Comparing Characteristic Markings of Metal Injection Molding and Progressive Die Stamping Extractors

BY

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THESIS

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This thesis is devoted to my mother; Hazel Gale-Daley, father; Oswald Daley and aunt; Judith Hill; without whom it would never have been accomplished.

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LIST OF ABBREVIATIONS OR NOMENCLATURE

AFTE	Association of Firearm and Toolmark Examiners
DNA	Deoxyribonucleic Acid
MIM	Metal Injection Molding
NRC	National Research Council
RT	Rapid Tooling

SUMMARY

The presence of small parts used in firearms usually produces marks that are valuable in the identification of cartridge cases from a firearm in which it was recently discharged. In the case of fired projectiles, the rifling barrel of a gun can also produce markings that can aid in determining the weapon from which fired projectiles may have been derived. Because it is impractical for two separate machined surfaces to be microscopically identical, problems can occur if firearm and toolmark examiners are unable to base an identification of weapons and other related components obtained from a crime scene (Heard 1-20). It is for this reason why it is important for research to be conducted on firearm parts and the manufacturing processes associated with these parts.

A comparison approach was used to study of the effect of reproducing marks on extractors utilizing two manufacturing techniques: Progressive Die Stamping and Metal Injection Molding. After obtaining parts for both manufacturing processes, ten rounds per extractor were fired from two weapons: Remington shotgun and Hi-Point Firearms. Visual comparisons were done between parts to see if there are enough individual characteristic markings for identification. Preparation for the use of each weapon; along with arrangements for an efficient labelling system for each part and the associating ammunition used was kept constant.

This research presented information that is especially relevant to the firearms industry. My results reveal that the manufacturing processes conducted to create Progressive Die Stamped extractors display more individual characteristic markings on fired evidence for identification when being microscopically compared to Metal Injection Molded extractors. Firearm and Toolmark examiners usually analyze markings produced by the firing pin as well as the breech face markings of a cartridge case. There are, however, other markings that can be involved in the identification process. These can include extractor markings. It is, however, only in rare instances would an analyst use these extractor

markings to aid in the identification of firearm components. Although this analysis process is only conducted on rare occasions, its examination is essential as it aids in ensuring the uniqueness of the markings produced by various extractors.

At the conclusion of this research, I determined that microscopic differences seen after comparing the extractor markings as well as the results obtained from the statistical analysis revealed that the differentiation of markings produced by Progressive Die Stamped extractors and Metal Injection Molded extractors can be done. As such, mass produced parts by modern manufacturing processes can be differentiated by firearm examiners after comparing fired evidence.

ABSTRACT

Introduction: Because it is impossible for two separate machined surfaces to be microscopically identical, a problem can occur if firearm and toolmark examiners are unable to base an identification of weapons and other related components derived from a crime scene. The presence of small parts used in firearms usually produces marks useful in the identification of cartridge cases or bullets that was recently discharged from a firearm. There have been doubts regarding the uniqueness of these and other marks left on the fired evidence obtained due to a lack of characteristic markings (Bonfanti and De Kinder 3-10). Reproducing marks are more liable to happen due to the weapon's manufacture process. As such, manufacturing processes needs to be investigated as reproducing marks can vary from time to time.

Method: After obtaining and prepping the Metal Injection Molded extractors and ammunition as well as the Progressive Die Stamped extractors and ammunition, ten rounds per extractor were fired from a Remington Shotgun and Hi-Point Firearm, respectively. Comparisons for the identification of extractor markings were conducted on the ammunition.

Results: Analysis of the Metal Injection Molded extractors concluded that all the Metal Injection Molded extractors were created after being injected in the same mold cavity. After injection of the feedstock into the mold, the produced part was either removed or broken off the mold. This would help to explain why there was no sign of reproducing areas on the inside working surfaces of the extractors due to a grinding or polishing finishing procedure. Reproducing markings were, however, displayed on other areas of the extractor. The markings produced by these extractors were less profound and was determined that this was due to the cartridge contacting the extractor with enough force, but not with as much force as with the Progressive Die Stamped extractor.

Further investigation of the Progressive Die Stamped extractors revealed markings identified as markings obtained at the conclusion of the manufacturing process. Additional markings were also seen and was identified as those derived from a sandpaper. The comparison of extractor markings seen within the Progressive Die Stamped extractors revealed significant agreement of the overall pattern among each group of extractors. The markings produced by these extractors were more profound and it was determined that this was due to the cartridge contacting the extractor with much force. When comparing markings from various extractor groups, it was found that more differences than similarities existed among the markings.

Although there were more similarities among the Metal Injection Molded markings produced by different extractors when conducting an inner comparison, these markings can statistically and microscopically be differentiated.

Conclusion: Although microscopic comparisons produced similarities among the extractor markings from both manufacturing processes, mass produced parts by modern manufacturing processes; Metal Injection Molding and Progressive Die Stamping, can differentiated by firearm examiners after comparing fired evidence.

INTRODUCTION

Firearm and Toolmark (F/T) Identification

According to the Association of Firearm and Toolmark Examiners (AFTE), toolmark identification is a discipline of forensic science whose examiners are expected to determine if a toolmark originated from a particular tool (AFTE). AFTE also noted the definition of firearm identification. Firearm identification; according to AFTE, is a discipline under toolmark identification whose examiners are solely responsible for determining the firearm from which bullets, cartridge cases and other firearm components may have been derived (AFTE). Because of the presence of miniscule marks that can be transferred to different components of a weapon, this allows a Firearm and Toolmark examiners to verify or deny any connections between a component of a firearm and its weapon. Firearm and Toolmark can be further categorized into five sub-fields: shooting reconstruction, firearm examination, distance determination, serial number restoration and toolmark analysis, which will be discussed briefly in the following paragraphs.

Shooting reconstructions are conducted to aid in determining the order of events, make sense of the scene, determine the number of fired evidences discharged and to exclude what could not have happened at a crime scene. A firearm examiner compares and determines whether fired evidence from a scene was fired from a specific weapon (Utah Department of Public Safety). Determining the distance between a firearm and its target is oftentimes dependent on the remaining residues found on the surface. Consequently, it is the job of an examiner to evaluate these distances (Utah Department of Public Safety).

Serial numbers provide pertinent information to an examiner and can include alphabetical characters, integers and letters, numbers, and special attributes used for the identification of a firearm, equipment or vehicle. Restoration of serial numbers is, at times, very essential (Utah Department of Public Safety). This is especially true if the serial numbers have been intentionally destroyed. It then becomes the job of an examiner to recreate the identifying characters of the machine. A Firearm and Toolmark examiner conducts mindless examinations on fired evidence to determine if a tool was used to mark an object found at a crime scene (Utah Department of Public Safety).

Ballistics is a unit of forensic science responsible for the path taken by projectiles as they are discharged from the weapon. However, when used in forensic investigations, "ballistics" is often referred to as a forensic firearm examination as it helps in the reconstruction of a crime scene involving a firearm. This aspect of forensic science also includes the successful tracing of weapons as it aids investigators in positive identification of suspects. Firearm and Toolmark Analysis, on the other hand, refer to the examination and comparison of fired evidence. Although they may seem different, ballistics and firearm and toolmark analysis are closely related. When conducting investigations involving fired ammunition, any material damaged by a projectile will be considered. This includes, but is not limited to, cartridge cases, bullets and trace ammunition; all of which can be analyzed by a ballistic and firearm and toolmark examiner (Jackson and Jackson).

For the remainder of this paper, focus will be placed on the Firearm and Toolmark section of Forensic Science. Now let's discuss; briefly, the history of Firearm and Toolmark industry.

History of firearm and toolmark industry

In 1863, Confederate General Stonewall Jackson was fatally injured during battle. When the Confederates were in battle with the Union army, the Confederates used round balls as their ammunition while the Union army used ammunition that resembles that of shuttlecock used in the sport badminton. Today, this ammunition is now referred to as a “Minié Ball.” After removing the fired evidence from Confederate General Stonewall Jackson’s body for examination, the caliber and shape of the projectile; a round ball, proved that he was killed by his own men.

Approximately one year later, Union General Sedgwick was also killed in battle. Upon examination of the fired evidence removed from his body, it revealed that the diameter of the barrel of the gun; caliber and hexagonal formation of the bullet were consistent when compared with the ammunition used by someone in the Confederate army. As such, it was determined that Union General Sedgwick was murdered in battle by a Confederate army guard.

In 1907, a riot involving the US Army Infantry Regiment took place in Brownsville, Texas. Pieces of evidence such as cartridge cases were collected for analysis. After comparing the evidence collected with the firearm obtained, the findings proved that there was no association between the items. Although there was no success in determining the cause of the riot; or the identity of the perpetrators involved, this riot was recorded as the first evaluation of fired evidence.

The Vanzetti and Sacco court proceedings began after two employees with payroll funds were murdered near their place of employment. Witnesses were able to identify one individual that had a handlebar moustache while the other bore a resemblance of someone with an Italian decent (Hamby and Thorpe). Nicola Sacco and Bartolomeo Vanzetti were arrested and questioned after matching the descriptions given by the witnesses. During the court proceedings, the bullets and cartridge cases found at the crime scene matched the fired evidence obtained from one of the suspect’s weapon. Due to the findings linking the bullet and cartridge cases to the suspect’s weapon, both individuals were found guilty of the crime and were both executed a few years later.

"The St. Valentine's Day Massacre," as was most known, took place on February 14th, 1929 in Chicago, Illinois. It was on this day that seven men were gunned down by gangsters at a local garage company. It was rumored that police officers may have been involved in the crime, and as such, Calvin Goddard collected all firearms from individuals within the Chicago Police Department that were related to the evidence found at the crime scene. After coming up empty handed after a thorough analysis of the weapons within the Chicago police department, due to the shooting of a police officer a couple months later, someone by the name "Burke" was identified as a suspect and was subsequently charged for both crimes. This was only after analyzing both pieces of evidence from the two crime scenes, thus the generation of a positive identification.

As murders, attempted murders and other serious crimes were being committed, various organizations were developed to aid in the analysis of fired evidence to a firearm and or its components. One of the first organizations included the Bureau of Forensic Ballistics and was established by four individuals; namely C. Goddard, C.E Waite, P. Gravelle and J. Fisher (Hamby and Thorpe). This organization was established as a means of providing "firearm identification services throughout the United States of America" (Hamby and Thorpe). As a well needed and useful organization in the firearm industry, it was not surprising to hear that P. Gravelle, who also helped to establish the Bureau of Forensic Ballistics, was successful in the manufacture of a comparison microscope for the identification of fired evidence. This microscope later aided firearm examiners during their analysis process and is still being used in this field (Hamby and Thorpe).

It should be noted that while there were other incidents that may have played a significant role in the history of Firearm and Toolmark identification, it was my intention to highlight the most relevant and related events in connection to Firearm and Toolmark (F/T) Identification.

Defining a firearm

A firearm can be defined as any weapon that has already been designed or will be designed to expel projectile(s) by way of combustion. It is after the explosion of burnt materials following the production of gas that causes pressure to be built up, which causes the projectile to be pushed down the barrel of the weapon causing the weapon to be discharged (ATF).

Types of Firearms

There are two types of firearms: handguns and long guns. In order to differentiate one from the other, the most noticeable difference is that handguns are designed to be held by both hands of the shooter. Long guns, on the other hand, can only be fired when the base; most known as the stock, is placed on the shooter's shoulder.

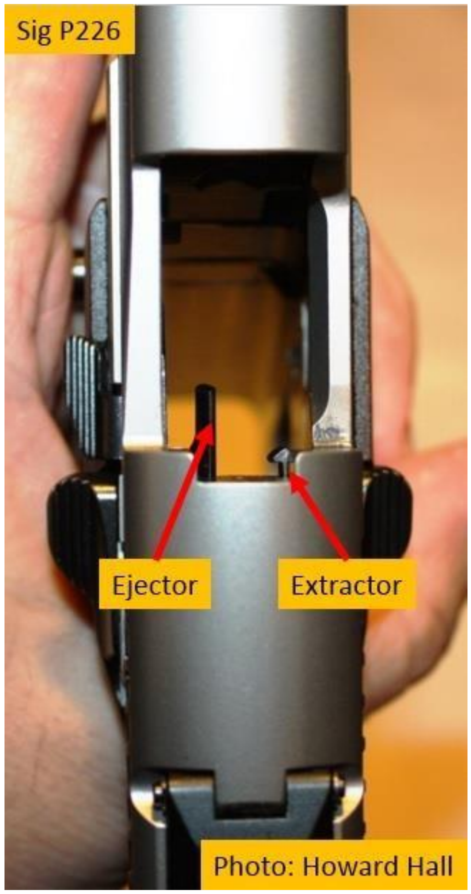
Firearms can be further distinguished one from another by how they are made. Handguns can either be divided into Pistols and Revolvers. Additional information is provided to ensure readers can identify each. In weapons where the chamber is included in the barrel, most firearm enthusiasts refer to these weapons as a "semi-automatic" seeing that a cartridge can be fed to the weapon from a single magazine. After feeding, the fired evidence is removed from the weapon after discharge. Discharge is activated when the shooter "triggers" the weapon; thus, causing a cartridge to be expelled from the weapon. Because of this, a pistol is not capable of continuous fire. As the name may imply, a revolver is a firearm with the cylinder having several chambers arranged around a rotating axis. Revolvers only have the potential of being discharged as the weapon is triggered. It should also be noted that unlike most semi-automatic weapons, revolvers do not possess ejectors or extractors.

Rifles and shotguns are a subdivision of long guns. A rifle is a firearm that has rifling on the interior of the barrel. A shotgun, on the other hand, is a weapon with a smooth bore that has no rifling and is more popular internationally as opposed to rifles (Gary, Wasserberger, and Balasubramaniam 624-631).

Throughout this experimentation process, both weapon types were used and was found to be a good way for the comparison of the two weapon types. For the handgun, a Hi-Point Firearm was used. On the other hand, a Remington shotgun was implemented for the long gun weapon type.

There are two main components of a firearm that are often used interchangeably: an ejector and an extractor. Although they work hand in hand, the two components are different, and their difference should be noted. An extractor is a component of a weapon that attaches itself to the cartridge and pulls it down to the base of the weapon to prepare the ammunition for discharge. It is then that the ejector comes into play as it pushes or expels the cartridge out of the weapon (Numrich Gun Parts Corporation). Below, one can visualize the placement of an extractor and ejector in a firearm.

Figure 1: Visual depiction of an extractor as well as an ejector



See Appendix for permission

Once a cartridge, shot shell or any ammunition is loaded into a firearm’s chamber, the weapon’s trigger is pulled which causes the firing pin to contact the ammunition. Due to this contact, the powder propellant in the ammunition is ignited and is burnt releasing gasses at a high velocity.

This process can be referred to as the extraction process as this explains how the ammunition is removed from the barrel of the firearm. After the removal of one piece of ammunition, another cartridge or shot shell is reloaded in the barrel of firearm as it awaits the initiation of the "trigger action" by the shooter. Depending on the weapon type, parts extracted from a firearm can travel long and short distances. In modern firearms, cartridges are automatically removed from the weapon after discharge. In other instances, the cartridge remains in the gun's chamber and must be removed by hand (Forensic Ballistics). Because the removal of the fired evidence is performed swiftly and with great force, the extraction and ejection process may cause markings to remain on fired evidence. There are a variety of markings that can be found on fired evidence. This can include rifling markings, impressed toolmarks and striated toolmarks. The following paragraphs aim to provide more detail on rifling, impressed and striated toolmarks.

Rifling

Rifling can be referred to as the "hills" and "valleys" found on the inner walls of a rifle's barrel. These "hills" and "valleys" are most often referred to as land and groove impression marks. This rifling pattern can be used to convey a rotary motion on projectiles as they are being discharged from the weapon at a high velocity (Sun et al.). It is because of this rifling pattern why the bullet would spin, thus, ensuring that the bullet goes where the shooter intends for it to go. It is also because of these helical grooves why there are markings left on fired evidence.

There is no doubt as to whether the presence of land and groove impression marks produced by the barrel of a firearm play a role in the presence of markings on fired evidence. There exists, however, other types of markings that can also significantly alter characteristic markings seen on fired evidence.

These markings can include impressed toolmarks and striated toolmarks; both of which are explained in-depth below.

Impressed Toolmark vs Striated Toolmark

An impressed toolmark is a mark produced on an object by a tool. As enough force is being placed perpendicular to the object by a tool, the mark produced is referred to as an impressed toolmark. A striated toolmark, on the other hand, like an impressed toolmark is produced by a tool against an object. As pressure is being applied perpendicularly to the tool, the tool or object itself can be moved, thus, producing another marking; a striated toolmark. Readers can refer to Figure 2 below for a visual aid of impressed toolmark vs striated toolmarks.

Figure 2: A representation of an impressed toolmark; pictured on the left, and a striated toolmark; pictured on the right placed on a piece of board with a screwdriver

As firearm examiners obtain fired evidence from various crime scenes, how exactly, do they analyze them? It is the aim of the following sentences to shed some light on this matter.

How do Firearm Examiners analyze fired evidence?

As stated by Craig Venter; one would need to have a very special microscope to see a single DNA strand (Venter). Because Deoxyribonucleic acid (DNA) is approximately 3.2 billion bases long, is shaped like a twisted coil, and is very miniscule, it is easy to understand why Mr. Craig Venter would highly suggest the use of a special microscope when working with DNA. The same tends to hold true when referring to the work conducted by Firearm and Toolmark examiners. Because most of the evidence obtained by these examiners tend to be very microscopic, it is not surprising to hear that Firearm and Toolmark examiners also depend on a specific type of microscope to assist in their analysis process. To obtain a clear understanding as it relates to the author's train of thought, one must grasp the concept of comparison microscopes. With the invention of comparison microscopes in the 1920s, a system capable of combining two compound light microscopes connected with an optical bridge that sits side by side as it allows the user to view two pieces of individual samples through a center eye piece displaying both images simultaneously, is a firearm and toolmark examiner's dream. This is because with the invention of this machine, their analysis process could be significantly simplified. Due to the invention of such a machine in the 1920s, P. Gravelle's invention was coined "Comparison Microscope" and has been efficiently used during all analysis processes conducted by a Firearm and Toolmark examiner (Thomson Gale).

As mentioned in the previous paragraph, comparison microscopes are efficiently used by firearm and toolmarks examiners to identify, verify or deny common sources of origin among cartridge cases and or bullets. The placement of two microscopes side by side allows the viewing paths of each microscope to be joined with the use of an optical bridge. This bridge, consisting of a series of lenses and mirror is used to recoup the two images at the single eyepiece. After placing each evidence in the appropriate area on the microscope for comparison, the user would use the eyepiece as they would a regular microscope. As individuals look through the eyepiece, instead of visualizing one image, the user would instead see a horizontal line in the middle of the field of view as it separates the circular field of view into two hemispheres. The left hemisphere represents the field of view of the image produced by the left microscope, while the image produced by the right microscope displays the field of view from the right hemisphere (Thomson Gale). A visual documentation of a comparison microscope can be seen in Figure 3 below. It is using a comparison microscope that Firearm and Toolmark examiners can determine whether fired evidence could have derived from a specific firearm due to the presence of various characteristic markings.

Figure 3: Visual documentation of a comparison microscope

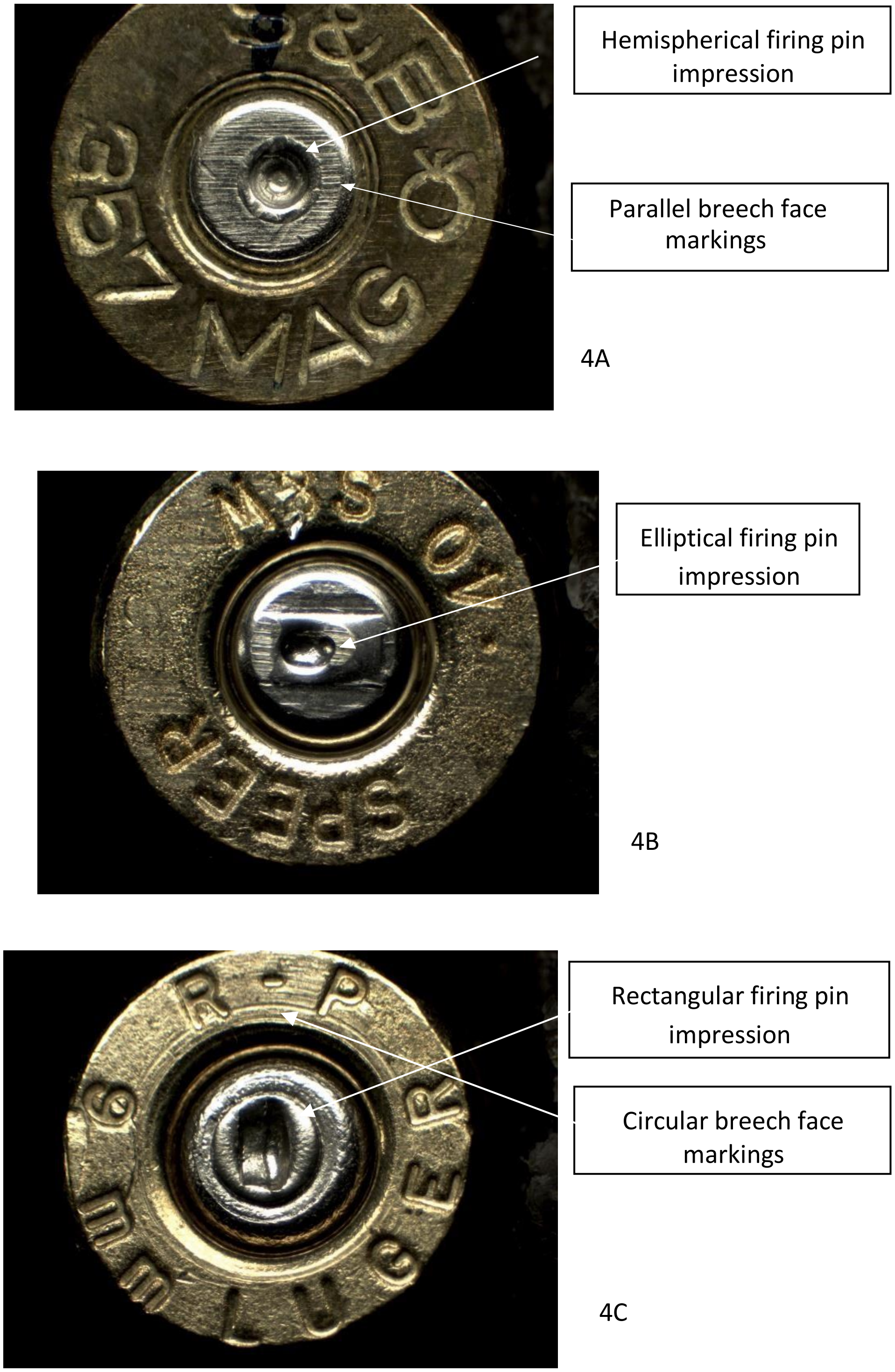
See Appendix for permission

What are fired examiners looking for when analyzing fired evidence?

While the firearm examiners are observing the two pieces of fired evidences using the comparison microscope, you may ask what exactly are they looking for? There are three types of markings that can be found when comparing the surface of fired evidence. These include class characteristic markings, subclass characteristic markings and individual characteristic markings. Class characteristic markings refer to the grouping of evidence based on the similarity of patterns within the same group. Subclass characteristic markings, on the other hand, can be defined as the unintentional markings made by a tool during manufacture, which are only seen on a consecutive number of fired evidences. These markings are only being produced during the construction period until the manufacturers become aware of these unintentional markings or until the defective reproducing tool has been corrected. The final type of mark seen when comparing fired evidence includes individual characteristic markings. Individual characteristic markings refer to marks produced by the random irregularities of a firearm or its part(s). These irregularities are so prominent and distinctive that the examiner can foster a conclusion based on the individual characteristic markings. This conclusion is based on the items being compared and it can solely be derived from one specific firearm or its part; hence the term “individualization.”

Figure 4 below provides examples of three types of class characteristics that can be seen on fired evidence. Figure 4A depicts a hemispherical firing pin impression with parallel breech face markings. Figure 4B shows an elliptical firing pin impression while Figure 4C illustrates a rectangular firing pin mark with circular breech face markings on a cartridge case. The class characteristics include the shape of the firing pin impression mark as well as the general nature of the breech face markings. Firing pin impressions are the markings seen on the head of cartridge cases when the firing pin hits the base of the cartridge case causing the weapon to be discharged.

Figure 4: Pictograph of class characteristics on a bullet



The parallel lines seen on the fired cartridge cases; the breech face impressions, occurs when the bullet goes down the barrel of a firearm, making the cartridge case hit against the inside of the gun; causing these markings to be transferred to cartridge cases during the firing process.

Evidence of subclass characteristics on cartridge cases can only be seen in consecutively manufactured evidence. Because of this, I was unable to provide image documentation or examples of subclass characteristics. It is the writer’s hope that the definition of subclass evidence mentioned previously was clear and easily understood.

