visible lighting methods. Figure 12, shows an example of how scanning electron microscopy is useful while deciphering multi-hit Microstamp codes on primers.

Cartridge Code Extraction Data
(Optical Microscopy Only)

Cartridge Tray (Range)	Extracted Code
Sample	
1 to 250	92.8%
251 to 500	92.8%
501 to 750	99.0%
751 to 1000	99.0%
1001 to 1250	99.0%
1251 to 1500	98.0%
Total	96.8%

Figure 11 – Code Extraction Data Summary

Microstamping technology is meant to provide leads for law enforcement to follow when all that is found at a crime scene are empty cartridge casings. The resulting data from this research into intentional Microstamping shows that when a firearm is properly optimized, outfitted and tested with intentional Microstamping features, even if law enforcement willingly limits their analysis to optical microscopy, the process of microstamping has the ability to yield >90% code extraction rates. It is evident that even higher levels of extraction are possible with scanning electron microscopy.

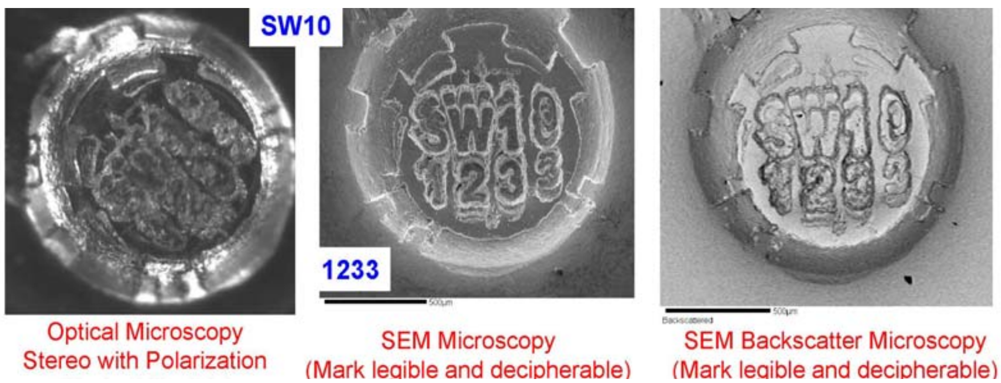

Figure 12 – When optical microscopy fails to resolve the characters of a multi-hit cartridge – SEM microscopy provides the answer.

Further analysis is continuing by pushing the sequentially captured and archived cartridge data set to a goal of 3500. Relationships between the first bullet fired and subsequent bullets fired are yet to be analyzed. Future reports will also show how additional standard forensic practices like scanning electron microscopy, confocal microscopy or micro-sil casting, can be employed to extract additional information from cartridges deemed as difficult to analyze.

THE ROLE OF MICROSTAMPING

Intentional Microstamping is an evolutionary step in the science of firearm and tool mark identification. As the technology is implemented, proper analysis and extraction of microstamped codes needs to be done by highly trained firearm and tool mark examiners, who have a tenacious desire to develop evidence. This research continues to show that a firearm is a multivariate and dynamic mechanism, which can be outfitted with intentional Microstamping technology and perform with a high degree of repeatability. It is also understood that firearm tool mark analysis methods and techniques for extracting these types of markings are a paramount requirement.

Another benefit is that even when intentional Microstamping creates a partial alpha numeric code, the forensic trail for developing evidence does not end. The gear code is capable of backing up the primary alpha numeric code. Furthermore the use of “Cycle of Fire” analysis in conjunction with the partial code will enable identification of the additional information that can narrow the number of possible matches. Information such as the caliber, type, make and model of the weapon can be ascertained with a higher degree of accuracy than is currently possible.[8] Such complimentary techniques can be combined to further narrow the specific firearm down to a manageable handful of guns for investigators. Simply stated, intentional Microstamping is a tool that augments existing traditional cartridge examination techniques by leveraging the experience, knowledge and infrastructure that exists within a modern firearm and tool mark lab, to extract useable trace data to target the supply side of illegal firearms trafficking – without having to recover the firearm.

ACKNOWLEDGEMENTS

The authors would like to thank, Richard Schneider from Kramer Scientific for helping us with the microscope setup and his insight into applied optical microscopy. We would also like to thank Zack Goulet for his assistance in taking microscope images of the cartridges and laser serialization of the cartridges for the archive.

REFERENCES

1. The Coming Paradigm Shift in Forensic Identification Science
Michael J. Saks[1] and Jonathan J. Koehler[2]
2. Hamby, James, et al, "The History of Firearm and Toolmark Identification," Association of Firearm and Tool Mark Examiners Journal, 30th Anniversary Issue, Volume 31 Number 3, Summer 1999.
3. Daniel L. Cork, John E. Rolph, Eugene S. Meieran, and Carol V. Petrie, Editors, Committee to Assess the Feasibility, Accuracy and Technical Capability of a National Ballistics Database, National Research Council, "Ballistic Imaging Report", Press Release, March 5, 2008
(http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12162)
4. Greco, Joseph, "Pattern crimes: firearms trafficking enforcement techniques", FBI Law Enforcement Bulletin, Sept, 1998.
5. George G. Krivosta, "NanoTag™ Markings from another perspective,", page 46, #38 AFTE Journal 41, 2006.
6. California Department of Justice, "Cycle of Fire: Course Slides", California Criminalistics Institute, 2008
7. E. J. Korda, H. L. MacDonell, J. P. Williams, "Forensic Applications of the Scanning Electron Microscope", The Journal of Criminal Law, Criminology, and Police Science, Vol. 61, No. 3, (Sep.,1970), pp. 453-458
8. Heard, Brian,"Handbook of Firearms and Ballistics", pgs 132-133, John Wiley & Sons Ltd, England, 1997
9. Wintemute, Garen, MD, et al, "The Life Cycle of Crime Guns", Annals of Emergency Medicine, June 2004
10. Tartaro, Joseph, "Gun Business at a Standstill in Massachusetts, Suit Likely", Gunweek, May 1, 2000