Figures 5A and 5B provides two varieties of individual characteristic markings that can be seen on fired evidence. The individual characteristic markings include the pattern of the parallel lines; to be more specific, the width, depth and length of the markings on the casing, as seen in Figure 5A. The parallel lines: breech face markings as they are most known as, are the machine marks of the inside of a firearm which gets transferred to cartridge cases during the firing process. These breech face markings can vary as they can be parallel, circular and or granular with no specific shape. Figure 5B, on the other hand, is a representation of the individual characteristic markings caused by the firing process. Due to the unique and random placement of markings on fired evidence, this would further help in the explanation of individual characteristic markings. Figure 5C is another example of individual characteristic marking because the distance between the breech face markings can vary from firearm to firearm.

Figure 5: Pictograph of individual characteristics on a cartridge case

5A

Individual markings; depth and length of the markings on the casing

5B

Individual markings; caused by the firing process

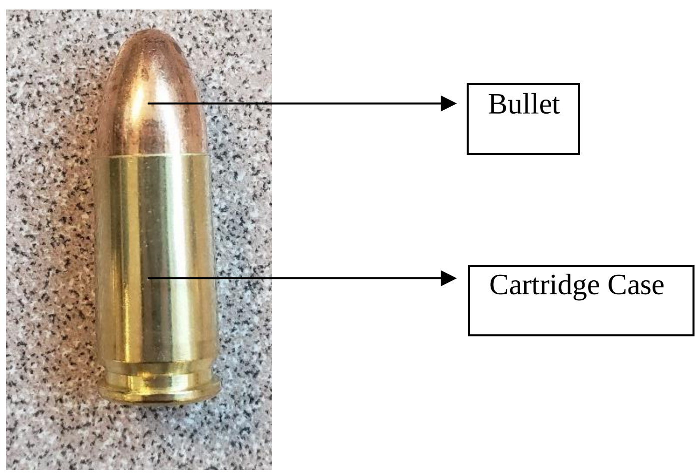
5C

Types of conclusions that can be drawn after analyzing fired evidence

After analyzing the two pieces of evidence under a comparison microscope, there are four conclusions that can be drawn by examiners at the conclusion of their analysis process: identification, elimination, inconclusive and unsuitable for microscopic identification. Identification; as defined in the Association of Firearm and Toolmark Examiners (AFTE) Glossary is an agreement of individual and class characteristic markings used to demonstrate that the evidence being compared was "produced by the same tool" (ATF). Elimination can then be identified as a disagreement of class characteristic and or individual characteristic markings. To generate an inconclusive deduction on the evidence in question, the examiner has decided that there may be some similar class and or individual characteristic markings among the fired evidence, but there may not be enough similarities for an identification. The conclusion "unsuitable for microscopic identification" occurs when there are no similarities among the pieces of evidence being compared (Steele 1-30). This means that there is not enough evidence available to generate a definitive conclusion based on the evidence analyzed, thus an unsuitable interpretation of the evidence after comparison analysis.

When someone commits an illegal act, there is a variety of evidence that can be found at a crime scene. Evidence can include, but is not limited to, fingerprints, saliva, hairs, fired evidence from a weapon, fibers, blood, and semen. Many times, these forms of evidence are left at crime scenes because the assailant(s) are determined to leave the crime scene in a hurry in hopes of not being identified as a suspect. Locard's Principle states that with contact between two items, there will be an exchange. The same tends to hold true in the Firearm and Toolmark industry. When a cartridge gets in contact with the firearm and or a part within a firearm, marking will be left on the cartridge, either on a cartridge case or bullet. Because components of a cartridge are oftentimes used incorrectly, the author intends to distinguish one from the other. A cartridge comprises of four components; the bullet that is used as a projectile, a cartridge case that holds all components together, a propellant; which is referred to as gunpowder and the primer; which ignites the propellant. A visual documentation of the cartridge and its components can be seen in Figure 6.

Figure 6: A visual documentation of the components of a cartridge which can be used to make an identification for fired evidence; cartridge case and bullet



Quite often, suspects are misled by the idea that they can get away with committing an illegal act with the help of a firearm. A firearm and toolmark examiner’s job are to compare the fired evidence obtained at a crime scene with the known fired evidence to generate a conclusion on the firearm or components of origin. If a firearm has not been collected in relation to the crime, Firearm and Toolmark examiners will then be expected to determine the type of weapon that could have been used in the crime.

According to author Daniel L. Cork, heavy research is needed to determine the uniqueness of firearm related tool marks or even to calculate the probability of uniqueness of markings on fired evidence (Cork). The statement mentioned in the previous sentence was reported in the NRC report; published in 2008. The NRC; National Research Council, is the section of the United States National Academies that produces reports responsible for shaping policies, advancing the pursuit of medicine, engineering and science while taking into consideration the opinion of the public (TETHYS). Since its formation in 1916, members of the NRC made it their duty to induce interest in the coordination of scientific and technological research and development. Every year, various experts in different fields serve on study committees to investigate some of the issues being faced by society relating to science and technology. Some examples of the issues discussed include, but is not limited to, problems including security, cyber weapons as well as radiation protection controversies (National Academy of Engineering 1-20). The result of their investigations usually bring forth a report providing their advice and guidance on resolving such issues (National Academy of Engineering 1-20).

Since the release of the 2008's NRC report, the terms "unique or uniqueness" as it relates to firearm and toolmark have been questioned by many. Merriam Webster Dictionary defines unique as "being the only one" (Merriam-Webster.com). While referencing this definition in relation to firearms, it should be noted that parts used in firearms such as an extractor, a barrel, and an ejector can produce markings that can be useful in the identification of cartridge cases or bullets that were recently discharged from a specific firearm. Doubts have been presented based on how unique these and other marks are. Due to the lack of characteristic markings left on the fired evidence, research on firearms, their parts and their manufacturing processes began and continues to date (Bonfanti and De Kinder 3-10).

Review of Manufacturing Processes

Now let's discuss manufacturing processes. There are four main manufacturing processes; namely Molding, Machining, Shearing and Forming and Joining (Faris). It was mentioned that if the products being made begin in a liquified form, the greater the chance of the manufacturer producing a part by the Molding process. Machining implements the use of certain tools such as saws, sheers and rotating wheels, which are not only helpful in making the manufacturing process more efficient, but they also aid in shaping items as they are being heated. During the production of multiple parts, a time will arise when parts; large or small, need to be combined. This brings us to the next manufacturing process, Joining. Joining allows multiple pieces to come together to be assembled into one object. With the use of other processes such as welding; along with heating, these parts can successfully merge. Shearing and Forming is the last of the four primary types of manufacturing processes. When referring to Shearing, this process produces metal products after using cutting blades as a fragmenting mechanism (Faris). Forming, on the other hand, incorporates metal and plastic using stress and pressure to form materials into the desired shape.

There has been much research conducted on the influence of tool marks on parts of a firearm after being subjected to a manufacturing process. It was proven that sequentially produced parts have toolmarks that are identifiable from one another. Although there are multiple manufacturing processes that parts of a firearm can be subjected to, only two manufacturing techniques will be the focus of this research: Metal Injection Molding (MIM) and Progressive Die Stamping. It should be noted that MIM and Progressive Die Stamping are two manufacturing techniques that have not been extensively researched before. Metal Injection Molding is a process listed under the Molding manufacturing process while Progressive Die Stamping is listed under the Shearing and Forming manufacturing process. Let's discuss each process, beginning with Metal Injection Molding manufacturing process.

From 1970 until 1980, Raymond Wiech developed a mechanism that allowed the processing of metal powders in the United States of America (Powder Injection Moulding International). It was after this new development of Powder Injection Molding that Metal Injection Molding (MIM) became useful in solving some of the most technological issues faced in many industries.

Molding involves the use of metals being heated until it becomes a liquified mixture. After being mixed, the solution would then be poured into a pre-prepared mold for part production. A general schematic for molding involves cooling of the metal after being liquified along with the removal of the part from the mold after production. Injection molding; one of four different types of molding, is the process done when metal is melted to create 3-D materials which can be used for the production of various parts (Faris). Blow molding: another type of molding is mostly used to make piping. The third type and final type of molding are compressed and rotational molding. Respectively, compressed and rotational molding are used for large-scale products like car tires and for the manufacture of furniture and shipping drums (Faris).

Metal Injection Molding (MIM)

Metal Injection Molding (MIM) is a procedure capable of producing very miniscule electromagnetic components with very detailed features (Ali et al. 274-282). This technique, after being developed in the 1980s, was an improvement from conventional forms of metal casting and was becoming more prevalently seen in firearm applications and their parts (NRA Staff). Although Metal Injection Molding parts were more fragile than traditional stamped or machined parts, they tended to be much cheaper and was easily produced. This does not necessarily mean that Metal Injection Molding parts are bigger in size. An approximate annual cost of 1.4 million dollars; as reported by the EPMA, can be used to produce 250,000 small Metal Injection Molded pieces weighing about 4.5 grams each. As such, a correlation was found between cost and the production of these miniscule parts. The bigger the part, the smaller the cost for production (European Powder Metallurgy Association, (EPMA)).

Parts created using the Metal Injection Molding (MIM) process can be found in many industries which may include, but are not limited to, defense/aerospace, automotive, electronics, dental, medical and, of course, firearm industries. It has been said that the machines used in this process need to have high material performance and excellent quantity production in order to produce efficient parts without costing the manufacturer an arm and a leg (*An Overview of Metal Injection Molding (MIM).*)

Metal Injection Molding (MIM) Process

The production of MIM parts may take a couple weeks to complete as it can involve multiple steps. The first step in the production of parts involves the creation of “feedstock.” Feedstock is produced by combining very fine powdered metal with binders.

One might ask; how are these metal powders obtained? There are various methods that can be used in the manufacture of metallic powders. Liquid metal atomization, chemical reaction, electrolysis and mechanical commuting are the four methods most commonly referenced when manufacturers need to convert metals into powdered metals (Nikolic´ and Popov). To provide the reader with additional information on the ways in which metal powders can be produced, the following paragraphs aim to provide excess details on the process.

Liquid metal atomization method would be completed after separating small droplets of liquified metal then rapidly freezing these droplets prior to them encountering one another or a hard surface. The metal would then fragment due to a high amount of gas or liquid. The production of metallic powders via chemical treatment can be conducted by thermal decomposition, precipitation from various solutions and oxide reduction. Before undergoing the electrolysis method, manufacturers must choose the best condition in which metals can be transformed. This would include the temperature used, density and electrolyte composition. After deciding the best factors for production, the metals would be subjected to additional processing states; washing, drying, crushing; thus, the production of high purity powders. Finally, mechanical commuting; solid-state reduction, occurs when the metal of choice is crushed, mixed with carbon and is passed through a continuous furnace. While in the furnace, the carbon and oxygen from the powder would be reduced leaving a "metal sponge." This "metal sponge" would be crushed and strained to produce the metal powder (Metal Powder Industries Federation). It should be noted that most metal powders applied in the industrial world were obtained from aqueous solutions (Metal Powder Industries Federation). As such, most metal powders used in the MIM process were produced via the liquid metal atomization method.

Metal powders in the shape of spheres are more desirable due to their high packing density and low flow viscosity. Although spherical metal powders tend to reduce the component's strength after being de-binded, spherical metal powders are the only shape that can be used in the Metal Injection Molding (MIM) process. According to authors Randall M. German and Animesh Bose, any rounded powder that is below 20 micrometers with a density near 60 percent that is also clump-free can be used in the MIM process (German and Bose).

Binders consist of a mixture of various additives such as stabilizers; which help to prevent degradation and plasticizers such as Polyethylene Glycol; which soften and enhances the flow of the feedstock. Used to provide strength to the component while aiding in the shaping process, the binder mixture is helpful in the successful production of MIM'd parts without defects. This can be said due to the fact that the binder system breaks down lumps of powder to produce a uniform feedstock without the separation of additives (Heaney).

Chemicals, it should be noted, are also present in the binder mixture. These chemicals are usually present in the form of polymers and waxes. There are two main compounds used in the formation of polymers: thermoplastic polymers and thermosetting polymers. Thermoplastic polymers such as Polyethylene are created by repeating small monomer groups along a chain without linking. Thermosetting polymers, on the other hand, allows cross linking only at high temperatures, and are soft and deformable until heated. After being cross linked upon heating at high temperatures, thermosetting polymers would become permanently rigid as they do not soften after being reheated. They do, on the other hand, begin to break down at high temperatures. Because the reactions conducted by thermosetting polymers occur slowly, the time needed to produce these parts with thermosetting polymers is usually longer when compared with parts made with thermoplastic polymers. Thermoplastic polymers are the total opposite of the thermosetting polymers as they soften after being heated and harden after being cooled (German and Bose).

German and Bose mentioned that the best mixing and cutting of feedstock occurs with a homogeneous distribution of powder without the production of cluster or lumps. There are two ways in which feedstock, after being formed, can be mixed. 1) The dry powders can be mixed with the binders and enter as a premixed composition into a compounder; 2) the binders can be heated to the compounder as the powders are added to the molten binder. The second method is the commonly used form when mixing feedstock. According to Randall M. German and Animesh Bose, when working with small or irregular-shaped particles, a longer mixing time is generally needed. The increase in mixing time is essential to obtain a consistent mixture. Having a well-mixed system produces a low viscosity; which can only be obtained by mixing the feedstock at a high temperature (German and Bose). The final step in the mixing process is conducted in a vacuum and occurs when the mixed feedstock is degassed. After mixing, pellets are formed using a heat extruder. A heat extruder has been mostly used in the industrial world for the production of pellets after pushing a mixture of heated metal into a die; thus the production of uniformed cross sectioned part (S. Surupa). As such, the use of a heat extruder during the production of feedstock in the Metal Injection Molding process is typical. It is during the production of the feedstock where defects can occur and can be attributed to the possible presence of bubbles in the feedstock. A predictable size of a pellet is 44 millimeters and is usually formed after the feedstock mixture has been cooled and chopped using a rotary cutter. After being cut, the pellets, which are now referred to as feedstock, are ready to face the next step of the Metal Injection Molding process.

After the feedstock has been heated and injected in a mold cavity; it is then that molding; the next step; would occur (Seerane 1-7). Molding involves the feedstock being poured into a pre-prepared mold to create the intended part. It should be noted that once molded under high pressure, the product obtained can be identified as a ‘green’ part. The geometry of this ‘green’ part is physically like the finished piece. It is at this stage of the manufacturing process that the ‘green’ part will be more or less 20% larger than the finished part and allows for shrinkage at the end of the MIM process (Seerane 1-7). After being molded, the part will be cooled in the cavity using external pressure.

Step three; de-binding. This involves the removal of binders, which help the part to retain its strength and durability as it is being used in the intended manufacturing industry. All pores in the MIM’d component after being mixed are filled by binders. During this process, thermal decomposition or solvent extraction is normally conducted on the ‘green’ part. The most widely used de-binding process occurs when the part is being Thermally De-binded. When being thermally de-binded, binders are removed from the ‘green’ component by the process of burning. This process can also be referred to as a “Polymer Burnout.” To prevent defects caused by trapped gases, the ‘green’ part can pass through a two-part Thermal de-binding process. In the initial stage of this process, binders of lower molecular weight are first removed to “form open pores for the rapid removal of binders” (Heaney). Although high molecular weight binders are needed for increased strength, these binders are also gradually removed from the part in stage two of the Thermal de-binding process. Solvent extraction is another way in which the part can be de-binded. It includes the submersion of the “green part” into a solvent solution that can include, but is not limited to heptane, acetone and water.

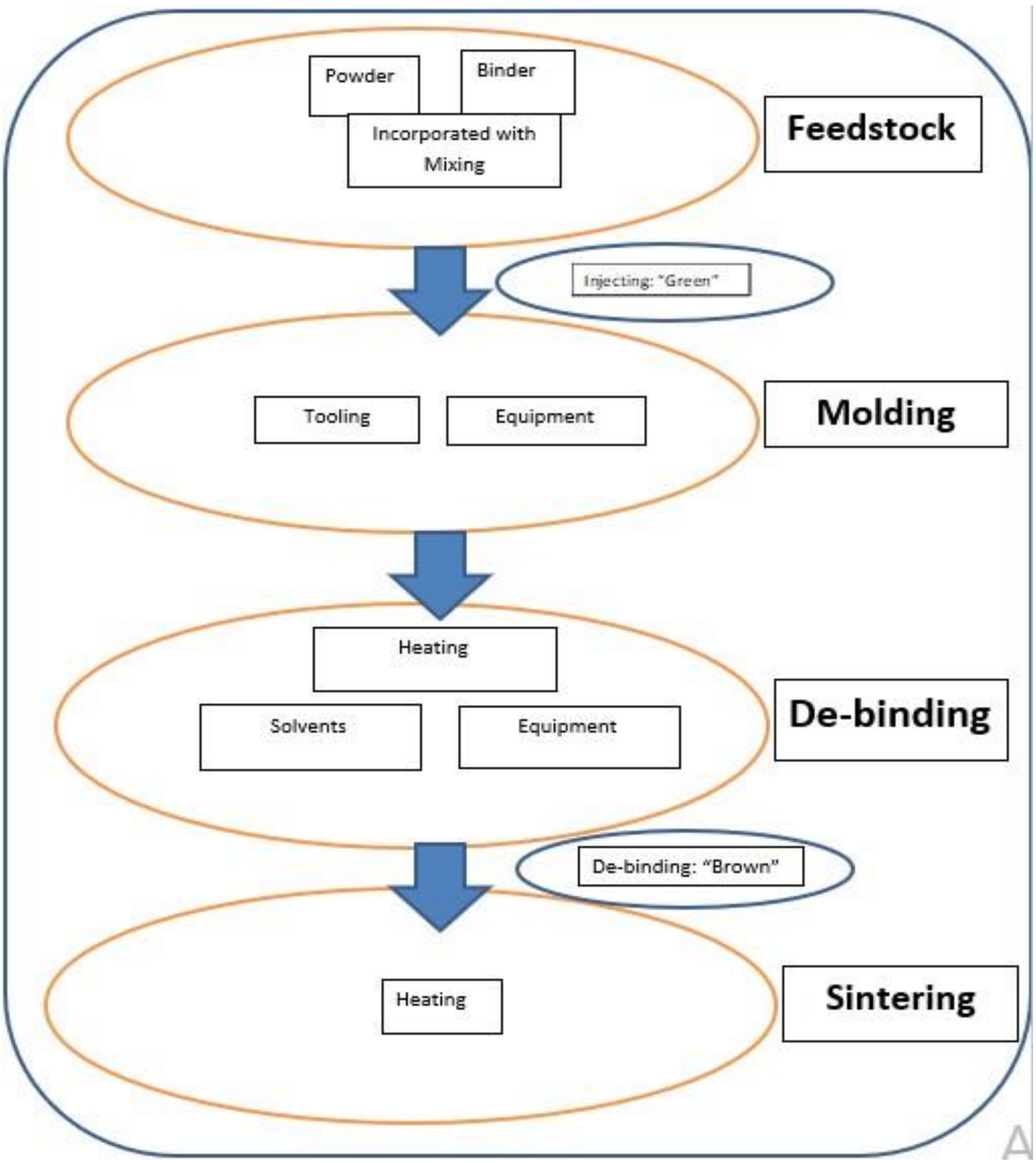
It is at this stage of the Metal Injection Molding process; after the produced part has been de-binded, that it is referred to as ‘brown.’ The ‘brown;’ is usually held together by a small amount of binder; making the part very fragile and more susceptible to defects. This is because the binder system; and essentially the strength of the part, was removed. In hopes of controlling and decreasing the presence of defects, the part is routinely de-binded at differing temperatures; from 150 ºC to 600 ºC.

Sintering is the final step in the formation of Metal Injection Molded (MIM) parts. This occurs when the remainder of the binder in the part is eliminated and the manufactured part regains its strength after being bombarded by a minimum temperature of 250 ºC. The manufacturing process of the produced part is now complete as the part forms its final geometry and increases in strength (Seerane 1-7).

Melt temperature is a factor that is to be considered during the sintering step. The melt temperature of parts is typically 10 to 20°C above the melting temperature of the feedstock and should be considered throughout the manufacturing process. If the temperature is too low, the feedstock will then experience poor flow rate (Heaney).

Below, the reader can visualize a structural diagram of the processes involved in the Metal Injection Molding manufacturing procedure.

Figure 7: A structural diagram of the processes involved in the Metal Injection Molding manufacturing procedure



There are certain factors that can negatively affect the production of a sturdy MIM’d part. This can include poor molding procedures within the Metal Injection Molding process. Having poor molding processes can cause the part to experience shrinkage during sintering. As such, manufacturers should always bear in mind that as melt and mold temperatures as well as the thickness of the produced part increases, so does shrinkage of the part.

Temperature plays a significant impact during this manufacturing process as various temperatures are crucial for some steps. As the viscosity of the feedstock decreases, the temperature experienced by the Metal Injection Molded part also decreases. Molding the feedstock at an increased temperature can cause defects in the molded part. This can be attributable to the fact that the part can decrease in size after cooling from the increased temperature (Heaney).

Injection speed is another factor needed to be considered. Injection of the feedstock takes place prior to the molding step. According to Donald F. Heaney, the speed set when completely filling the part without defect is oftentimes referred to as injection speed (Heaney). Although injection speed varies from manufacturer to manufacturer, having a constant injection rate from 10 to 30 cubic centimeters per second allows the mold to be filled in 1 second to ensure steady injection speed for the production of a solid part (AG). Donald F. Heaney continued to add that having a low injection speed could result in defects including, but not limited to incomplete fills and weld lines. On the other hand, having a high-speed during injection will result in the presence of blemishes due to separation voids.

Cooling time is an important aspect as it ensures that products are completely solidified prior to being ejected from the molding machine. The product, however, should not be cooled for too long as it can be damaged when being ejected from the machine. If the time period for the cooling process is too short, one consequence of this short cooling period can be damage to the ejection pin. If the cooling time is too long, this, on the other hand, can lead to cracking of the produced part.

There are a variety of things that should be considered during the design of parts in the Metal Injection Molding process. According to author Donald F. Heaney, "components that are less than 100 g[rams] and [are capable of] fitting in the palm of one's hand [w]ould be a good candidate for M[etal] I[njection] M[olded] technology" (Heaney). He further stated that manufacturers should avoid components that are over 12.5 millimeters thick and components that weigh 100 grams. Refraining from using long pieces and components more minute than 0.1 millimeters in diameter, avoiding walls that are thinner than 0.1 millimeters, as well as components that are capable of maintaining a thin and slender uniform thickness are suggested line items to ensure the production of structured Metal Injection Molded parts. Proponents of the Metal Injection Molding process stated that parts with sharp corners with a desired radius greater than 0.05 millimeters should also be avoided. During the designing of this process, they added, manufacturers should avoid inside closed cavities, remove the interior of thick areas to avoid sinks and to ensure that the part only has a flat surface during the sintering process. Most of these recommendations should be considered during the Metal Injection Molding process with the hope of circumventing sinks and voids as well as being able to limit distortions faced during the sintering process (Heaney).

As provided by Donald F. Heaney, there are certain features that are common in a Metal Injection Molded part. Some features, on the other hand, have been enlarged or minimized to satisfy the needs of the manufacturer. Weight and wall thickness of a Metal Injection Molding part was analyzed and an example of the minimum, typical and maximum measurements were suggested. The minimum, typical and maximum weight of a MIM'd part, respectively, is 0.030 grams, 10-15 grams and 300 grams. The wall thickness of the part was also provided and was found that the thickness of the walls should not exceed 0.06 inches. If the walls are thicker than 0.06 inches, this can lead to the part experiencing distortions. Wall thickness can, however, be as low as 0.01 inches. 0.2 inches is the typical wall thickness used when producing a MIM'd part (Heaney).

The mold cavity

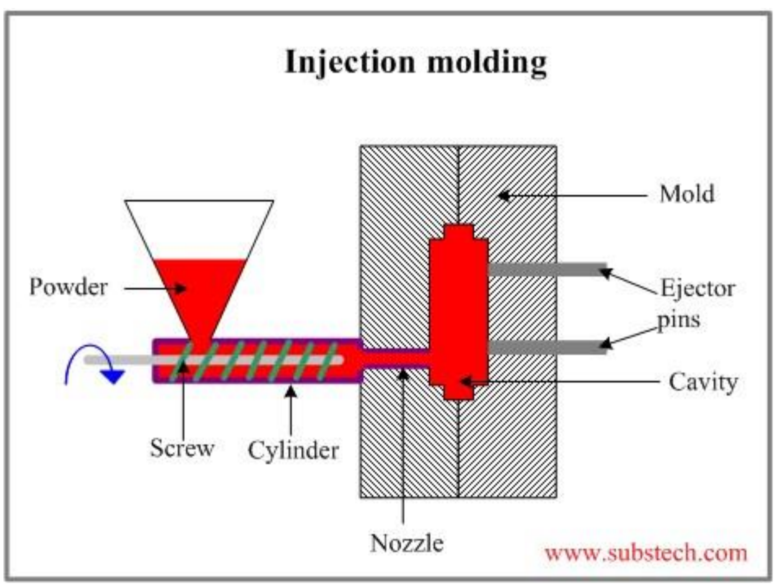
Remember, after the creation of the feedstock, this feedstock will then be heated and injected, under high pressure, in a mold cavity. In the MIM process, there is only one two-cavity mold. This means that all parts created by the MIM process would come from one of two molding cavities. The temperature of the mold cavity is typically controlled by hot water or oil as the feedstock circulates through the cavity. During manufacture of the Metal Injection Molded part, the mold cavity can sometimes be filled with air. Manufacturers, therefore, need to find ways for the air to be removed from the mold cavity to prevent holes from being incorporated in the molded part. To aid in the prevention of these voids, venting channels that are 0.005 to 0.01 millimeters deep can be incorporated in the mold cavity. Readers should also understand that these vent systems; although very beneficial in the removal of air, can also assist in getting excess feedstock out of the mold cavity (Heaney).

In order to get the feedstock into the mold cavity, the feedstock granules must be fed in a hot barrel. It is at this point that the feedstock; after already being heated, is compressed to create a homogenous mixture and is then injected in the mold cavity through a nozzle (Heaney). The barrel is also helpful in heating the feedstock as it progresses through the machine, therefore, the barrel must have an elevated temperature. If the barrel temperature is too low, there is a possibility that the feedstock may freeze before the mold cavity is filled. Having a very high temperature, on the other hand, would cause the liquified feedstock to drip through the nozzle opening. If the feedstock drips through the nozzle opening, this could essentially prolong the part's cooling time. Because of the effectiveness in filling the mold cavity, Donald F. Heaney would recommend keeping the barrel temperature as low as possible (Heaney).

After being injected and solidified in the mold cavity, the product can either be dropped into a container, onto a conveyor or picked up out of the molding machine by a robot or an operator. The use of the conveyor when removing the 'green' part is the most acceptable and widely used form of part removal. There are, however, drawbacks to the use of conveyors. Fragile components that should, by no means, have any defects on the manufactured part can be negatively impacted as conveyors can produce scuffs and defects on the produced part. Robots, on the other hand, are required mostly when a high level of self-regulation is needed to decrease costs or when the parts produced are vulnerable to contact damage. Another reason as to why manufacturers would utilize robots is because of its ability to provide precise placement of the component.

How are mold cavities made? According to Khurran Altaf and his collaborators, metallic molds are usually used in the MIM process (Altaf et al. 433). These scientists continue to add that although the machining process is time consuming and expensive, some advantages of the Metal Injection Molding process include the production of more suitable high-volume components. Rapid tooling (RT) can be defined as the process involved in the manufacture of molds. This mold making process can either be direct or indirect. Direct rapid tooling involves the creation of the molds themselves whereas indirect rapid tooling refers to the production of a replica of the object being casted. After the conclusion of experiments in 2018 by authors Mr. Altaf and his colleagues, they were able to conclude that the Metal Injection Molding process can also produce efficient molds after being 3D printed (Altaf et al. 433). As noted in the sentences above, there were numerous ways in which the mold cavity for MIM manufacturing process can be manufactured; by direct rapid tooling, indirect rapid tooling, by being 3D printed directly, as well as by indirect 3D printing. Once the manufacture of the mold cavity is completed, the mold would then be used to produce a series of standard parts. All machined parts should meet and or exceed a certain criterion for the legal use of manufactured parts. The same tends to be true for mold cavities. All mold cavities should always be produced according to the standards provided by the American Society for Testing and Materials (ASTM) to ensure that the MIM'd parts are durable enough for use in the field (Altaf et al. 433). An example of a mold cavity is depicted below.

Figure 8: Depiction of an example of a MIM mold cavity



See Appendix for permission

Besides Metal Injection Molding, there are other processes in the Firearm and Toolmark field that contribute to the manufacture of parts. This would include Progressive Die Stamping. Although there are other manufacturing processes; as discussed earlier, Progressive Die Stamping process will be explored throughout the remainder of the research paper and will, therefore, be compared with the manufacturing process discussed earlier, Metal Injection Molding.

Progressive Die Stamping Process

Progressive Die Stamping process was first accredited to a Frenchman named DeVere. Prior to that, punches and dies were being used in the 15th century "to ensure punch-die alignment" (Ulintz). Since DeVere's invention of the Progressive Die Stamping manufacturing process, he earned and was granted a patent for "Dies for Punching and Drawing Sheet Metal;" which birthed the beginning of this new manufacturing era (Ulintz).

Progressive Die Stamping Die Design

To produce a sturdy part via a Progressive Die Stamping manufacturing process, there are various parts that need to be collected. These include a flat piece of metal strip, multiple progressive dies capable of producing different stamping operations on the metal strip along with a cutting operation to remove the completed part from the remaining strip of metal.

The dies in the Progressive Die Stamping process are usually molded with tool steel in hopes that they would resist the high temperature that is usually associated with this manufacturing process.

Progressive Die Stamping dies mainly retain sharp cutting edges that are useful in the cutting process and can withstand any degradation. The design for a Progressive Die Stamping process is simple as it involves various dies contacting the metal strip. To summarize this manufacturing process, the reader should understand that as the metal enters the Progressive Die press, there are two dies involved: a top die and a bottom die. The top die would strike the bottom die; essentially "sandwiching" the metal placed between both dies. After striking the metal, this movement would cause a change in the metal as it is being stamped. As the metal travels down the production line encountering various dies, it is then that the metal would face different stamping processes until the production of the final part; the Progressive Die Stamped extractor (Bahrs Die & Stamping).

According to Khairul S. Shaffee, et al., in order to fulfill the requirements needed to create functional parts via the Progressive Die Stamping process, there are four essential die designs that need to be taken into consideration. These include requirements relating to the use of equipment and tooling, the limitations of the Progressive Die Stamping process as well as the production rate and size of the product throughout the process (Shaffee and Sulaiman 1-10). Reflecting on the die design considerations mentioned formerly, manufacturers need to ponder upon what this manufacturing process can and cannot do and the amount of parts that can be produced at a given timeframe. Although it would be superb to have an instrument that does not malfunction, this desire is unrealistic. As such, manufacturers need to be able to trouble shoot their machine if difficulties should arise.

There are various metals that can be used in the manufacturing of parts via the Progressive Die Stamping process. These metals usually include, but are not limited to silver, gold, bronze, brass, zinc, beryllium copper and stainless steel (Mills).

After completion of the die design and the collection of the proper materials, the manufacture of the part in question can commence.

Progressive Die Stamping

The process involved in Progressive Die Stamping can be described as an “assembly line” process. This is because the metal strip moves from one station of the Progressive Die Stamping process to the next as it performs various operations while manufacturing products to be used in various industries; from agriculture, computer, construction to plumbing businesses (Keats Manufacturing). To provide a summary of this process, the strip of metal goes through a series of steps before reaching its final form. When the metal strip is obtained and is placed into the metal stamping machine, the metal will experience various punches and bends to achieve the desired shape (Lange; Lin et al. 1887-1899). A more in-depth description of what can be done at each station will be discussed later. Because of its versatility, Progressive Die Stamping is used for the production of a variety of merchandise and can without a doubt meet the needs of various clientele (Keats Manufacturing).

Progressive Die Stamping Process

Having individual workstations involved in the reshaping of a flat metal sheet describes the simple operation involved in the creation of a Progressive Die Stamped component. The metal strip faces various dies in an enclosed location with room temperature conditions (Keats Manufacturing). This process includes multiple tasks in a single die referred to as a “Progressive Die.” Each step performed within the process comprises of various stations. The stations referenced in the Progressive Die Stamping process include piercing, blanking, bending, drawing, re-striking, side punching and cutting. I will provide further information to provide readers with a better understanding of what takes place at each station. A metal coil is first fed into a stamping press with Progressive Stamping Dies. As the metal sheet continues down the production line, the die would close to stamp the metal. This process would continue; allowing simultaneous cutting and forming operations until the production of the part has been completed (Mills). It is only after the final cutting or forming operation has been done on the part that the finished product(s) will be removed from the die. Because this process allows multiple operations, this saves manufacturers significant time during production (Keats Manufacturing). The Progressive Die Stamping process is very durable as the dies involved are long-lasting when not damaged or broken. The Progressive Die Stamping process also limits the amount of wasted scrap metal left. Seeing that this system only requires a one-time set up, it grants the user the opportunity to operate it at extremely high speeds with minimal downtime (Mills).

The different processes involved in the Progressive Die Stamping procedure are described as follows.

Step One:

Piercing *(Rohit O. Tembhurkar Pankaj K. Bhoyar Prafulla S. Thakare)*

Piercing is a cutting operation by which various holes are made in metal sheets. The first operation done on the strip would be the piercing of guide holes. These holes are expected to be placed horizontally on the metal strip. These guide holes have been pierced to hold the strip while other operations are being performed on the metal strip.

After the metal sheet has been pierced, it is then that the part travels along the remainder of the die.

Step Two:

Blanking *(Rohit O. Tembhurkar Pankaj K. Bhoyar Prafulla S. Thakare)*

In this step, the outline is cut from the raw material from step one; thus, forming the desired shape seen at the end of the production line.

The piece then continues along the remainder of the die.

Step Three:

Bending *(Li, Nee, and Cheok 883-895)*

This step: bending, of the Progressive Die Stamping manufacturing process occurs when the edges of the flat metal sheet is bent or folded as a way of pre-preparing the product for manufacture of a 3D part. It should be noted that a minimal radius for bending a material without any chance of defects on the outer surface is ideal for the development of any part. This bending radius varies by material and can be from a radius as small as 90 degrees to as high as 145 degrees. As a result, any material that is to be bent should always be proportional to the material thickness to avoid any future defects, voids or unwanted materials.

The part then follows the path to the remainder of the die for step four of the Progressive Die Stamping process.

Step Four:

Drawing *(Suchy ; Lin et al. 1140-1152)*

Drawing is the process during which a flat piece of material; referred to as a blank, is successfully transformed into a three-dimensional object. As a force is applied to the blank restricting the flow of metal, the blank would be transformed to a wrinkle-free three-dimensional object. This step can occur in a single step or in a sequence of operations; thus, allowing a change in the shape of the material at each step. Starting out as a flat sheet of metal, the blank is placed over an opening so that it can be transformed into a three-dimensional object.

The part produced then travels along the remainder of the die.

Step Five:

Re-striking *(Rohit O. Tembhurkar Pankaj K. Bhoyar Prafulla S. Thakare)*

Re-striking is conducted because of the presence of unwanted materials that can be formed on the manufactured part during any of the previous operations. Re-striking is usually done to remove any unwanted materials and bent aspects of the part by applying a set of cutting dies, shaping dies, punching dies or a combination of cutting, shaping and punching dies that are identical to the component's size.

The piece then proceeds to step six of the Progressive die stamping process.

Step Six:

Side Punching *(Merriam-Webster Dictionary)*

Side punching can be defined as the insertion of holes around the part as it prepares itself for the separation of the product from the remaining metal strip.

This takes us to the final step of the Progressive Die Stamping.

Step Seven:

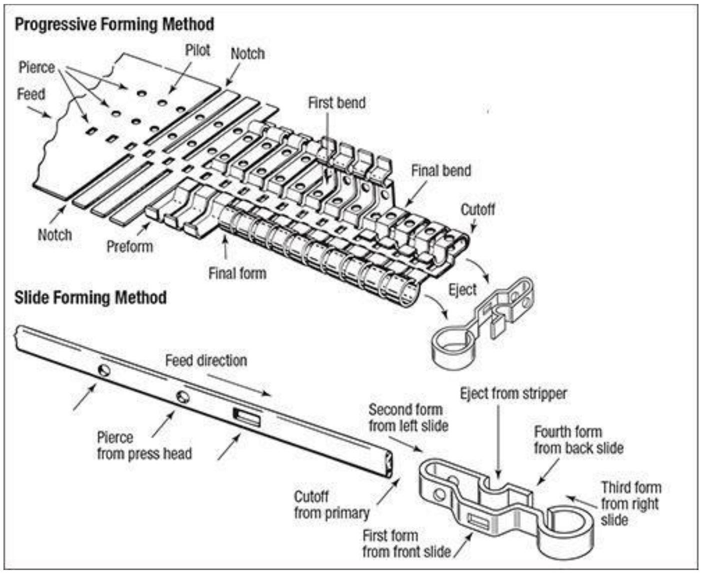
Cutting

It is at this final station of the Progressive Die where the newly- manufactured part will be separated from the rest of the metal as it is cut and removed from the metal strip.

It should be noted that I had difficulties finding a good depiction of each step within the Progressive Die Stamping process, therefore, readers should refer to the figure below for further clarification of the steps involved in the Progressive Die Stamping manufacturing process.

Figure 9 below provides a visual depiction of Steps 1 through 7 of the Progressive Die Stamping process. Readers should focus on the Figure shown under the title “Progressive Forming Method.” The manufacturing process begins at the left of the figure and terminates on the right. The piercing, bending and cutting steps of the manufacturing process can be clearly seen.

Figure 9: A visual depiction of the progressive die process from beginning to end



See Appendix for permission

The cutting process is considered as one of the most extensively used manufacturing processes in the die and metal sheet work (Lin et al. 1887-1899). Since its development in the twentieth century, metal cuttings have been useful for the separation of the part from a pre-established portion of a metal sheet. The quality of the surface of these parts, the condition of the part and the tools used in their production, the thickness of the finished product; along with other important criteria all contribute to the production of hundreds and thousands of metal stamped parts (Suchy).

One of the main defects found in the cutting station is lead burr. A lead burr defect can be defined as a small piece of material that is still attached to a workpiece after production. Seeing that this material is usually not wanted on the part by the manufacturer, it should be removed. Lead burr defects do not always happen. Because of the geometry involved in the punching station, lead burr defects are prominently seen on 1-sided lead parts. This can be attributable to the fact that the 1-sided lead have thinner surfaces when compared to the 2-sided lead. For that reason, stress seen on 1-sided lead parts always tend to be higher; and are, thus, easily breakable (Shaffee and Sulaiman 1-10).

It was stated that the number of features needed for the manufacture of any part of a firearm was dependent on the tooling being utilized and the amount of stations a Progressive Stamping Die machine will have. Many companies would suggest refraining from using complex features to assist in keeping the cost of the Progressive Stamping Die to a minimum. Individuals working for the Bahrs Die & Stamping company also recommends refraining from having narrow cuts and bulging in manufactured parts as these can lead to problems later on in the manufacturing process (Bahrs Die & Stamping). After the completion of the Progressive Die Stamping manufacturing process, finished items can range from orthodontic brackets, electrical terminals to firearm parts.

Weapons: being in existence for decades, have encountered few research experiments on Metal Injection Molded (MIM) and Progressive Die Stamped parts since the twentieth century. No prior research has been found on whether individual characteristic markings from extractors on fired evidence can be differentiated by an examiner after comparing fired evidence. As such, it is in my interest to investigate this topic extensively.

Weapons are frequently manufactured and used worldwide. With the passing of time, various types of weapons used have gradually become more technical and advanced. The use and increased number of weapons; along with the many issues that can be associated with having these weapons essentially led to them becoming a problem in many countries. This essentially caused the task of crime fighting to be more challenging for law enforcement officers worldwide. The Beretta, Remington, Ruger LCP guns; although less popular, all utilize parts made using the MIM process. The method used in the creation of parts for the Metal Injection Molding process has only one two-cavity mold. As mentioned before, this means that all parts involved in the molding process could have only come from one of two mold cavities. Because the parts involved in the MIM process are molded and can be of great importance in a firearm analyst's analysis process, it should also be noted that parts within shotguns may too have a greater potential of the production of reproducible marks. The Progressive Die Stamping manufacturing process includes a piece of metal strip, multiple progressive dies capable of producing different stamping operations on a metal strip along with a cutting operation used to remove the completed part from the remaining strip of metal. It should be noted that parts within the Hi-Point Firearm may have a greater potential of the production of identifiable reproducible marks. As such, it is the intent of the writer to investigate the accuracy of the statements regarding the production of reproducible marks using various manufactured extractors and weapons.

COMPARISON OF METAL INJECTION MOLDED PARTS VERSUS PROGRESSIVE DIE STAMPED PARTS

Problem:

The presence of small parts used in firearms usually produces marks useful in the identification of cartridge cases or bullets that was recently discharged from a firearm. There have been doubts regarding the uniqueness of these and other marks left on the fired evidence obtained. This is due to a lack of characteristic markings (Bonfanti and De Kinder 3-10).

Reproducing marks are more liable to happen due to the weapon's manufacture process. As such, manufacturing processes needs to be investigated as reproducing marks can vary from time to time (Thompson 1-36). Seeing that it is impossible for two separate surfaces to be microscopically identical, this can become a problem if firearm and toolmark examiners are incapable of forming an identification and differentiation of weapons and other related components retrieved from a crime scene.

Thesis Hypothesis:

Mass produced parts by modern manufacturing processes can be differentiated by firearm examiners after comparing fired evidence.

Location

This research was conducted at the Illinois State Police (ISP) Forensic Science Center at Chicago with the assistance of an expert firearm examiner; Mr. Marc Pomerance. He not only assisted in the firing of the weapons; but also aided in the replacement of extractor parts and examination of the cartridge cases after discharge.

Goals and Aims:

- Goal #1:
  - Obtain: Metal Injected Molded extractors, Remington shotgun and ammunition

    Progressive Die Stamped extractors, Hi-Point Firearm and ammunition
- Aim:
  - Seek assistance; if needed, to obtain standard Metal Injection Molded extractors, Remington shotgun and Remington shotgun ammunition
  - Seek assistance; if needed; to obtain standard Progressive Die Stamped extractors, Hi-Point Firearm and Hi-Point Firearm ammunition

- Goal #2:
  - Test fire ten rounds of ammunition per Metal Injection Molded extractor using Remington shotgun

- Test fire ten rounds of ammunition per Progressive Die Stamped extractor using Hi-Point Firearm

• Aim:

- Seek assistance; if needed, from a firearm expert qualified or licensed to discharge Remington shotgun using appropriate ammunition
- Seek assistance; if needed, from a firearm expert qualified or licensed to discharge Hi-Point Firearm using appropriate ammunition

• Goal #3:

- Examine Metal Injection Molded and Progressive Die Stamped ammunition to determine if individual markings are present
- Determine whether individual markings found on Metal Injection Molded and Progressive Die Stamped ammunition can be differentiated after comparing fired ammunition

• Aim:

- Use a reliable computer device to capture images
- Analyze the results of the comparisons then generate a conclusion based on observations, experimentations and findings

It should be noted that after comparing the extractor markings, statistical analysis; t-testing, on these markings was conducted. The aim of this research was to prove that mass produced parts by modern manufacturing processes can be differentiated by firearm examiners after comparing fired evidence. Although after conducting the t-test, “p-values” from 0 through 1 were obtained. All “p values” greater than 0.05 were eliminated. This was because having “p-values” less than and equal to 0.05 means that there are differences between the markings being compared.

Materials Used:

Figures of all materials were taken using a Leica comparison microscope with a PAX-cam digital camera utilizing the “LIM S-Beast” software unless otherwise noted. Magnification ranged between 10X and 40X on the PAX-cam digital camera.

- Weapon 1: Remington shotgun
    - Serial number T031600V
    - Wingmaster Model 870
    - 12 Gauge pump action
    - 28-inch smoothbore barrel

Figure 10: Illustration of the Remington shotgun being used in this experimentation process

- Weapon 2: Hi-Point Firearm
  - Serial number P1387420
  - Model C9
  - 9 mm Luger; semi-automatic pistol
  - 3½ inch barrel
  - 9 lands and grooves with a left-hand twist
  - Beemiller, Inc; Mansfield, OH

Figure 11: Images of the Hi-Point Firearm being used in this experimentation process

- Remington shotgun ammunition

*Figure taken with camera using my cellular device; Samsung Galaxy Note9

Figure 12: Illustration of the Remington ammunition used in this experimentation process

- Hi-Point Firearm ammunition

*Figures taken using my cellular phone camera from Samsung Galaxy Note9

Figure 13: Illustration of the Hi-Point Firearm ammunition being used in this experimentation process

To determine the number of ammunitions to be used and analyzed during this research, a few experimentations conducted by other specialists were reviewed. It was concluded that the smallest sample size of test fires would provide enough evidence to be able to visualize any possible individual reproducing characteristic markings. It was also found that a minimum of ten ammunitions were enough for a representative sample. This was after reviewing Morris, Keith B., Law, Eric F., Jefferys, Roger L., Dearth, Elizabeth C.'s work (Morris, Keith B., Law, Eric F., Jefferys, Roger L., Dearth, Elizabeth C. 1-260). As such, ten rounds of ammunition were test fired per weapon.

- Comparison Microscope: Leica Comparison Microscope
    - Leica Microsystem Inc.
    - Model: UFM4
    - Serial number: 000235176RW0001
    - Buffalo, N.Y
    - Made in U.S.A

Although the serial number of the comparison microscope used throughout this experimentation process was noted, this, however, does not indicate the possibility of the production of different images if other microscope(s) were used.

Figure 14: Comparison microscope used to conduct the comparisons of the cartridge case

- Extractors

-There were three Metal Injection Molded extractors used.

Figure 15: Illustration of the Metal Injection Molded extractors being used in this experiment

15A

15B

Figure 15A above shows all the Metal Injection Molded extractors that were obtained for this experiment. All extractors were received in a small manila envelope. After examining all six extractors, it was found that the extractors contained stamped numbers: one, two and four. There were repetitions among some extractors as two extractors were numbered “1,” and one extractor numbered “2.” Three extractors had the number “4.” Because there were more of the extractors numbered “4” along with the fact that there were the only extractors available at the time of this research, these three Metal Injected Molded extractors were used throughout this experimentation process. These three extractors can be seen in Figure 15B above.

-There were five Progressive Die Stamped extractors used.

Figure 16: An illustration of the Progressive Die Stamping extractors being used in this investigation

It should be noted that the extractors used for this project were obtained by Mr. William Demuth II, a Forensic Science Administrator II- Training Coordinator. All 3 Metal Injection Molded extractors as well as the 5 Progressive Die Stamped extractors used throughout this research was, again, used based on availability from the various manufacturing companies. The Remington shotgun extractors were obtained from Remington Arms in New York. The Hi-Point extractors were obtained from Hi-Point Firearms in Ohio. Remington Arms is a manufacturing company that produces Metal Injection Molded extractors while Hi-Point Firearms is a company that manufactures Progressive Die Stamped extractors. Five extractors were obtained for the Progressive Die Stamping process and three extractors for the Metal Injection Molding process. All extractors for each process was used interchangeably throughout the test firing process between both weapons, which was, again, conducted by Mr. Marc Pomerance.

Why are Remington and Hi-point weapons important in this investigation? Seeing that handgun and long guns are the most popular weapon types used, experimenting with both weapon types; Hi-Point Firearms and Remington shotgun, would provide readers with results on the comparison of fired evidence from two different type of weapons.

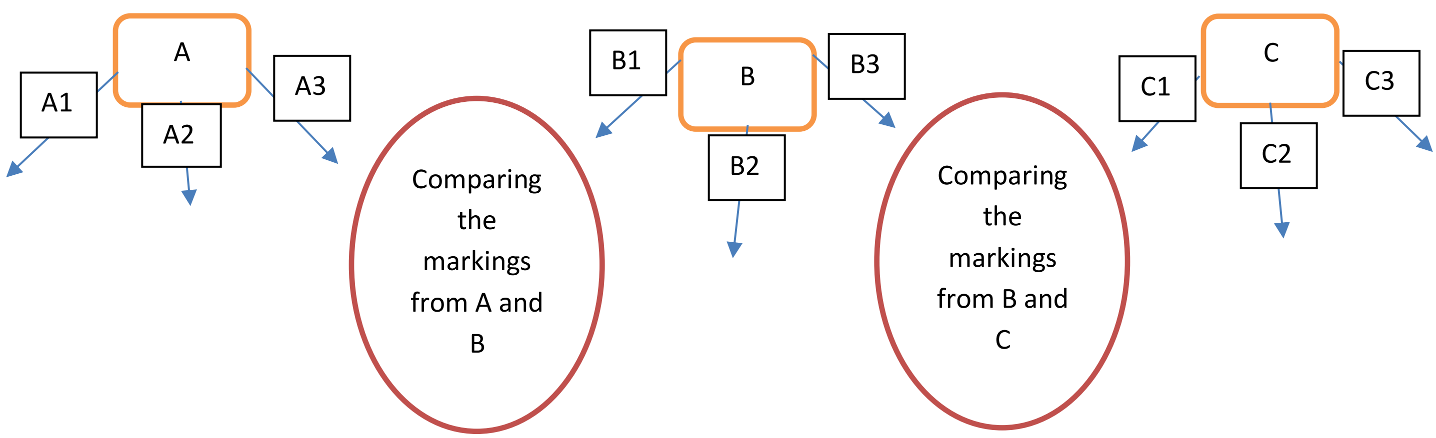
For individual characteristic markings to be identified on fired evidence, the extractor markings must be identified on fired evidence. Because of the different processes in which the analyzed extractors were manufactured; Progressive Die Stamping and Metal Injection Molding, this may cause reproducing marks to be displayed on cartridge cases and shot shells after discharging various weapons. To test this theory, the markings on cartridge cases obtained after discharging a Remington shotgun with Metal Injection Molded extractors as well as possible reproducing marks on shotshells obtained after discharging a Hi-point Firearm with Progressive Die Stamped extractors were analyzed and compared.

COMPARING MARKINGS PRODUCED BY THE METAL INJECTION MOLDED AND PROGRESSIVE DIE STAMPED EXTRACTORS

It is, thus, the author's intention to obtain pertinent information that can help to determine if parts produced by mass production can be differentiated by firearm examiners after comparing fired evidence. As such, the characteristic markings produced by the manufacturing processes of Metal Injection Molded extractors and Progressive Die Stamped extractors were compared.

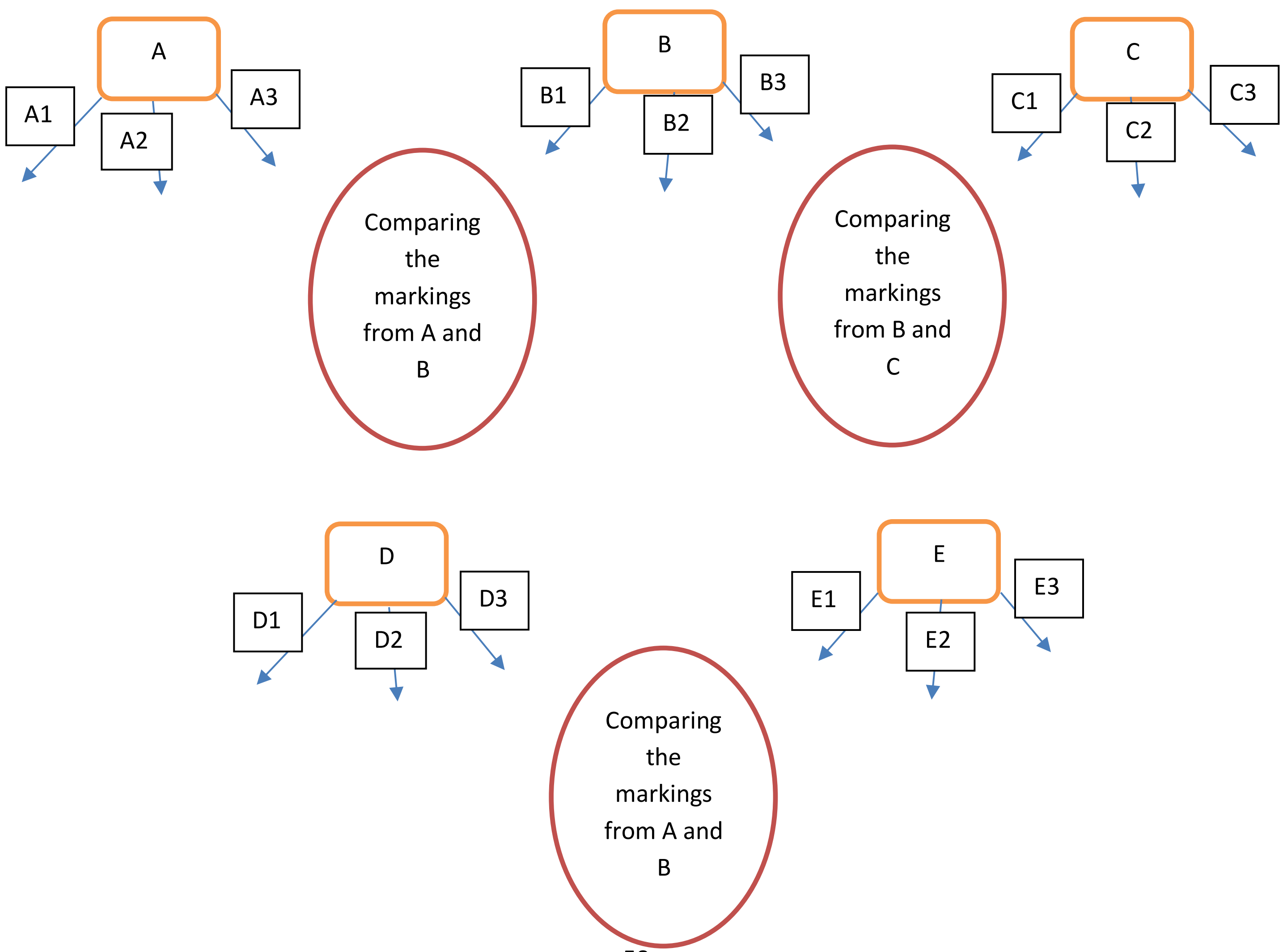
Below is a visual schematic of the two comparisons conducted on the extractor markings for both manufacturing processes: within and inner comparisons. Figure 17 references Metal Injection Molded comparisons while Figure 18 references Progressive Die Stamped comparisons.

Figure 17
Comparisons conducted on the Metal Injection Molding manufacturing markings



When referencing Figure 17, it should be noted that the within markings produced by extractor A, B and C were similar. This means that markings produced (A1, A2 and A3), (B1, B2 and B3) and (C1, C2 and C3) amongst each group were indistinguishable. When comparing the inner markings produced by the three extractors; for example, markings produced by extractor A being compared with the markings produced by extractor C, there were significant differences amongst these markings.

Figure 18
Comparisons conducted on the Progressive Die Stamping manufacturing markings



When referencing Figure 18, it should be noted that the within markings produced by extractor A, B, C, D and E were similar. This means that markings produced (A1, A2 and A3), (B1, B2 and B3), (C1, C2 and C3), (D1, D2 and D3) and (E1, E2 and E3) amongst each group were indistinguishable. When comparing the inner markings produced by the three extractors; for example, markings produced by extractor A being compared with markings produced by extractor C, there were significant differences amongst these extractor markings.

After comparing the extractor markings, both the within and inner comparisons, statistical analysis on theses markings was conducted.

STATISTICAL ANALYSIS

To determine whether a correlation exists between the markings produced by the Metal Injection Molded and Progressive Die Stamped extractors, a statistical analysis was conducted.

To compare these extractor markings after capturing image documentation of the markings, individual images of the Metal Injection Molded and Progressive Die Stamped extractor markings were recaptured and converted to statistical data. The Progressive Die Stamped extractor markings were captured at a magnification of 40X while the markings produced by the Metal Injection Molded extractor was captured at a 30X magnification. Image recapture was done to ensure the extractor markings can be compared. Without statistical data, the task of validating or refuting my research hypothesis was not possible. tpsDIG, a program created by Mr. James Rohlf, was used to convert the images of both the markings produced by the Progressive Die Stamped extractor and the Metal Injection Molded extractor markings into data points. This was done by first downloading the tpsUtil32 and tpsDIG232 on my computer and obtaining a “digitized landmark” of all markings. tpsUtil and tpsDIG was utilized because they were the best software available at the time that this research was conducted. Throughout the entirety of this research, I tried to be as objective as possibly. Using the tpsUtil and tpsDIG software due to their availability may, however, seem subjective in nature, but it is indeed objective. This is because of the ability of these programs to produce information proving its data repeatability factor.

To obtain a digitized landmark of all markings, the images were first inputted in the tpsUtil program. After being inputted, the images were then retrieved using the tpsDIG software. The markings were then traced or outlined using the “digitize landmark” cross-haired option found on the home screen of the software as is indicated in Figure 18 for the Metal Injection Molded extractor marking and in Figure 19 for the Progressive Die Stamped extractor marking. After digitizing the landmarks, the images were then saved. The data points for each extractor was obtained and was displayed after reopening the saved image using the “Notepad” text editor. An example of the data points that can be obtained after digitizing landmarks is displayed in Figure 20.

Figure 19: A depiction of how each extractor marking was traced within the tpsDIG software. Extractor 1-1 for the Metal Injection Molded extractor marking

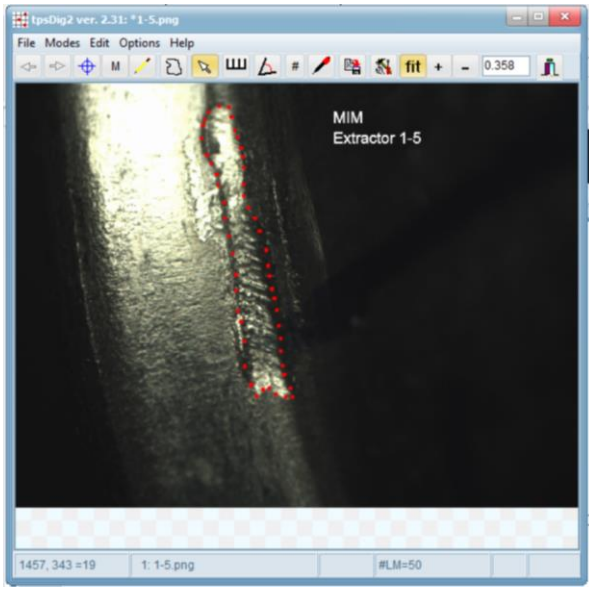


Figure 20: A depiction of how each extractor marking was traced within the tpsDIG software. Extractor 1-1 for the Progressive Die Stamped extractor marking

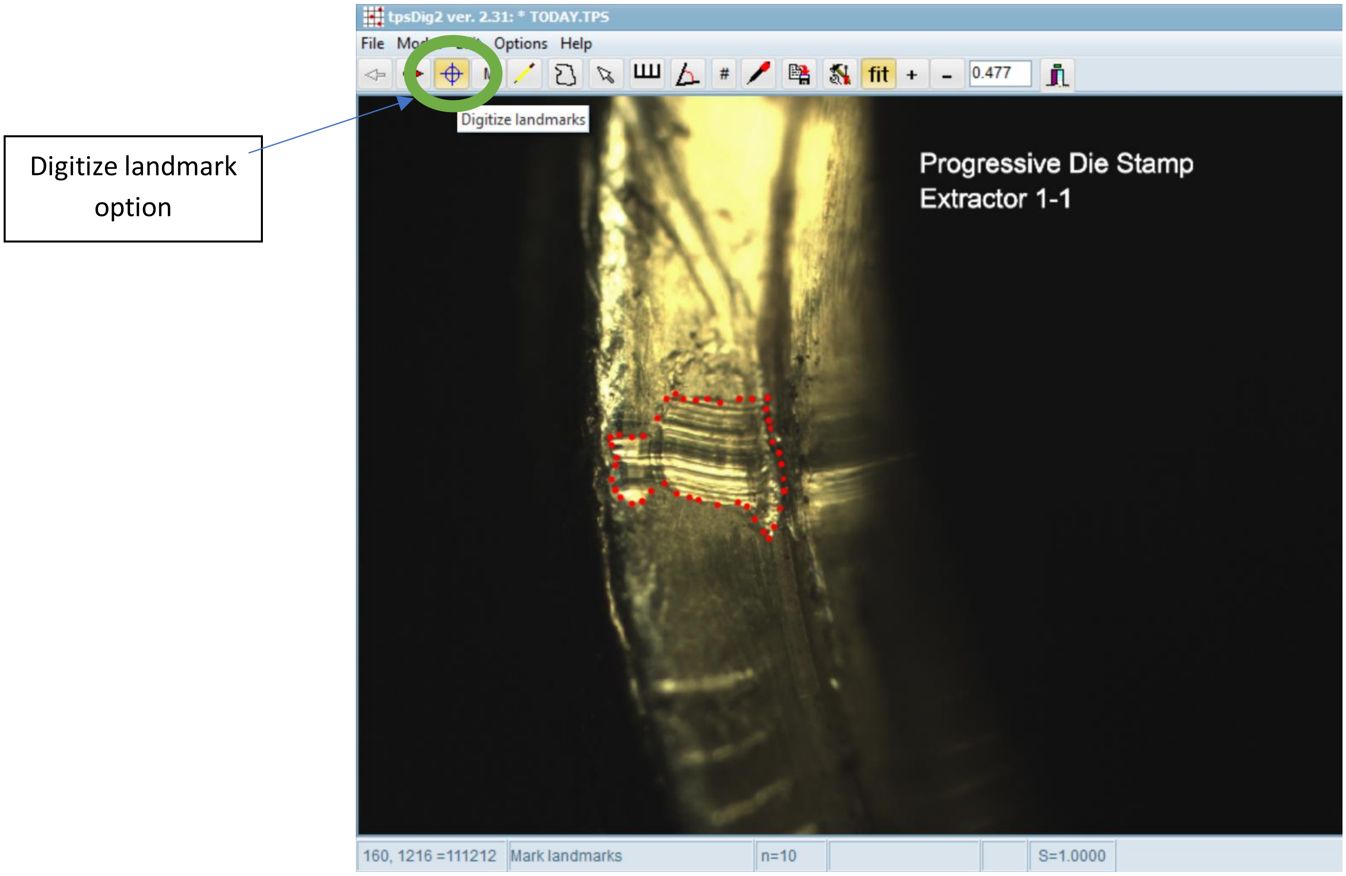


Figure 21: An example of the data set that could be obtained after digitizing each landmark within the Progressive Die Stamped and Metal Injection Molded extractor marking

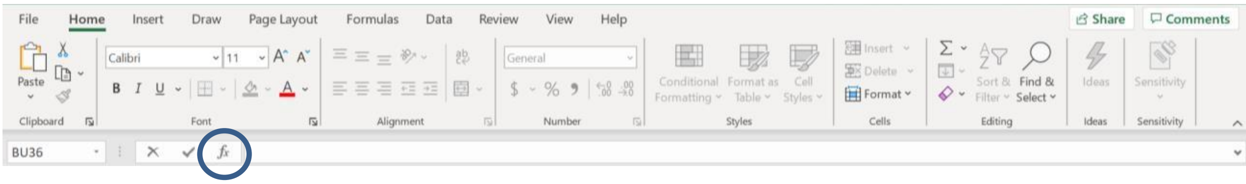
449.00000
468.00000
491.00000
506.00000
520.00000
533.00000
554.00000
573.00000
593.00000
625.00000
625.00000
646.00000
671.00000
671.00000
669.00000
673.00000
680.00000
690.00000
694.00000
697.00000
699.00000
699.00000
692.00000
682.00000
673.00000
665.00000
650.00000
638.00000
623.00000
590.00000
558.00000
543.00000
522.00000
502.00000

An alpha value sets the standard for how extreme a data set must be before the researcher can accept or reject the hypothesis. The two mostly used alpha values are 0.01 and 0.05.

Throughout this research, an alpha value of 0.05 was used. This was because having an alpha value of 0.01 makes it more difficult for the detection of differences among two data sets. “P-values” can vary from 0 to 1. As mentioned in the research article written by Wasserstein and Lazar, the smaller the “p-value;” closer to zero, the more incompatible the data sets are as they are compared (Wasserstein and Lazar 129-133). The aim of this research is to prove that mass produced parts by modern manufacturing processes can be differentiated by firearm examiners after comparing fired evidence. As such, although “p-values” from 0 through 1 were obtained, all “p values” greater than 0.05 were eliminated and converted to “N/A” values in the Excel spreadsheet. By doing so, the within compatibility of the Progressive Die Stamped extractor markings as well as the Metal Injection Molded extractor markings can be statistically proven or disproven after conducting a t-test. Four tables with “p-values” gathered from each manufacturing process was obtained in Excel to serve as a visual aid for the comparisons. Two tables for the within comparison of the Progressive Die Stamped extractor markings and the Metal Injection Molded extractor markings. Two additional tables; one for each manufacturing process, were then obtained after the elimination of all “p values” greater than an alpha value of 0.05.

To conduct a t-test, a Microsoft Office software “Excel” was used after copying and pasting all “p-values” obtained for the Progressive Die Stamped extractor markings as well as the Metal Injection Molded extractor markings. It was then that the t-test was conducted. After opening an excel spreadsheet and selecting the excel cell; “AT” for the Progressive Die Stamped extractor marking, the function button as below was selected.

Figure 22: The “function” button used to begin the “t-test analysis”



After selecting the function button, an “Insert Function” box emerged and the intended “t-test” function was selected. In Figure 23 below, the “t-test” function appeared under the “Most Frequently Used” category as it was regularly utilized throughout this research. If, for some reason, this test does not appear as seen in Figure 23, it can be found under the “Statistical” category as illustrated in Figure 24.

Figure 23

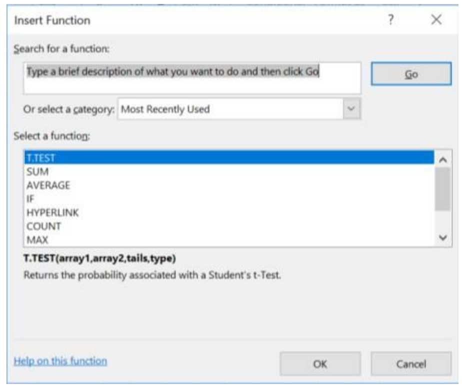
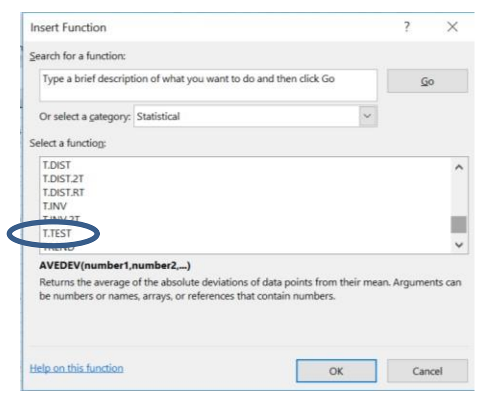
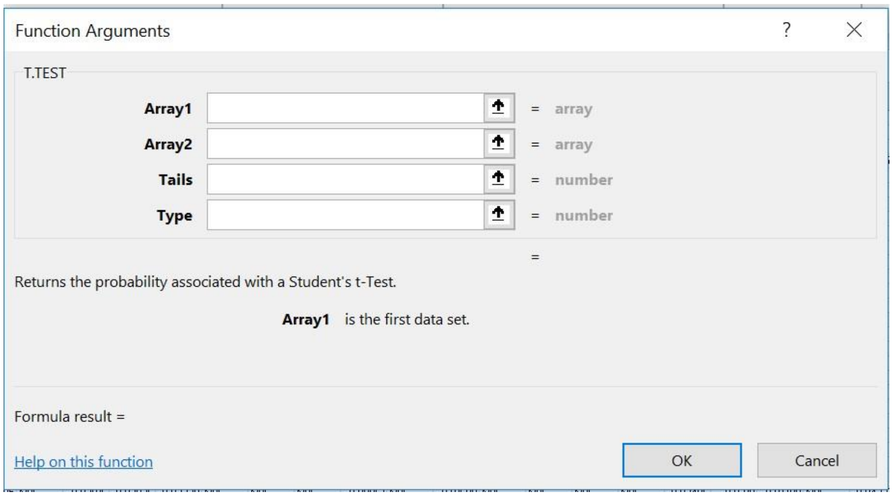


Figure 24



After finding and selecting the “t-test,” a “Function Argument” box emerged for me to select the data sets that are to be compared. In reference to Figure 24 below, “Array 1” represents the location of the first data set. “Array 2” represents the location of the second data set. “Tails” refers to how open ended a hypothesis is. The following is an example of “tails.” For this study, my hypothesis was “Mass produced parts by modern manufacturing processes can be differentiated by firearm examiners after comparing fired evidence.” Based on the meaning of “tails,” my hypothesis could be considered an open-ended question and “two tailed.” If my hypothesis was, on the other hand, “Progressive Die Stamped extractor markings and Metal Injection Molded extractor markings can be differentiated by firearm examiners after comparing fired evidence,” it would then make this testing “one tailed.” This is because the question is now closed in one direction and is more specific to the different markings being compared. “Type,” on the other hand, refers to whether the data sets being analyzed are linked and if they belong to a specific item. For example, the “p-value” obtained for the comparison of Extractor 3-4 and Extractor 4-7 only presents information that helps the investigator to determine whether the two extractors being compared are incompatible.

Figure 25



As it relates to the research being conducted, a t-test analysis was used to make a comparison. An example of the comparison done between the Progressive Die Stamped extractor markings produced by Extractor 1-1 and Extractor 5-1 can be followed below for the step-by-step procedure. The following information was placed in the "Function Arguments" box as depicted in Figure 25.

- Array 1: An example of some of the data points for Extractor 1-1; found in column "A4"

Figure 26

A
437
455
468
491
493
522
535
548
564
585
602
623
640
663
671
678
665
673
682

- Array 2: An example of some of the data points for Extractor 5-1; found in column "AO"

Figure 27

652
667
686
711
738
768
789
810
826
839
866
889
894
902
913
919
917
919
923

- Tails: the number 2 as this is a "two tailed" test
- Type: the number 1, which is a representation of "Paired"

After entering all the required information and selecting the "OK" key seen in Figure 24, the probability or the "p values" of the selected data for Extractor 1-1 and Extractor 5-1 appeared in cell "AT". After following the steps mentioned above to obtain the "p values" for the remaining comparison of the Progressive Die Stamped extractor markings as well as the Metal Injection Molded extractor markings, it was concluded that this testing analysis can be easily administered and understood.

For the Metal Injection Molded markings, 100 locations indicated on the extractor marking produced 200 data points. This was because each location produced two data points. This was because each location produced two data points. To determine the number of locations; and essentially the number of data points to be used, another analysis was also conducted after choosing 200 locations on the extractor marking. After analyzing the "p-values" obtained, there does not seem to be any identifiable differences between having 100 locations indicated versus 200 locations indicated. As such, I chose to use 100 locations being identified on the extractor marking because it outlines the markings well, provides important information relating to the data points, includes all identifiable markings, does not leave out any data points and it also does not add data points that lack information. As such, outlining more data points to the extractor makings was purposeless as pertinent information was not added to my results. Table 1 below can be referred to for a visual depiction of the "p-values" 0.05 and below obtained for the 100 extractor markings versus the 200 extractor markings identified.

Table I

		Extractor 1-1	Extractor 1-2	Extractor 1-3	Extractor 1-4	Extractor 1-5	Extractor 1-6	Extractor 1-7	Extractor 1-8	Extractor 1-9	Extractor 1-10
A	Extractor 1-5	0.004304862	0.746696549	0.857735969	1.0228E-31	N/A	0.00544957	0.00177507	0.40282187	0.33115035	0.003102414
B	Extractor 1-5	0.001517	N/A	1.75E-11	3.85E-10	N/A	5.65E-08	N/A	N/A	7.84E-15	2.19E-18

For all Progressive Die Stamped markings, 50 locations indicated on the extractor marking produced 100 data points. This was, again, because each location produced two data points. were obtained by tracing the outline of all markings. Another analysis was also conducted after choosing 100 locations on the extractor marking. After analyzing the “p-values” obtained, there does not seem to be any identifiable differences between having 50 locations indicated versus 100 locations indicated. As such, I chose to use 50 locations being identified on the extractor marking because it outlines the markings well, provides important information relating to the data points, includes all identifiable markings, does not leave out any data points and it also does not add data points that lack information. As such, outlining more data points to the extractor makings was purposeless as pertinent information was not added to my results. Table II below can be referred to for the “p-values” 0.05 and below obtained for the 50 extractor markings; seen in row “A” with 50 identified locations versus the 100 extractor markings identified; seen in row “B” with 100 identified locations.

Table II

		Extractor 1-1	Extractor 1-2	Extractor 1-3	Extractor 1-4	Extractor 1-5	Extractor 1-6	Extractor 1-7	Extractor 1-8	Extractor 1-9	Extractor 1-10
A	Extractor 1-5	6.88908E-07	0.072702995	6.41873E-08	6.58915E-20	N/A	8.43934E-07	0.033810439	4.01027E-23	0.772927926	0.235247888
B	Extractor 1-5	7.13E-07	N/A	6.69E-08	7.47E-20	N/A	1.64E-06	3.46E-02	1.88E-23	N/A	2.11E-01

There were more data points for the Metal Injection Molded markings because these extractor markings were more elongated. It should be noted that these points were in units of pixels and they were used to determine the similarities and or differences between each marking. After obtaining the data points for both manufacturing processes, a student’s t-test was then performed.

The following paragraph provides a brief background on the student's t-test.

Student's t-test, which is often referred to as 't-test," was developed by William Sealy Gosset. As a scientist working with different of barleys, Mr. Gosset wanted to determine if there were any significant differences between the types of barleys used. Prior to the successful invention of the t-test, Gosset conducted a variety of experiments to develop a methodology for estimating population mean using small samples. Experiments included the use of data sets; including but not limited to, criminal heights written on pieces of cardboard. After drawing 750 samples at random, the mean and standard deviation was obtained. After obtaining the differences between each sample mean and population mean, seven hundred and fifty "z scores" were acquired. Z scores can be defined as the relationship between a value to the average of a group of values. These z scores were then plotted as probability functions. Based on his findings, William Sealy Gosset discovered that one can estimate the population mean and error rate of a data set. After publishing his results in the "Biometrika" in 1908, his vivid description of his test became widely known as the "t-test;" which was primarily developed to look for significant differences in data sets (Raju 732-735).

The student's t-test has, thus, been used in several disciplines mainly to determine significant differences between two data sets. One such experiment was conducted by Haslenda Yusop and his colleagues. The study was focused on the improvement of the mathematical understanding of students in a Calculus class. Prior to every lecture, the students were given a pre-test to see what they knew about a specific topic. A post-test was then given to the students to test their knowledge after a lecture was given. The average values for the pre and post-test were conducted using the student's t-test. The researchers expected to produce a higher mean for the post-test as opposed to the pre-test. The t-test validated the researchers' expectations as it proved that the student's scores significantly improved after the lecture as 37.1%, 51.4% and

5.7% of students produced excellent grades, good grades and moderate grades respectively. Only 5.7% of the students failed (Yusop et al. 453-461).

Seeing that t-tests have been used by many groups of individuals, I consider t-tests to be an acceptable and credible statistical methodology to be used in this research. At the conclusion of a t-test, a “p-value” is generated. With the increasing amount of concerns regarding the misuse and misunderstood interpretation of “p-values;” especially from researchers and writers of science who are not well versed in statistics, a group of experts came together in October 2015 to develop a statement on behalf of the American Statistical Association (ASA). After the release of this statement in 2016, it should be noted that the American Statistical Association Board of Directors discussed “p-values” in detail. After defining a “p-value” as the probability of two data sets being equal to or more extreme than the actual value obtained, they then discussed six principles relating to “p-values” (Wasserstein and Lazar 129-133).

METHODOLOGY

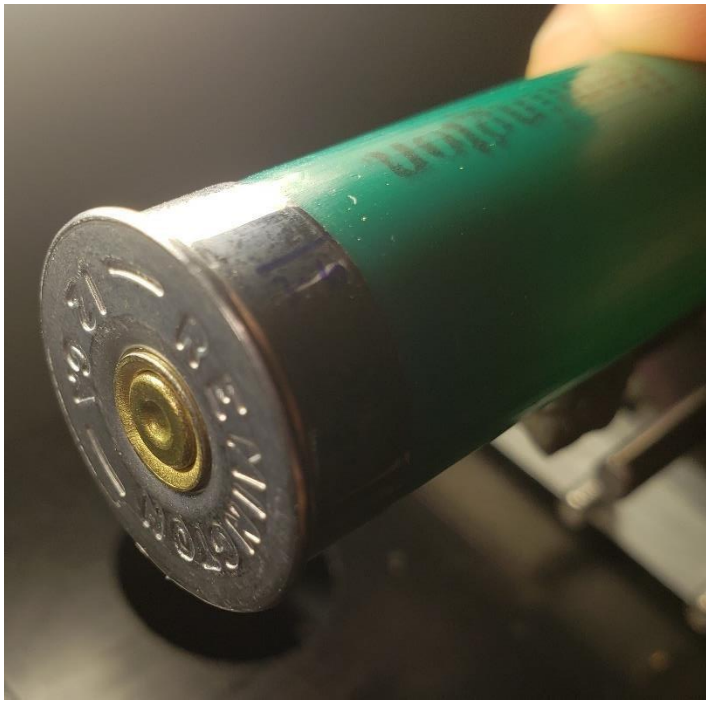
Method: Metal Injection Molded extractors and Remington Shotgun

Step One: Preparation

A marking was placed on all shot shells using a blue sharpie. This marking was aligned with the “R” in Remington found on the head of the shotshell and was also done to ensure that all shotshells were loaded in the Remington shotgun in a similar manner. If there happened to be other markings or indentations present on the shotshells, the location of the blue sharpie marking was moved either slightly above or below the intended marking location. Below is an example of how each shot shell was labelled and loaded in the Remington shotgun.

Figure 28: A depiction of how shotshells were labelled and loaded in the shotgun

Figures 28A depicts how the shotshells were labelled



28A

Figures 28B and 28C depicts how the cartridges cases were loaded in the Remington shotgun

28B

28C

Figures 29 below can be referred to for a visual comparison of the microscopic documentation conducted on all cartridge cases before and after discharge for Extractor 1-8; Figure 29A and Extractor 3-4; Figure 29B. It should be noted that in both images, the intended location of the extractor marking was slightly shifted below the intended marking location. This shift was caused due to the rapidity and force exerted during the ejection process involved in the removal of the cartridges.

Figure 29: Examples of the microscopic documentation conducted on all shot shells before and after discharge

Figure 29A

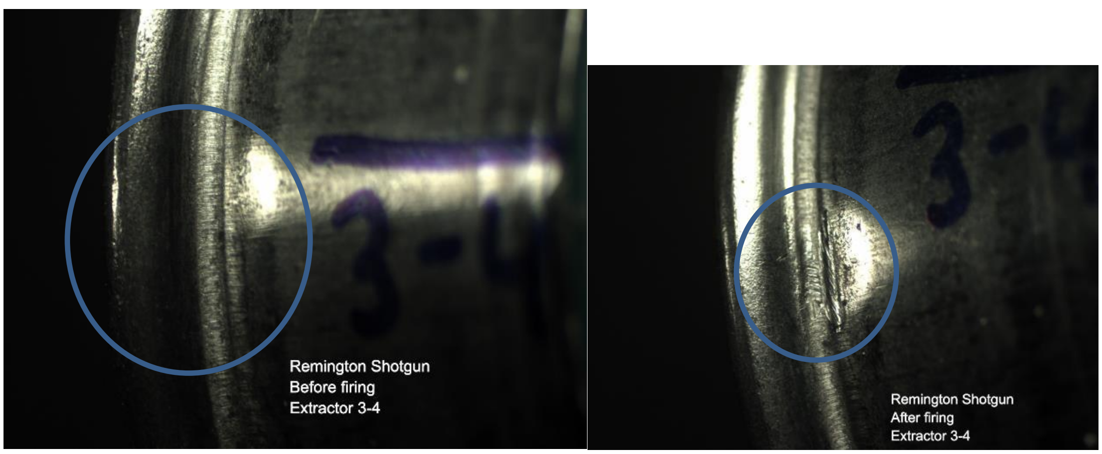


Figure 29B

Prior to the discharge of the Remington shotgun, additional preparation was done. A machine identified by an expert firearm and toolmark analyst as a 'Silent Shot' was used. A 'Silent Shot' is a device used in decreasing the risk of lead exposure faced by individuals during the discharge of a shotgun. The 'Silent Shot' used throughout this experimentation process was located at the Illinois State Police Forensic Science Laboratory at Chicago. It was originally obtained from Michigan Arms Corporation; located in Michigan U.S., 48084. Readers can refer to Figure 30 for a visual aid of the "Silent Shot."

Figure 30: A visual depiction of the Silent shot used throughout the Shotgun's discharge

Step Two: The discharge of the weapon

Ten test fires per Metal Injection Molded extractor were expelled using shot shells. All extractors and shot shells were analyzed after discharge. Microscopic documentation of the extractors after discharge; overall and close-up images, were then collected. Additional information on the magnification of the images of the extractors was tabled as seen below. The overall and close-up documentation of all three extractors was found below in Figure 31.

Figure 31: The inside working surfaces of the Metal Injection Molded Extractors 1, 2 and 3 prior to and after discharge

Figure 31A; Extractor 1; Overall image

Figure 31B; Extractor 1; Close-Up image

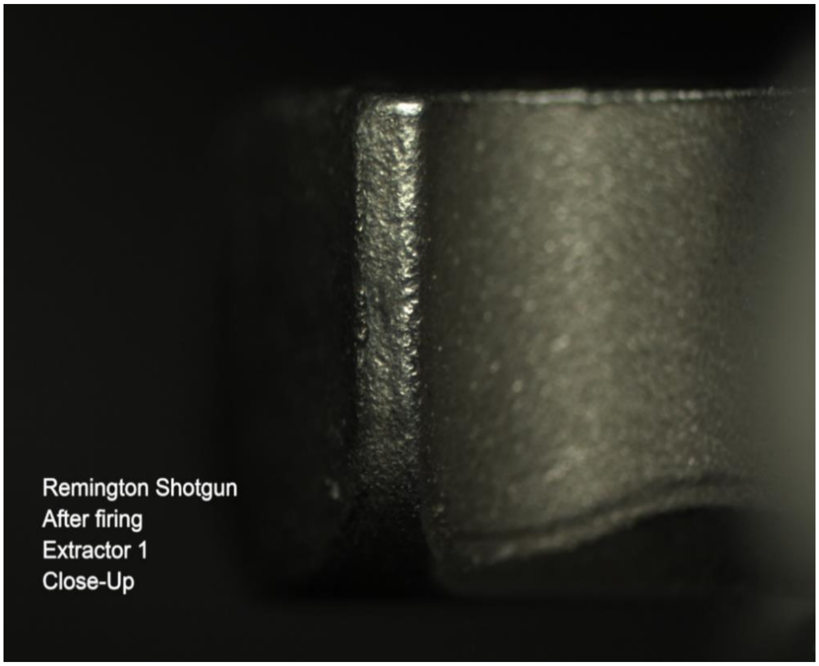


Figure 31C; Extractor 2; Overall image

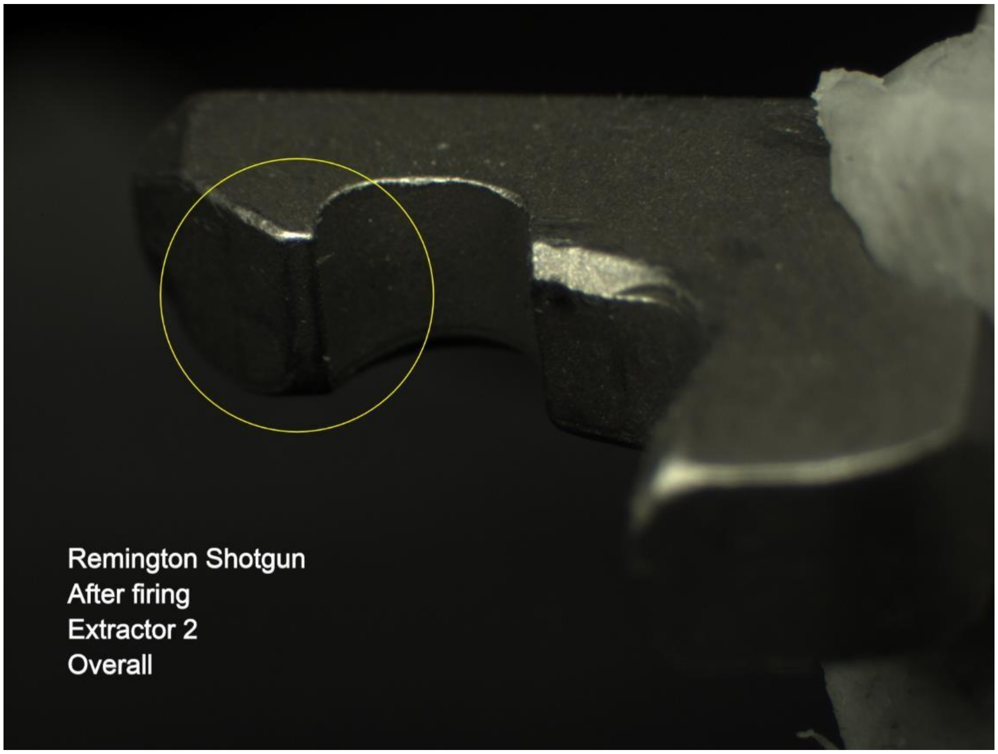


Figure 31D; Extractor 2; Close-Up image

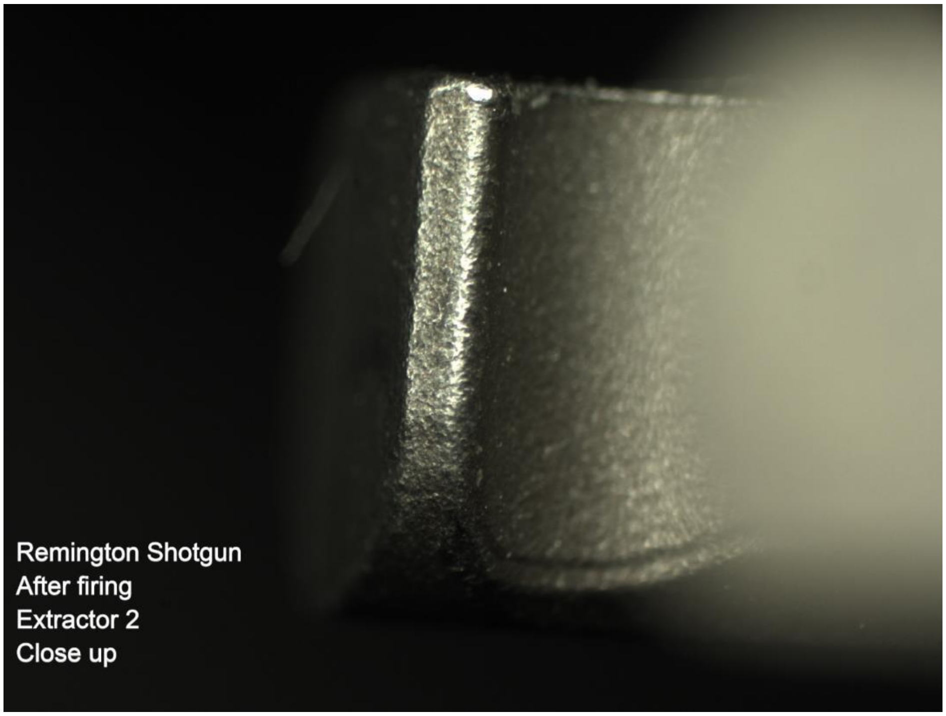
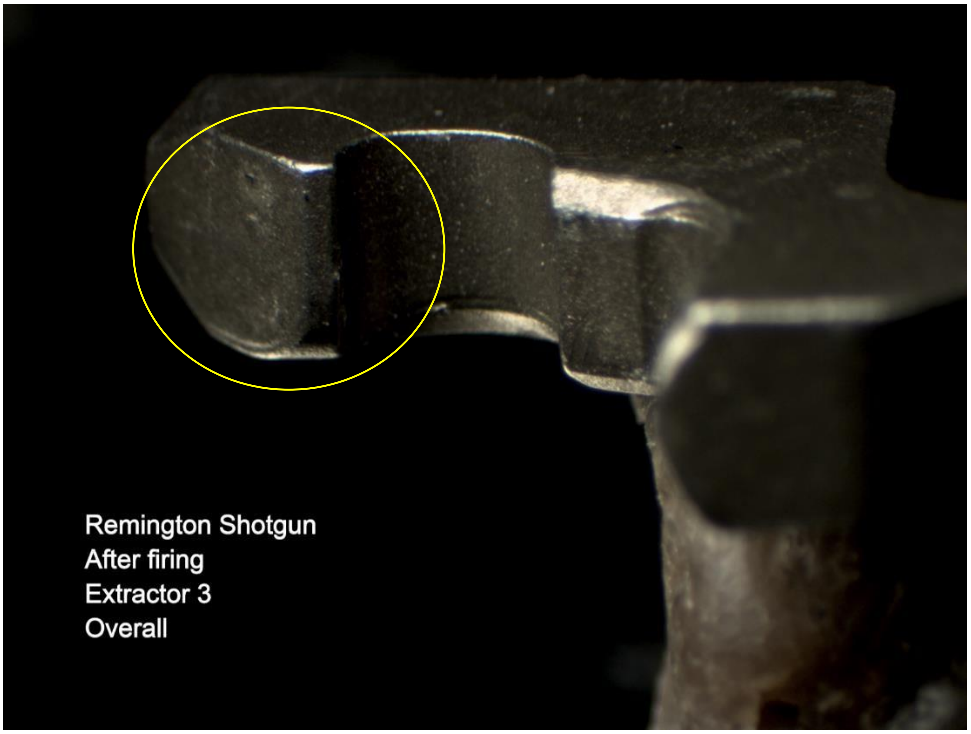


Figure 31E; Extractor 3; Overall image



It should be noted that the image above was re-taken with a reflector. This was done after it was brought to my attention that the original image of the same reflector was too dark.

Figure 31F; Extractor 3; Close-Up image

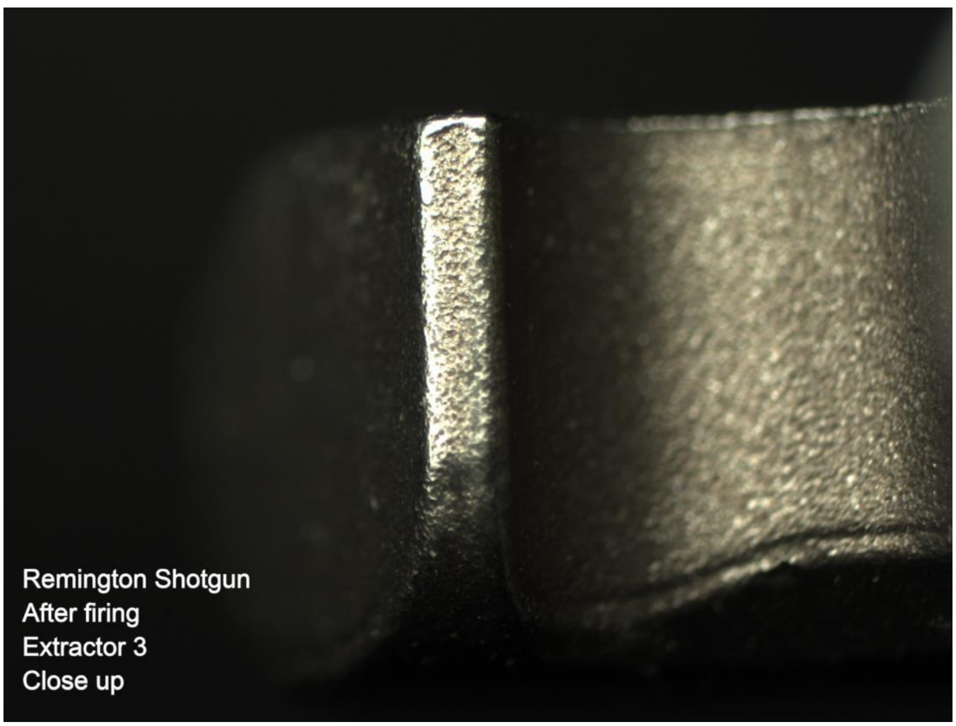


Table III:
Magnification of the images of the Metal Injection Molded extractors

Process Two	
Extractors	Magnification
1; After discharge: Overall	10X
After discharge: Close-up	25X
2; After discharge: Overall	10X
After discharge: Close-up	10X
3; After discharge: Overall	10X
After discharge: Close-up	25X

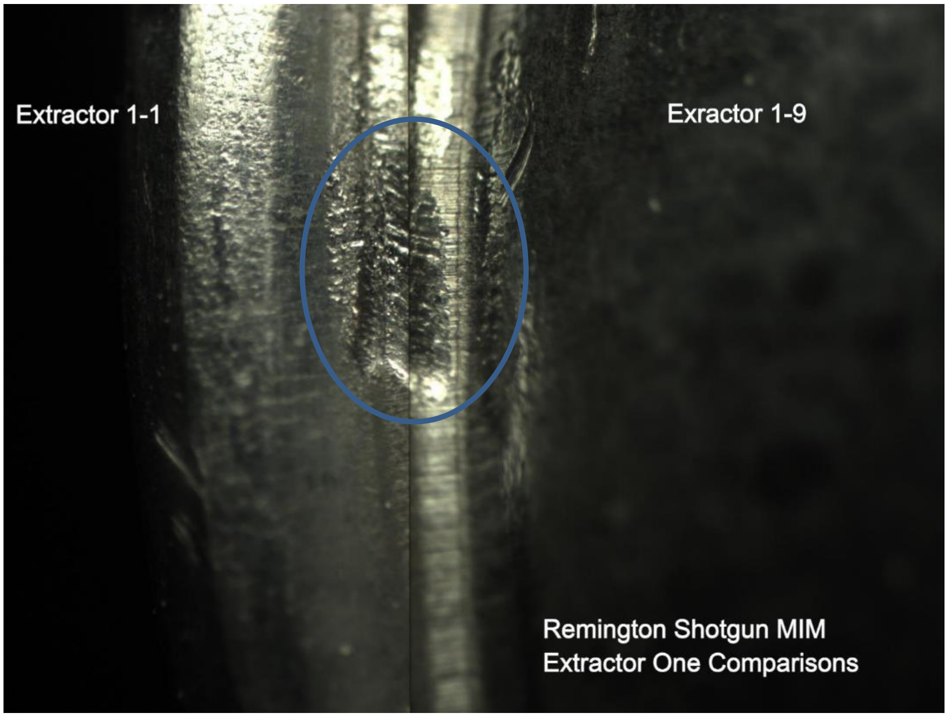
Step Three: Comparisons

There were three different Metal Injection Molded extractors used in this research project. After the completion of visually documenting the overall and close-up images of all three inside working surfaces, images of the comparisons of the extractors and shot shells obtained after the Shotgun weapon was discharged were captured. Once the images of each extractor were obtained, within comparisons were first conducted. For example, Metal Injection Molded Extractor 3-2 was compared with Metal Injection Molded Extractor 3-4. Nine comparisons per group was conducted. And as such, a total of 27 comparisons was done: starting with Extractor 1-1 with Extractor 1-2 all the way through to Extractor 1-10. Although all microscopic comparisons were conducted, not all images of the comparisons seen were captured.

The “best” extractor markings among each group based on the similarities of the overall pattern of the extractor markings was identified and chosen. Notes were made to indicate whether comparable extractor markings were observed. In Figure 32A through 32C, readers can find the “best” extractor markings among each group. There were differing results among Figure 32 as some images indicated a “match” or more similar patterning between the markings while some images demonstrated more of a difference or “non-match” between the markings on the shotshells.

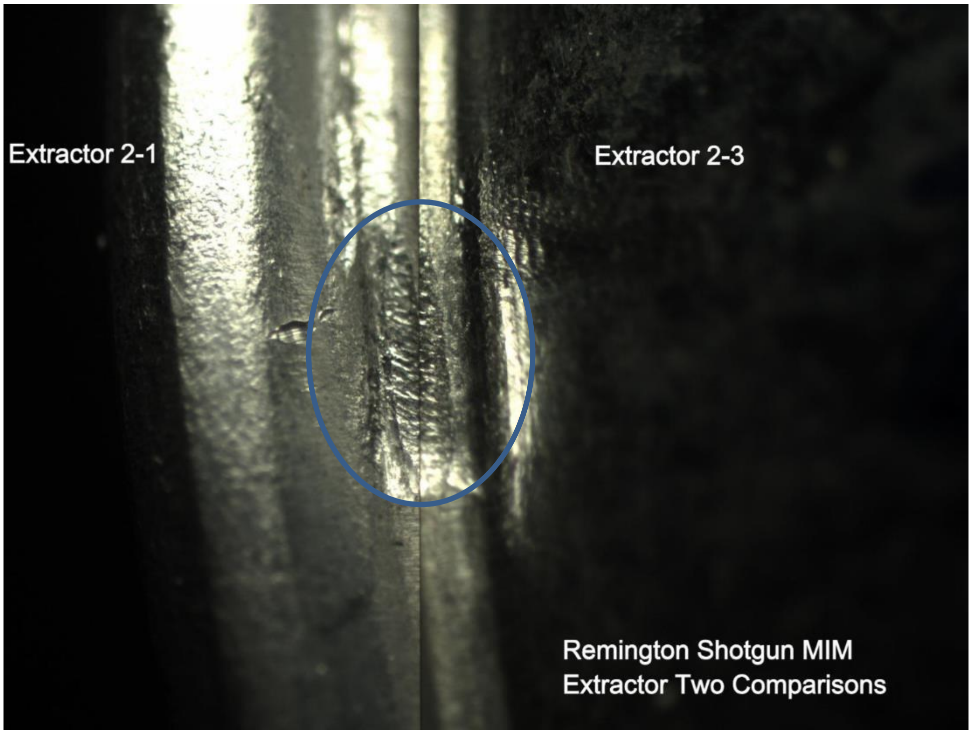
Figure 32: Comparison conducted between Metal Injection Molded extractors

Figure 32A: A “match” for the comparison of extractor markings between Extractor 3-2 and Extractor 3-4. Markings shown prove to be very similar



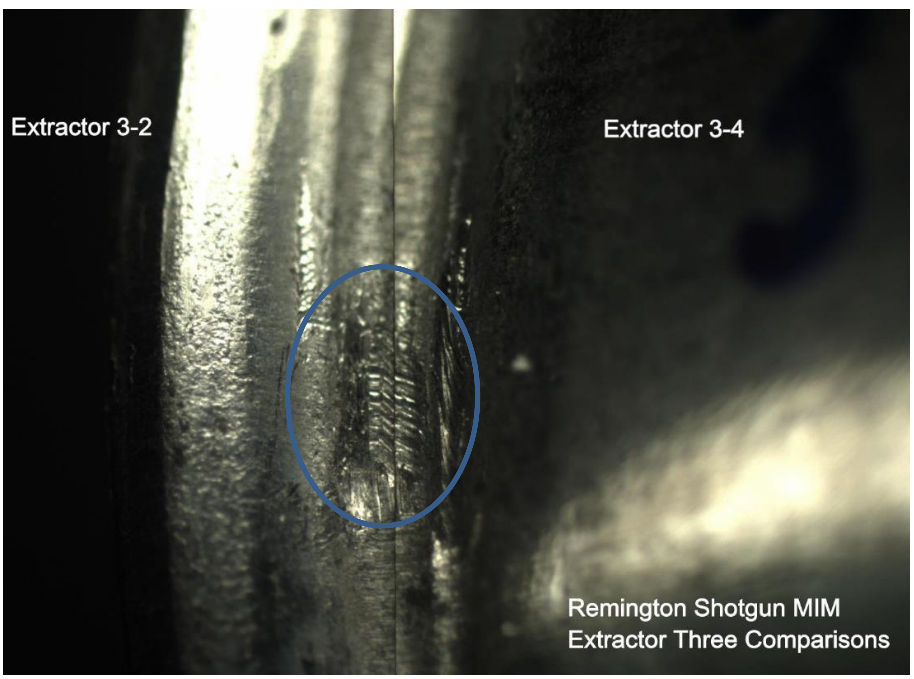
32A

Figure 32B: A “non-match” for the comparison of extractor markings between Extractor 2-1 and Extractor 2-3. Markings shown prove to be very different



32B

Figure 32C: A “match” for the comparison of extractor markings between Extractor 3-2 and Extractor 3-4. Markings shown prove to be very similar

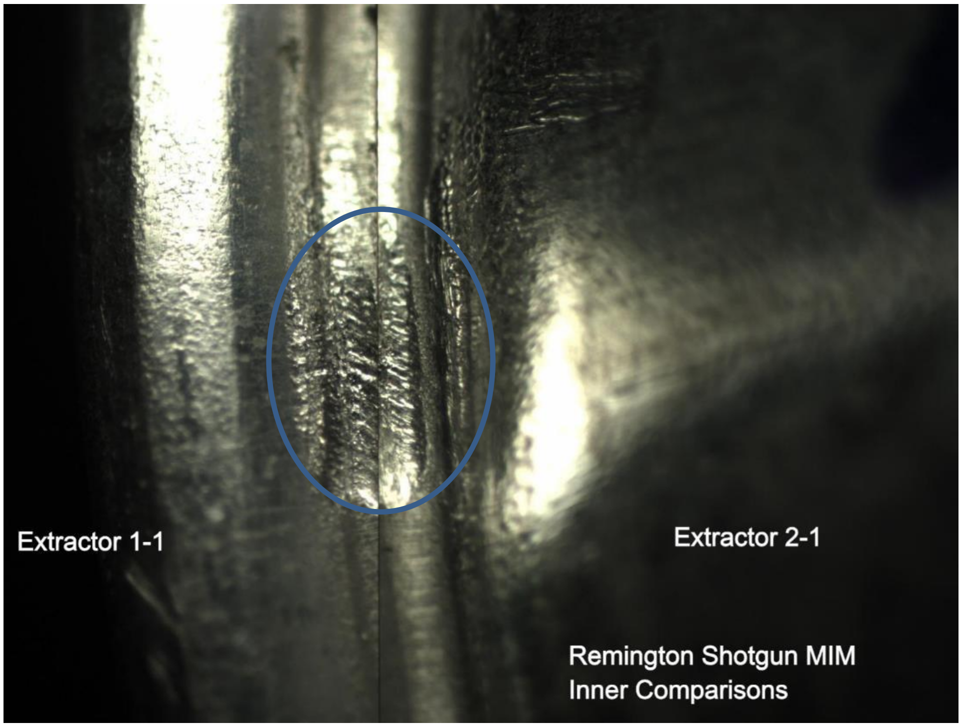


32C

Inner comparisons for the markings made by the Metal Injection Molded extractors were then conducted. This was accomplished by comparing extractors from different groups. For example, in Figure 33A, Metal Injection Molded Extractor 1-1 was compared with Metal Injection Molded Extractor 2-1. The overall pattern of the extractor markings; as well as the similarities and differences among each were compared. A system in which all possible pairs between the three extractors was conducted. All repeating pairs were sought and eliminated. Ensuring that each pair was represented once, this system made it easy to analyze cartridge cases in an orderly manner, which essentially minimized any chance of confusion. By the end of this system, twelve inner comparisons were conducted and captured. All images taken of the comparison of the extractor markings were obtained at a magnification of 25X.

Figure 33: Examples of inner comparisons conducted between Metal Injection Molded extractors

Figure 33A: Inner comparisons conducted between Extractor 1-1 and Extractor 2-1

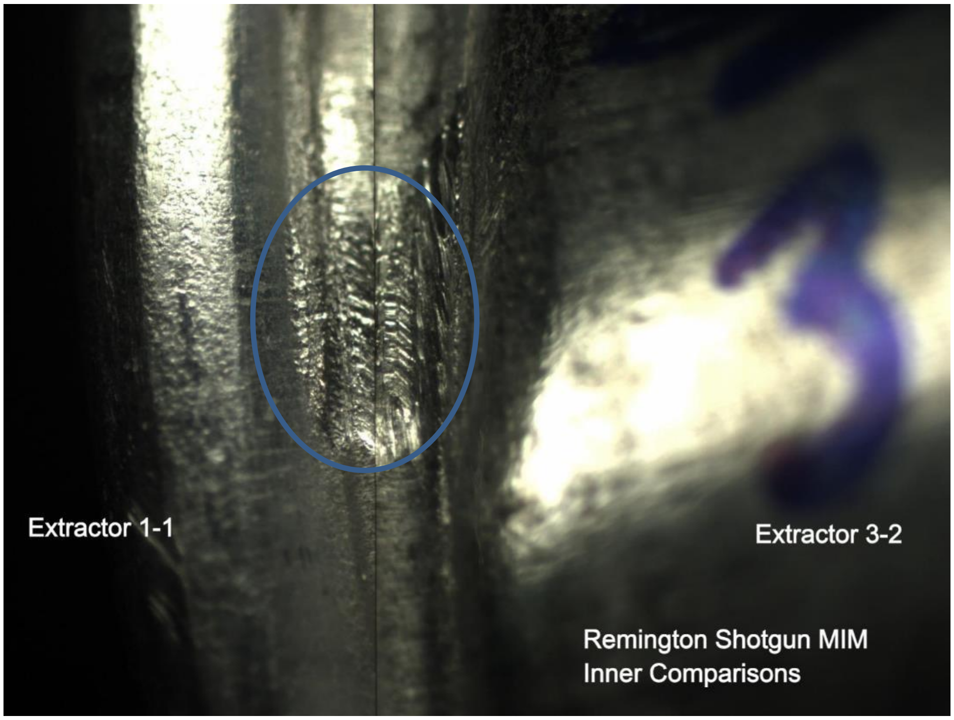


33A

Figure 33B: Inner comparisons conducted between Extractor 1-1 and Extractor 2-3

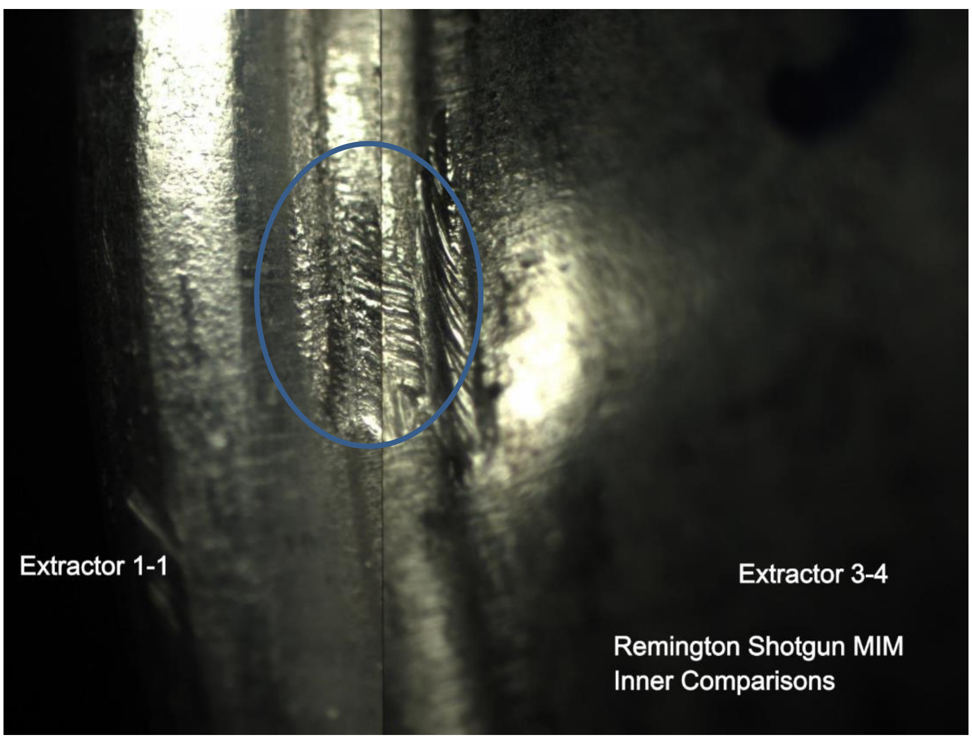
33B

Figure 33C: Inner comparisons conducted between Extractor 1-1 and Extractor 3-2



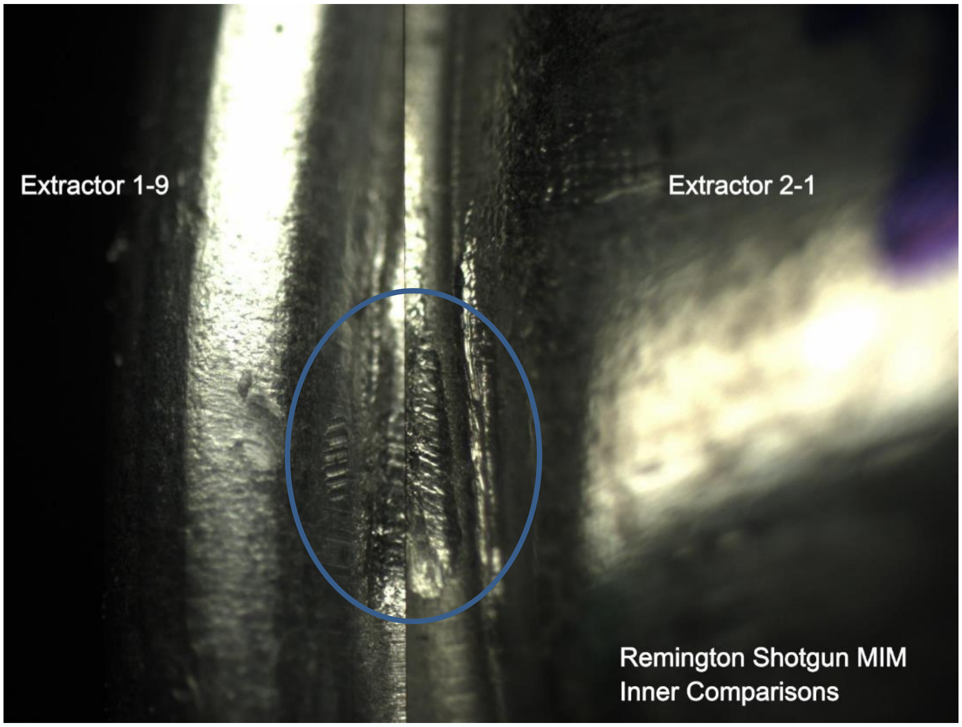
33C

Figure 33D: Inner comparisons conducted between Extractor 1-1 and Extractor 3-4



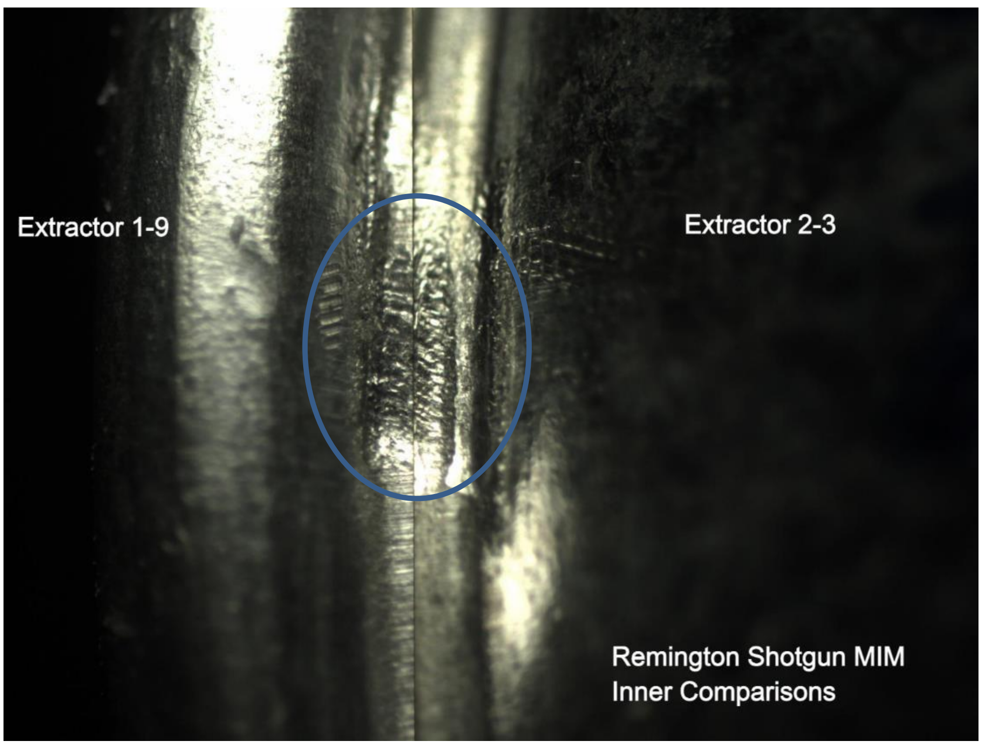
33D

Figure 33E: Inner comparisons conducted between Extractor 1-9 and Extractor 2-1



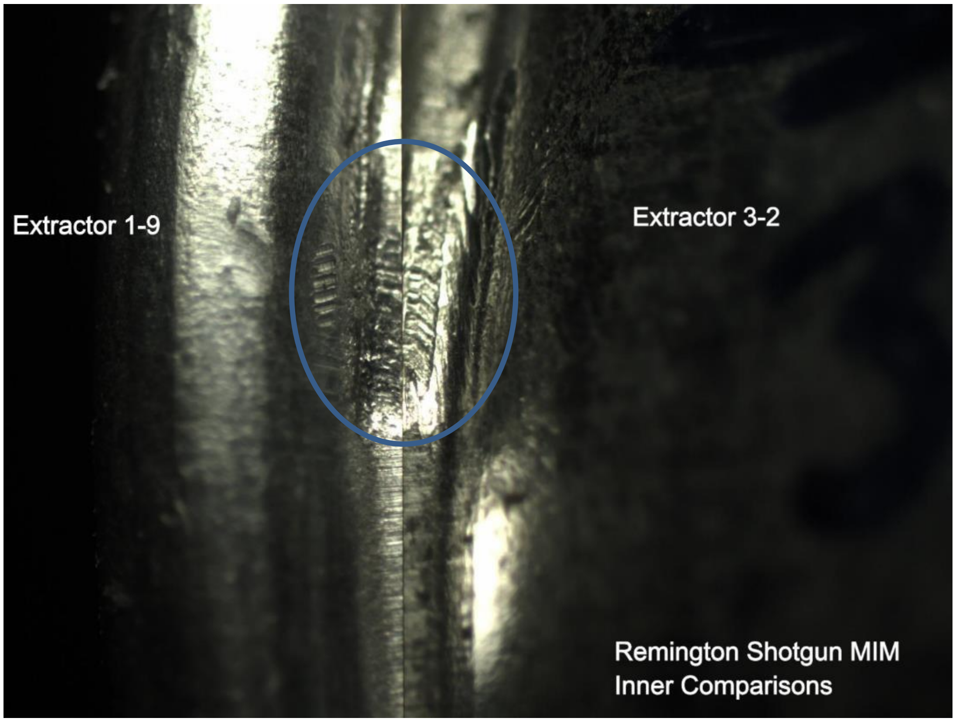
33E

Figure 33F: Inner comparisons conducted between Extractor 1-9 and Extractor 2-3



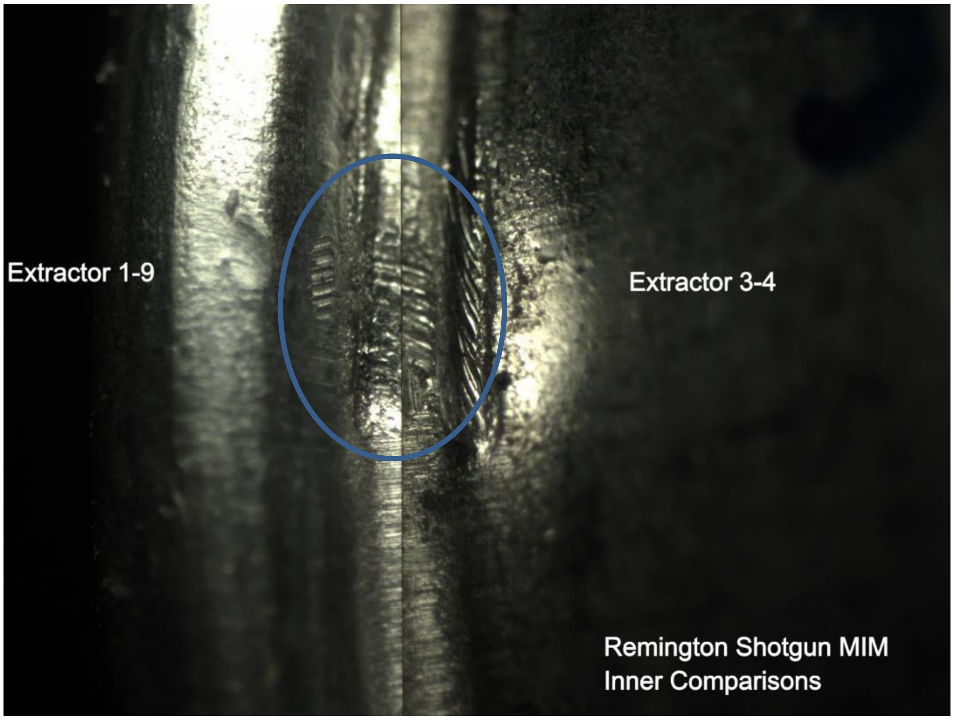
33F

Figure 33G: Inner comparisons conducted between Extractor 1-9 and Extractor 3-2



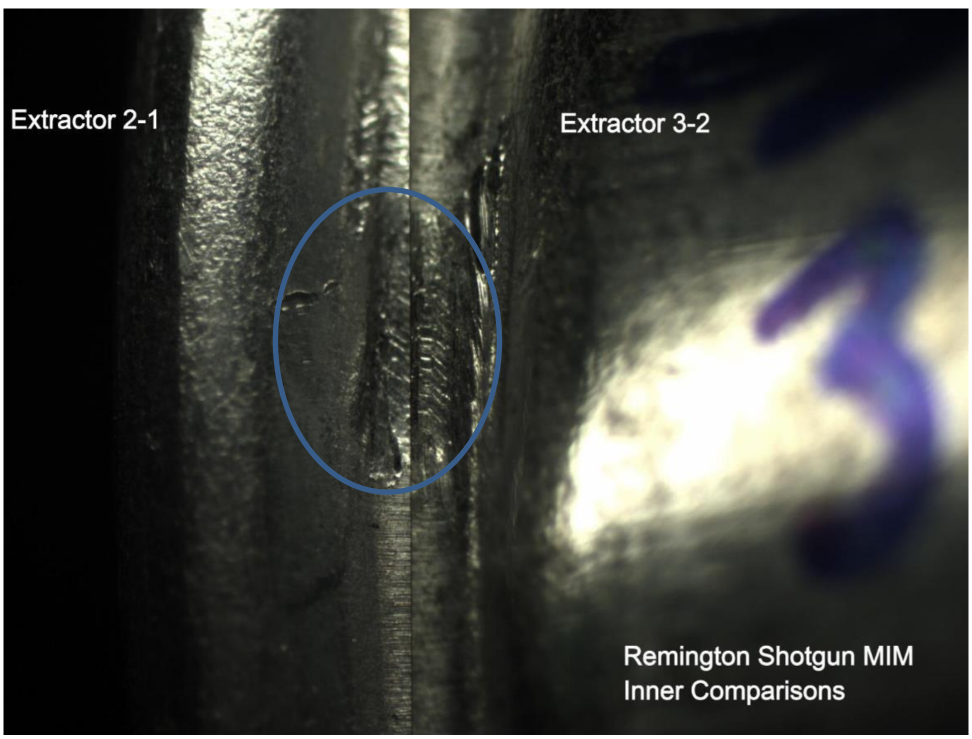
33G

Figure 33H: Inner comparisons conducted between Extractor 1-9 and Extractor 3-4



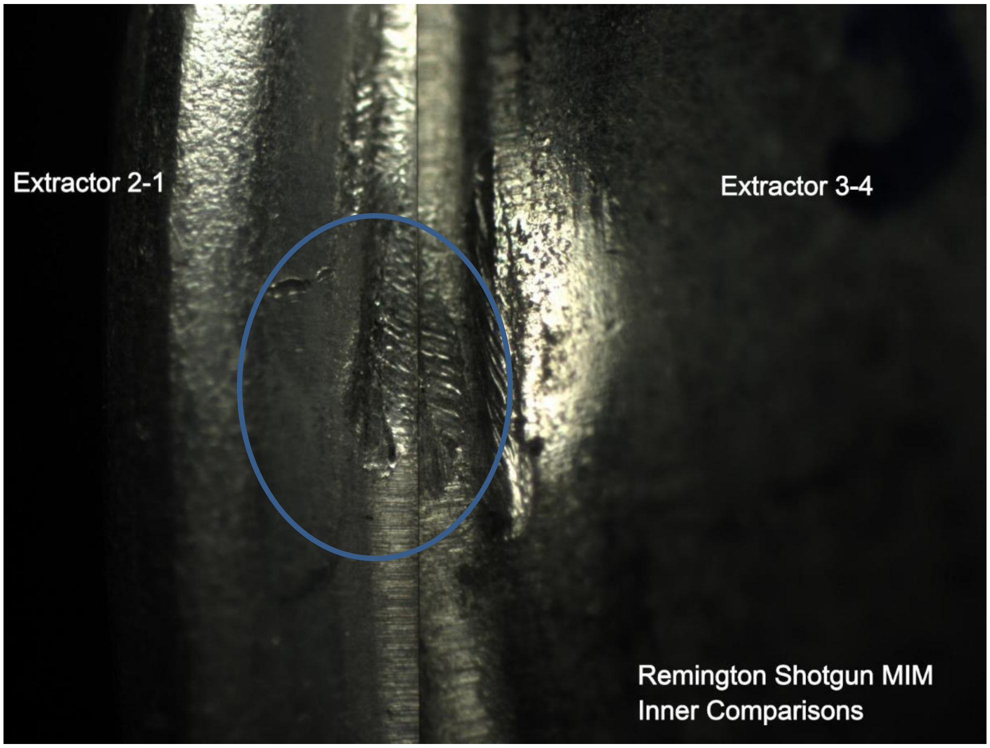
33H

Figure 33I: Inner comparisons conducted between Extractor 2-1 and Extractor 3-2



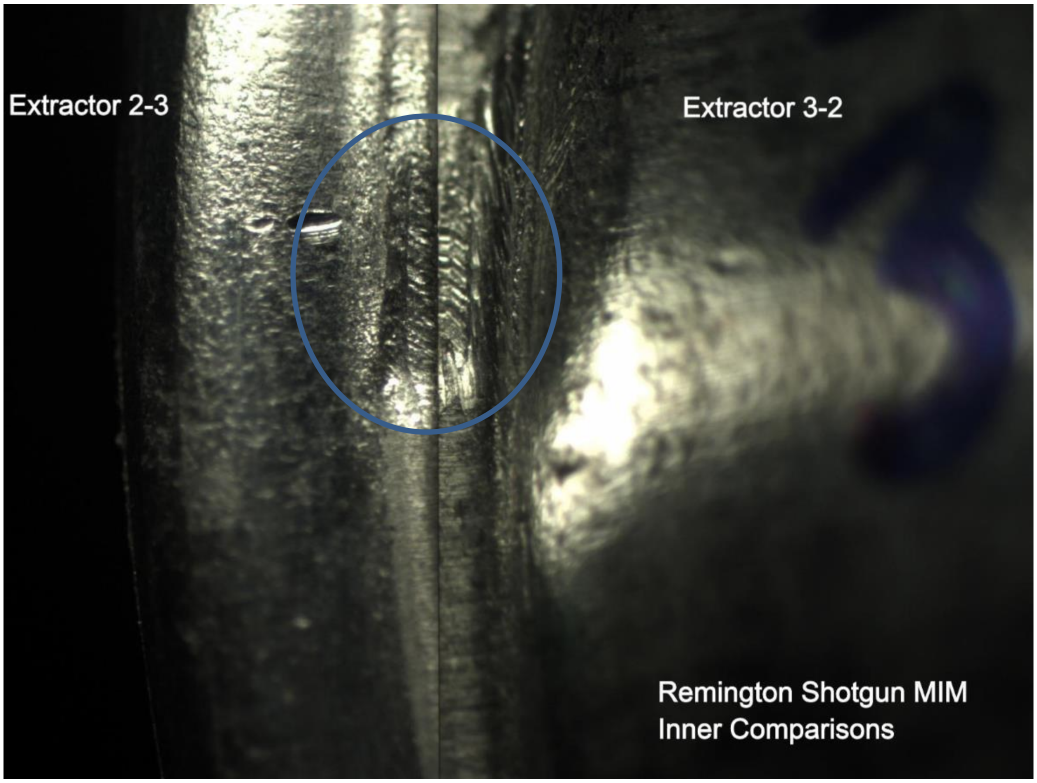
33I

Figure 33J: Inner comparisons conducted between Extractor 2-1 and Extractor 3-4



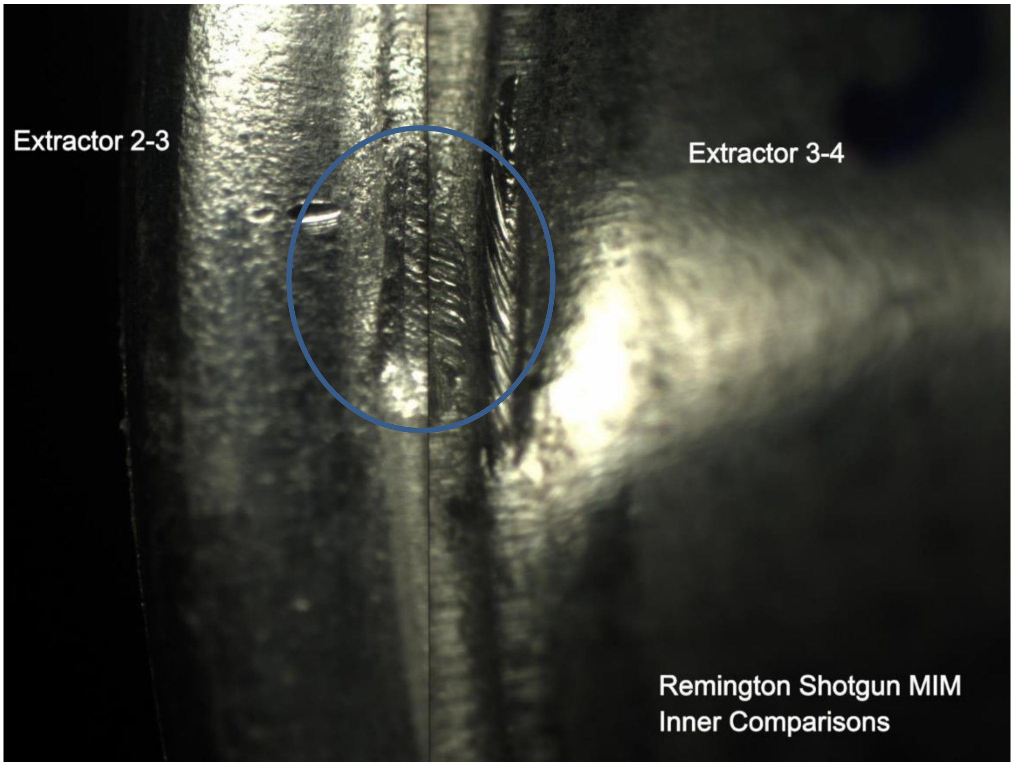
33J

Figure 33K: Inner comparisons conducted between Extractor 2-3 and Extractor 3-2



33K

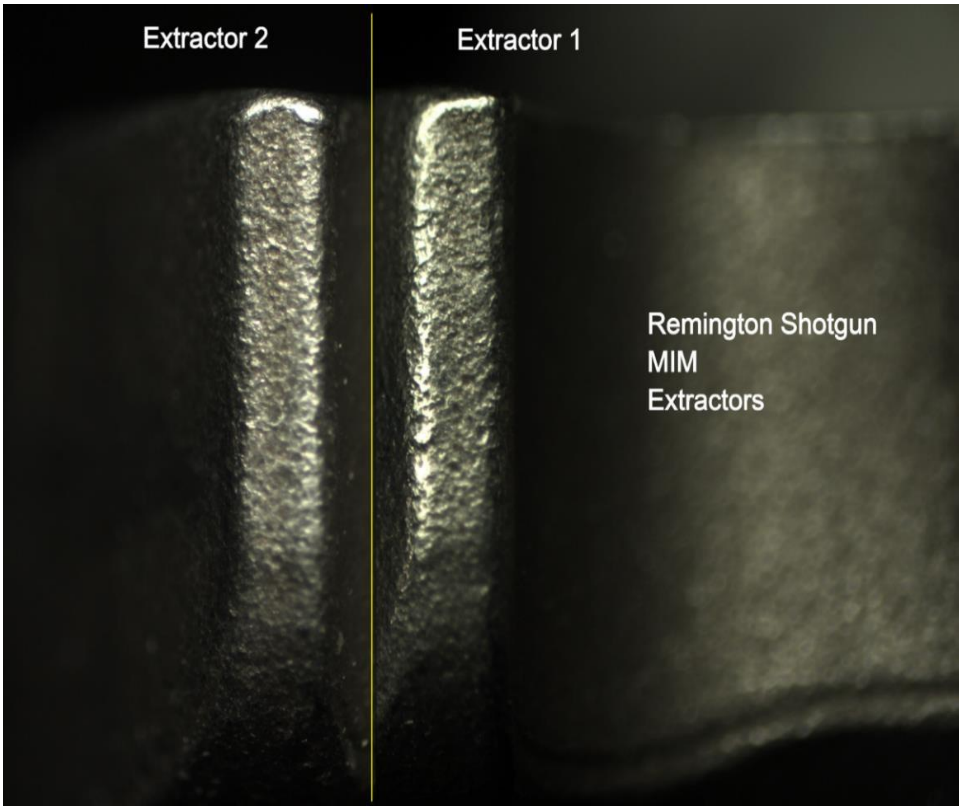
Figure 33L: Inner comparisons conducted between Extractor 2-3 and Extractor 3-4



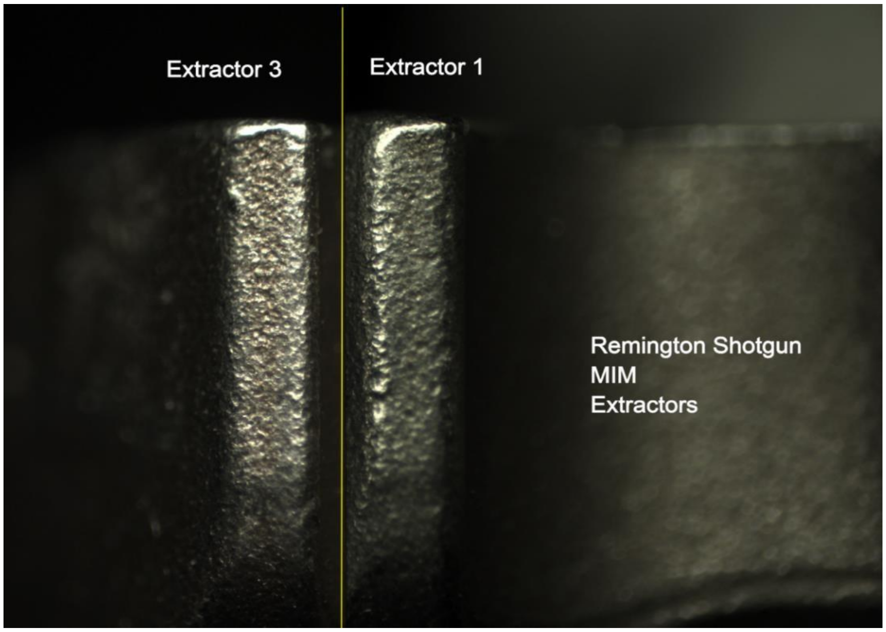
33L

Comparisons on the extractors; only the inside working surfaces, can be seen in Figure 34. All images taken of the comparison of the extractor markings were obtained at a magnification of 10X. Although the inside working surfaces of the extractors were obtained, a conclusion of these comparisons could not have been drawn. This was because no visible signs of reproducible markings were observed. As such, different areas of the same extractors were examined resulting in the presence of visible markings. These areas can be identified in Figure 35. Hence, a definitive comparison of the extractors could be made.

Figure 34: Inner comparisons that were also conducted on the extractor



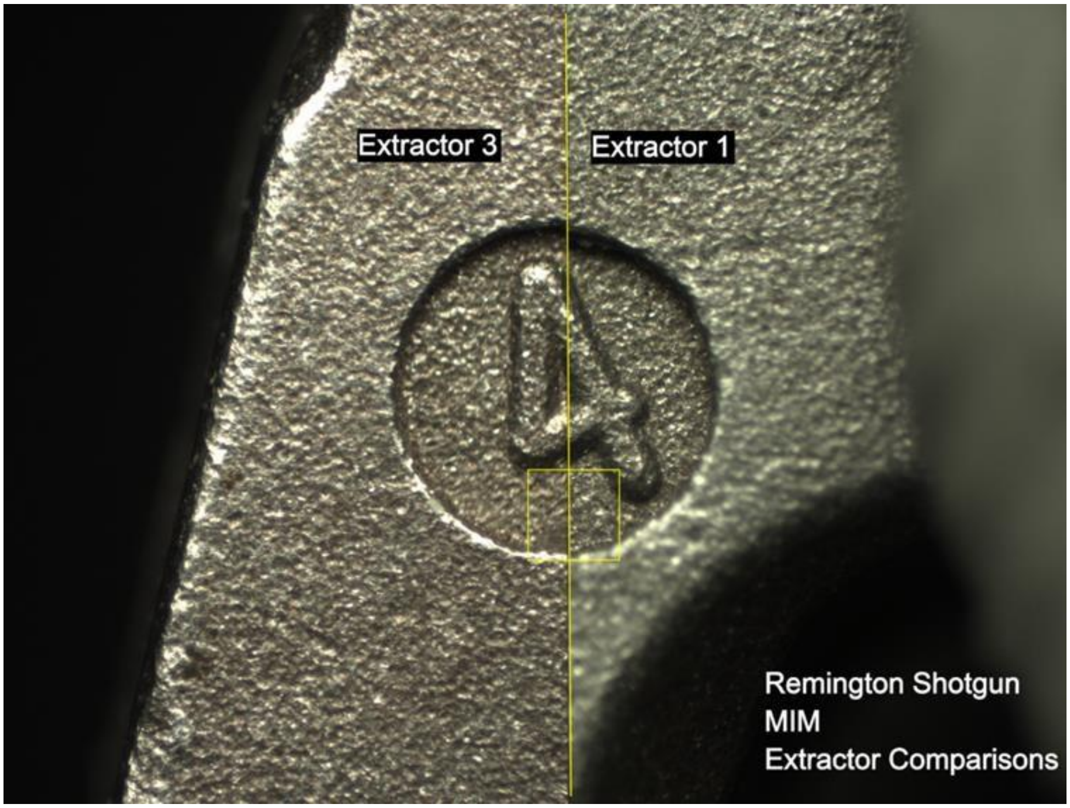
34A



34B

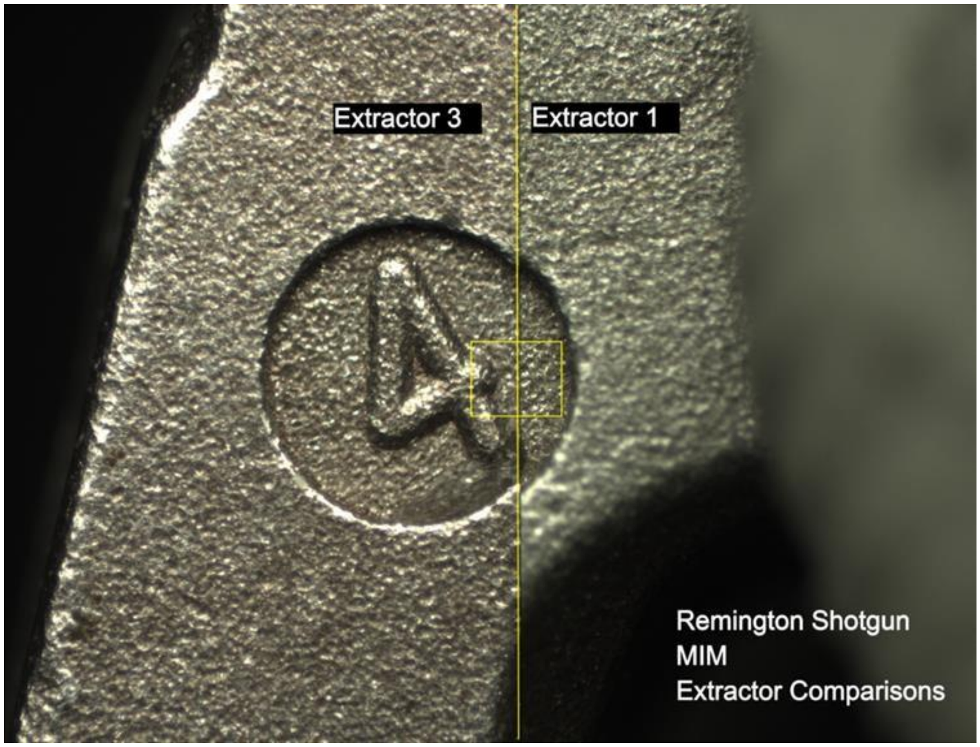
Figure 35: A visual depiction of the similarities seen in different areas of MIM'd extractors

Figure 35A: Similarities seen in different areas of MIM'd extractors



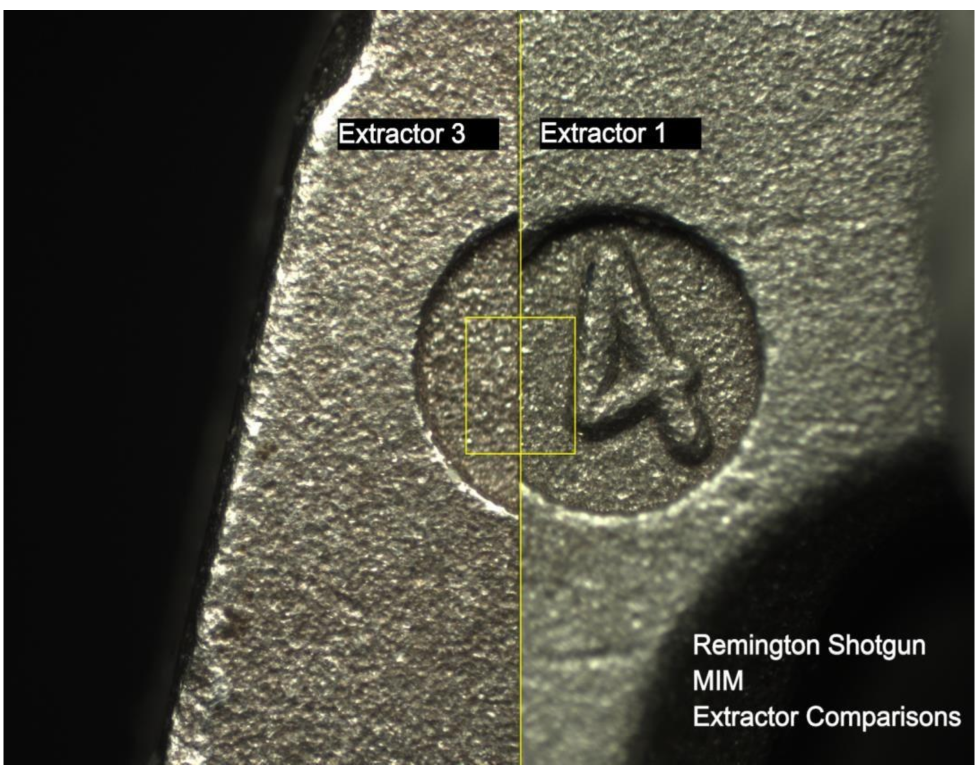
35A

Figure 35B: Similarities seen in different areas of MIM'd extractors



35B

Figure 35C: Similarities seen in different areas of MIM'd extractors



35C

Although the areas of the extractors being analyzed and discussed above did not contact the shot shells, it is important to mention that they derive from the same mold cavity. This is because this proves that the extractors are the most sequentially related parts produced via the Metal Injection Molding manufacturing process. As such, having identical striations on the machined parts prove the consecutive nature of the MIM'd extractors, thus an increased possibility of having similar markings transferred on the shot shells if they were to contact each other.

The same analysis was conducted on the Progressive Die Stamped extractors in the Hi-Point shotgun. For additional information, the below information can be referred to.

Method: Progressive Die Stamped extractors and Hi-Point Firearm

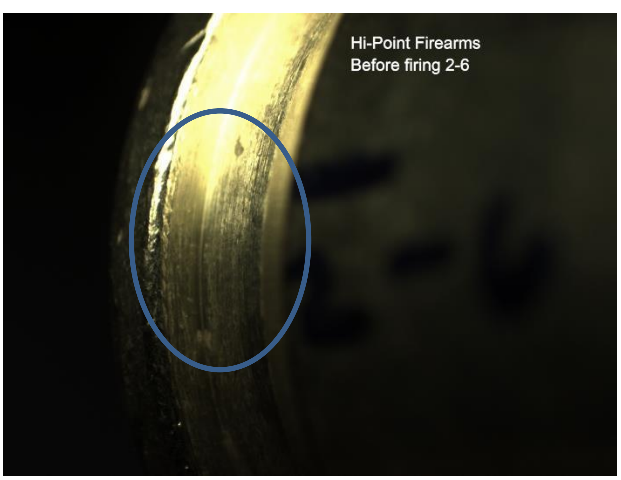
The method discussed in reference to "Metal Injection Molded extractors and Remington Shotgun" was the same method conducted for the Progressive Die Stamped extractors and Hi-Point Firearms. Although similar methods were used in both methodologies, the various processes as well as the work done in preparation of both methods produced differing results which will be discussed.

Step One: Preparation

Experimenting using the Hi-Point Firearm and ammunition lasted a few weeks. Three medium-sized manila envelopes with different number of extractors via the Progressive Die Stamping Process were obtained. After examining each package, the envelope containing the most extractors; five, were obtained and labelled 1 through 5 for further analysis. Images of all the extractors and the areas of focus; the inside and outside working surfaces of the extractors, prior to and after discharge were microscopically captured for visual documentation. After microscopically documenting the extractors, the same type of microscopic documentation was conduct on all cartridges prior to and after discharge. This was done to ensure there were no distinguishing marks present on the cartridge cases prior to discharge. Figure 36 below can be referred to for a visual comparison of the microscopic documentation conducted on all cartridge cases before and after discharge.

Figure 36: Examples of the microscopic documentation conducted on all cartridges before and after discharge

Figure 36A; the general region where the extractor markings are expected to appear



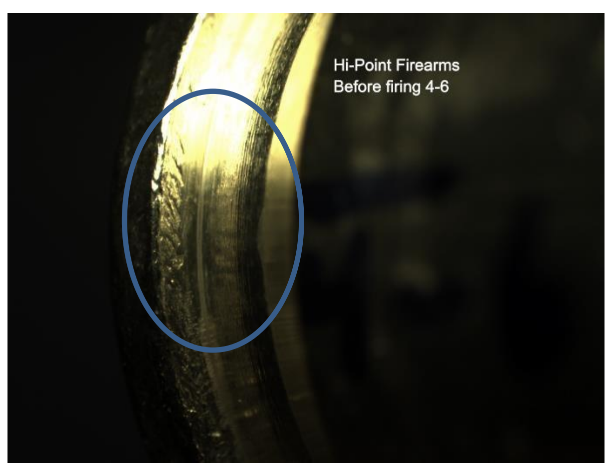


Figure 36B; the actual location of the markings seen on the fired evidence

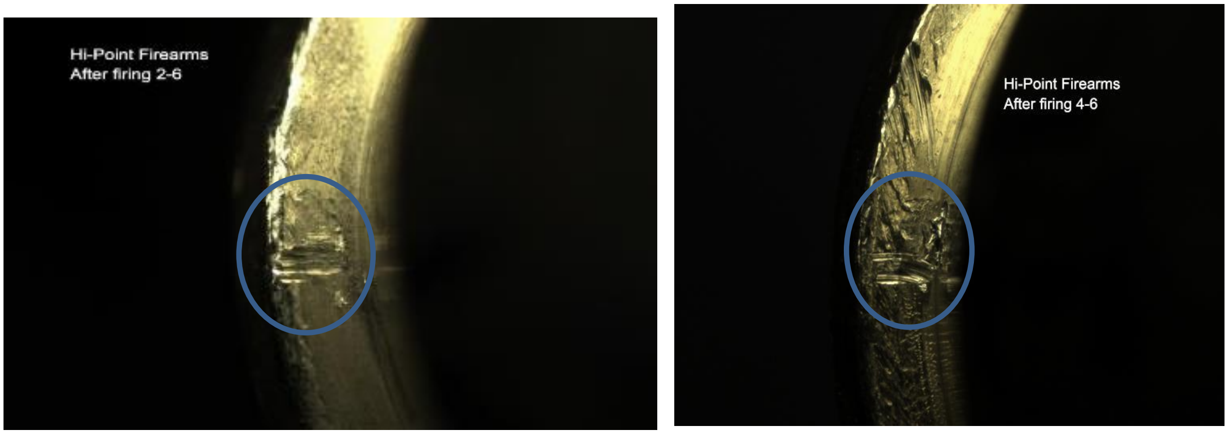
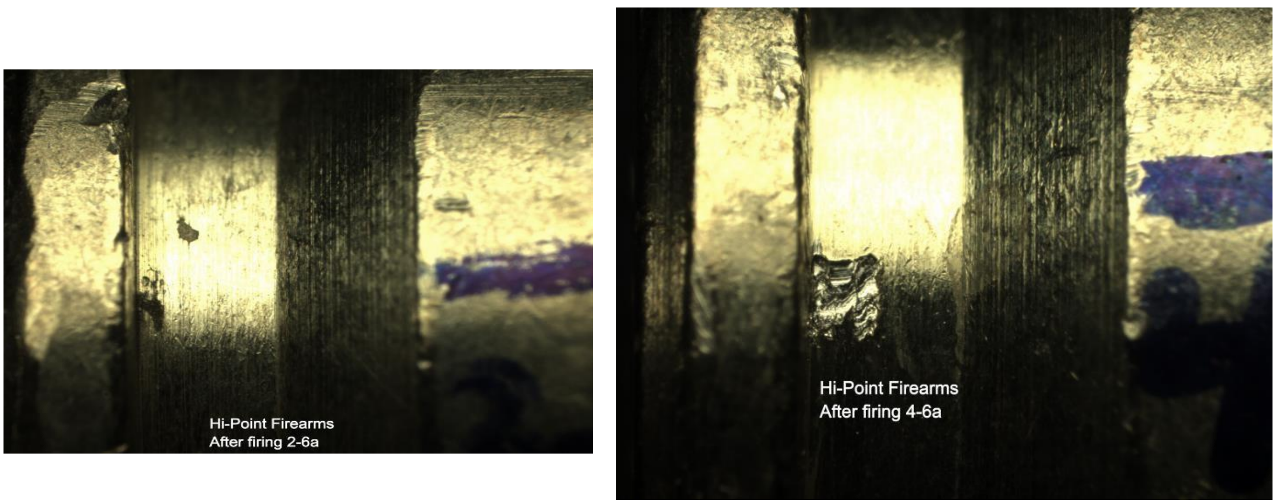


Figure 36C; the general region where the extractor markings are expected to appear



It should be noted that Figures 36C represents a different angle of the extractor marking seen on the fired evidence produced by a Progressive Die Stamped extractor. Although these types of markings may seem useful for comparison, they were not actively used and compared with other markings throughout this experimentation process. This was because these markings were not consistently present throughout all Progressive Die Stamped extractors after discharge and would be considered a confounding problem in the Firearm and Toolmark industry. As such, comparisons involving the markings seen in Figures 36C were not conducted.

All cartridges were labelled and loaded in the Hi-Point Firearm in a similar manner. To ensure consistency among all, a line was placed on all cartridges using a blue sharpie between the “9” and “M” on the “9 MM” that was engraved on the head of the cartridge. If, after placing the line on any of the ten cartridges, there seemed to be other markings or indentations present, the location of the line marking was moved either slightly above or below the intended marking location. This was done with the second and ninth test fire cartridge for Extractor 2 of the Progressive Die Stamp process. The placement of the line using a blue sharpie was done for all five extractors and their ten corresponding cartridges used for test fire. Below is an example of how each cartridge was marked and loaded in the Hi-Point Firearm.

Figure 37

Figure 37A depicts how the cartridge cases were labelled

37A

Figures 37B depicts how the cartridges cases were loaded in the Hi-Point weapon

37B

Figures 37C depicts how the cartridges cases were loaded in the Hi-Point weapon

37C

Figures 37D depicts how the cartridges cases were loaded in the Hi-Point weapon

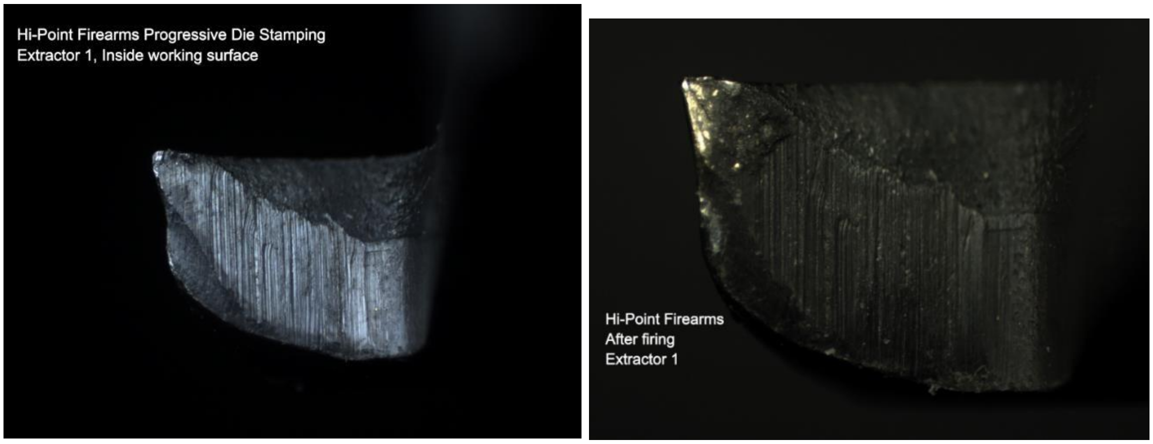
37D

Step Two: The discharge of the weapon

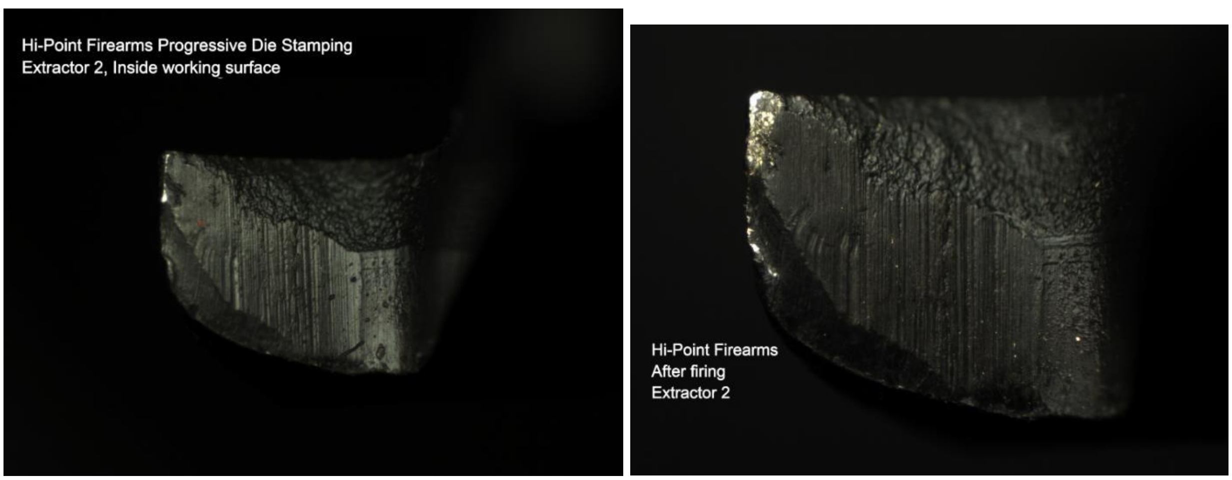
Ten test fires per Progressive Die Stamped extractor were expelled using various cartridges. After analyzing the extractors after discharge, the presence of brass transfer was observed. The brass transfer was documented as the silver extractors scratched the brass cartridge, thus, the transference of brass on the extractor. This was proof that the specific areas on the Progressive Die Stamped extractors did contact the cartridges. The inside working surfaces of the extractors were identified as the area responsible for contact with the cartridges as the brass color was transferred and mainly observed on the tip of the silver extractors. After analyzing the inside working surfaces of the extractors, different types of extractor markings were observed. These differences can have an impact on the transfer of reproducible extractor markings found on fired evidence after being discharged. Below is a visual illustration of the inside working surfaces of all Progressive Die Stamped extractors prior to and after discharge.

Figure 38: Inside working surfaces of the Progressive Die Stamped extractors prior to and after discharge

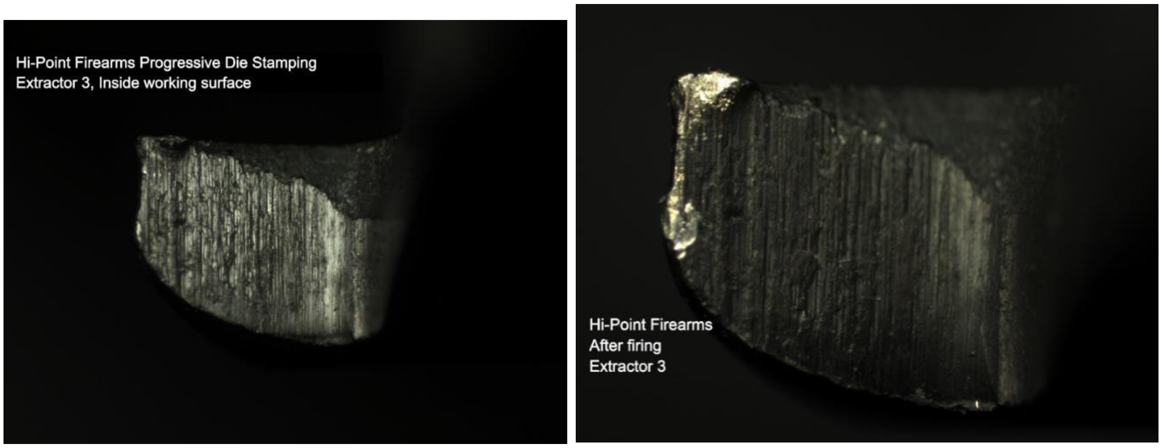
38A; Image of Extractor 1; Prior to and after discharge



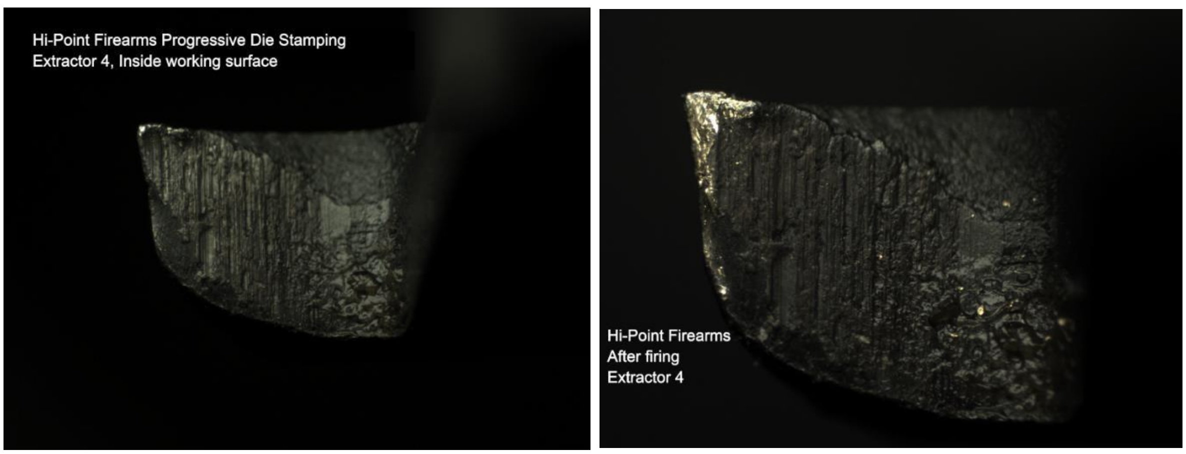
38B; Image of Extractor 2; Prior to and after discharge



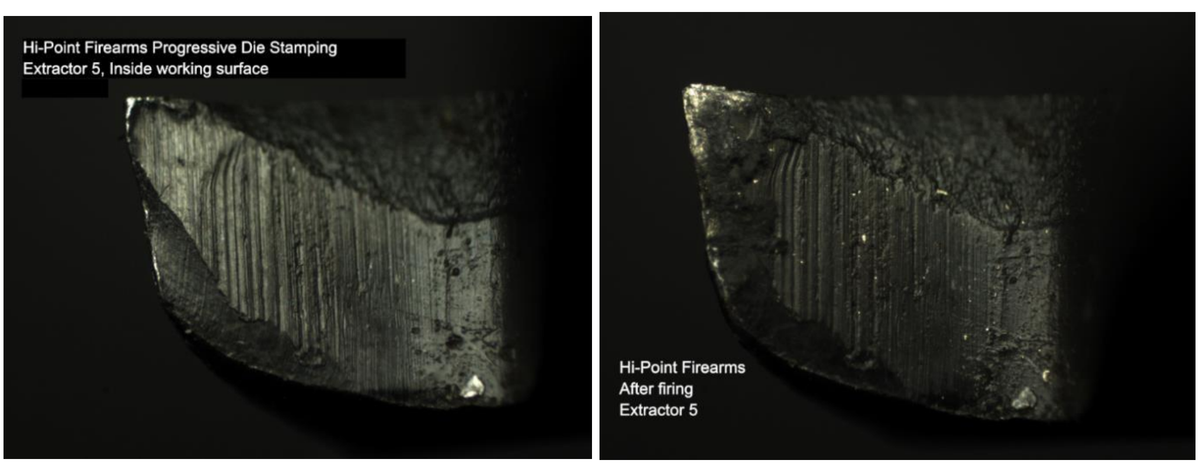
38C; Image of Extractor 3; Prior to and after discharge



38D; Image of Extractor 4; Prior to and after discharge



38E; Image of Extractor 5; Prior to and after discharge



Brass transfer is something that scientists should watch out for because the brass coloration can fill and remain in the striated markings, thus cause the loss of pertinent information. Although this was not observed throughout this experimentation with the number of test fires conducted, it is something that should be considered as this brass transfer could affect the striated markings over time.

Table IV:

List of magnification for the inside working surfaces of the Progressive Die Stamped extractors

Process One	
Inside Working Surfaces of extractors	Magnification
1	15X
2	15X
3	15X
4	15X
5	15X

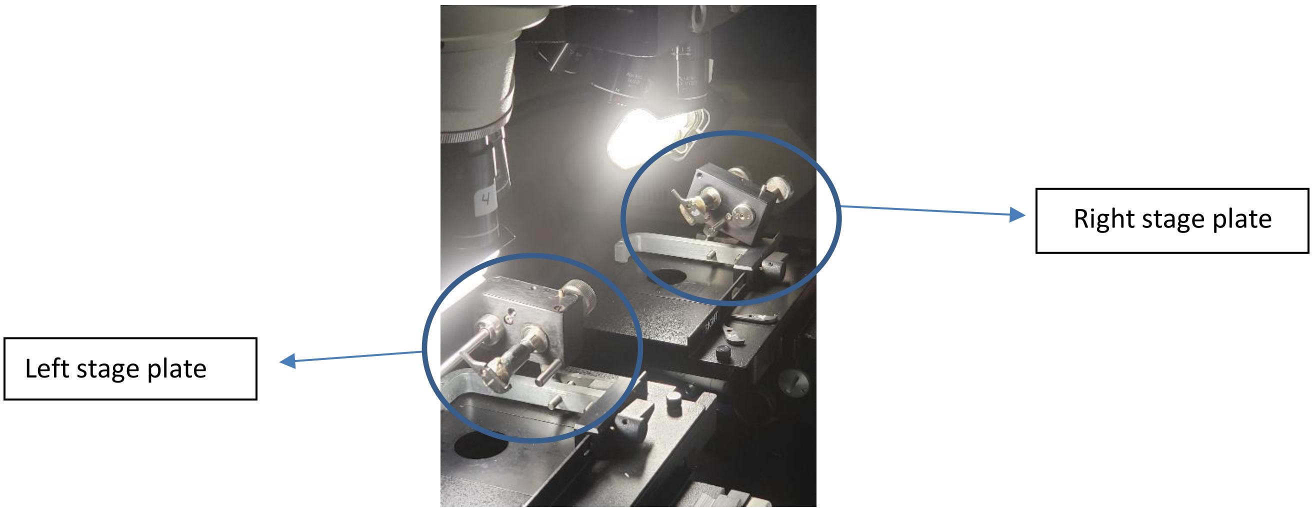
Table V:
List of magnification for the cartridges prior to and after discharge of the Progressive Die Stamped extractors

Process One	
Cartridge	Magnification
1; Before discharge	10X
After discharge	10X
2; Before discharge	20X
After discharge	30X
3; Before discharge	20X
After discharge	30X
4; Before discharge	20X
After discharge	30X
5; Before discharge	20X
After discharge	30X

After discharging the Hi-Point Firearm with the five Progressive Die Stamped extractors, the final step was to compare the markings produced. This step was also microscopically documented.

Step Three: Comparisons

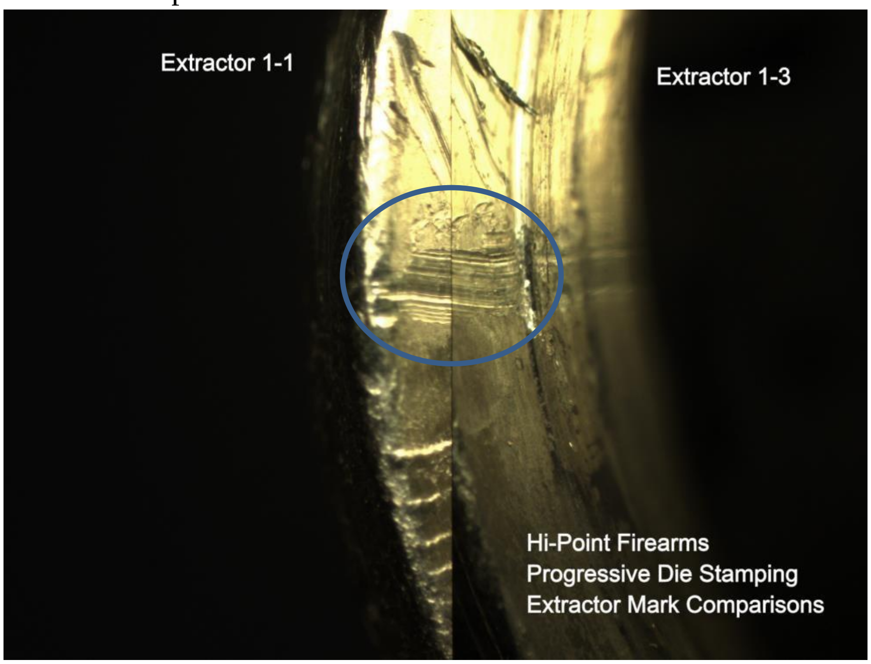
Figure 39: A visual depiction of how comparisons were conducted; with one piece of evidence on the left stage plate and the second evidence on the right stage plate



Once images of all five extractor markings were obtained after test firing, one extractor marking was compared with another extractor marking from the same extractor group: within comparison. Extractor 1-1 and Extractor 1-2 all the way through to Extractor 1-10 were compared, which resulted in nine comparisons per group. As such, a total of 45 comparisons were conducted. Although all microscopic comparisons were conducted, not all images of the comparisons seen were captured. The best extractor markings among each extractor group was identified based on the similarities of the overall pattern of the extractor markings. Notes were made to indicate whether comparable extractor markings were observed. In Figure 40A through 40E, readers can find the “best” extractor markings among each group. Differing results were obtained as comparisons with similar and different extractor marking were identified. Figure 40B shows a “match” for the comparison of extractor markings between Extractor 2-3 and 2-8 as the markings shown are very similar. Figure 40C, on the other hand, shows a “non-match” for the comparison of extractor markings between Extractor 3-9 and 3-4.

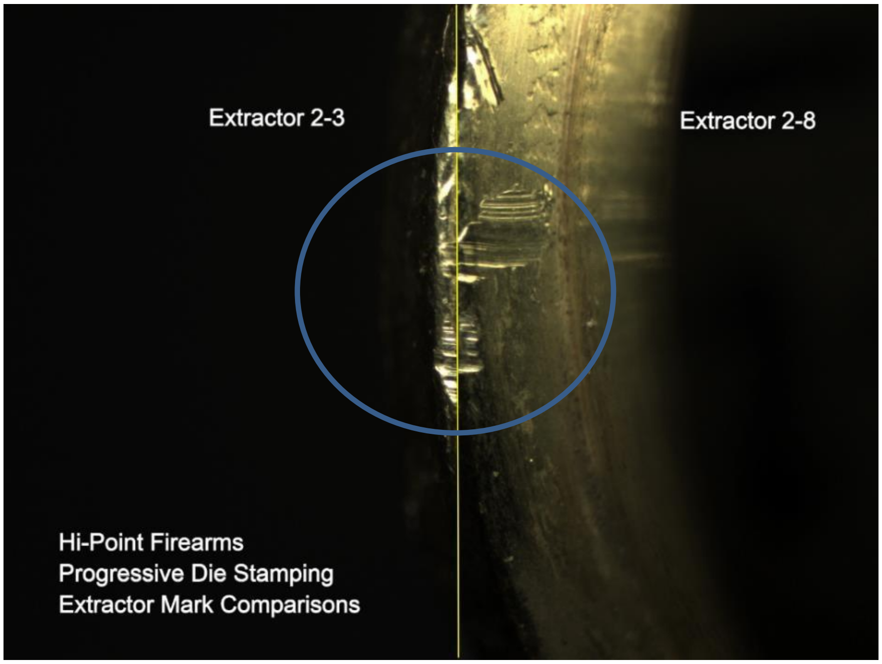
Figure 40: Comparisons conducted on the markings seen among similar groups made by the Progressive Die Stamped extractors

Figure 40A: Comparisons conducted between Extractor 1-1 and Extractor 1-3



40A

Figure 40B: Comparisons conducted between Extractor 2-3 and Extractor 2-8

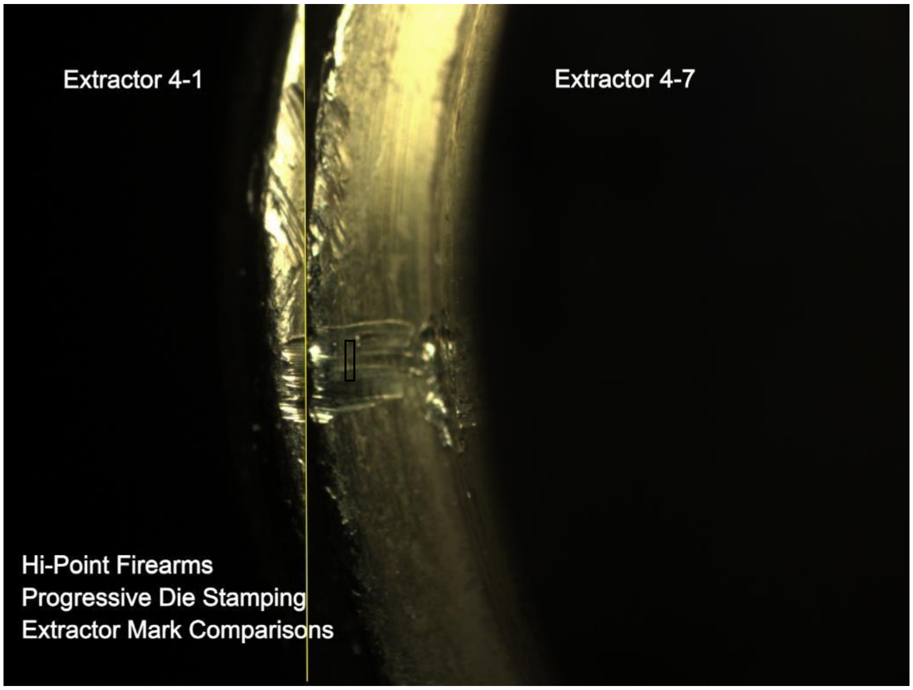


40B

Figure 40C: Comparisons conducted between Extractor 3-9 and Extractor 3-4

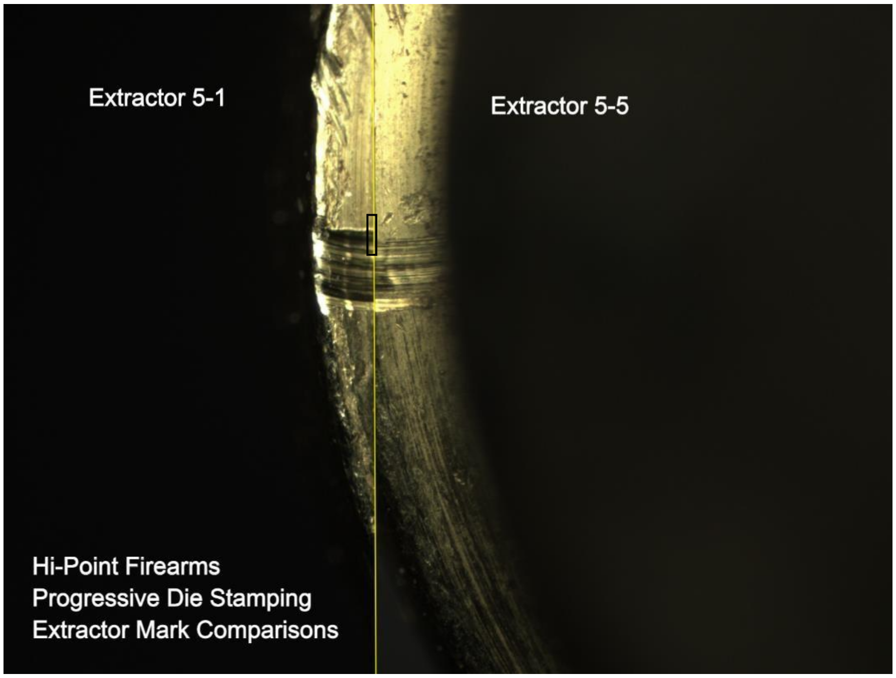
40C

Figure 40D: Comparisons conducted between Extractor 4-1 and Extractor 4-7



40D

Figure 40E: Comparisons conducted between Extractor 5-1 and Extractor 5-5

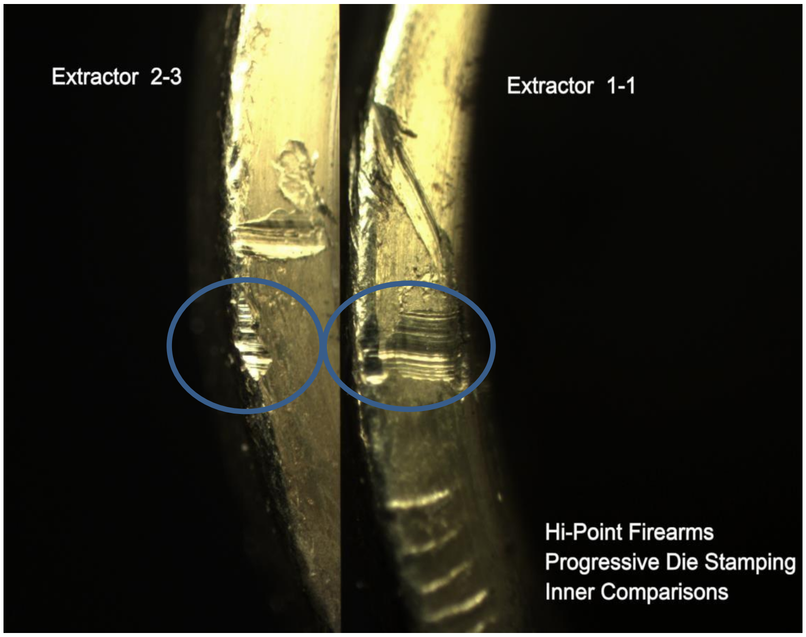


40E

Inner comparisons for markings made by the Progressive Die Stamped extractors were then conducted. This was accomplished by comparing extractor markings from different groups. For example, markings made by Progressive Die Stamped Extractor 3 was compared with markings made by Progressive Die Stamped Extractor 4. The overall pattern of the extractor markings; as well as the similarities and differences among each were compared. A system in which all possible pairs between the five extractors was documented. All repeating pairs were then sought and eliminated. Ensuring that each pair was only represented once, this system made it easy to analyze all cartridge cases in an orderly manner, which essentially minimized any chance of confusion. By the end of this system, forty-one true comparisons were conducted and captured. Examples of some inner comparisons of the markings produced by the Progressive Die Stamped extractors can be seen in Figure 41. All images taken of the comparison of the extractor markings were obtained at a magnification of 30X.

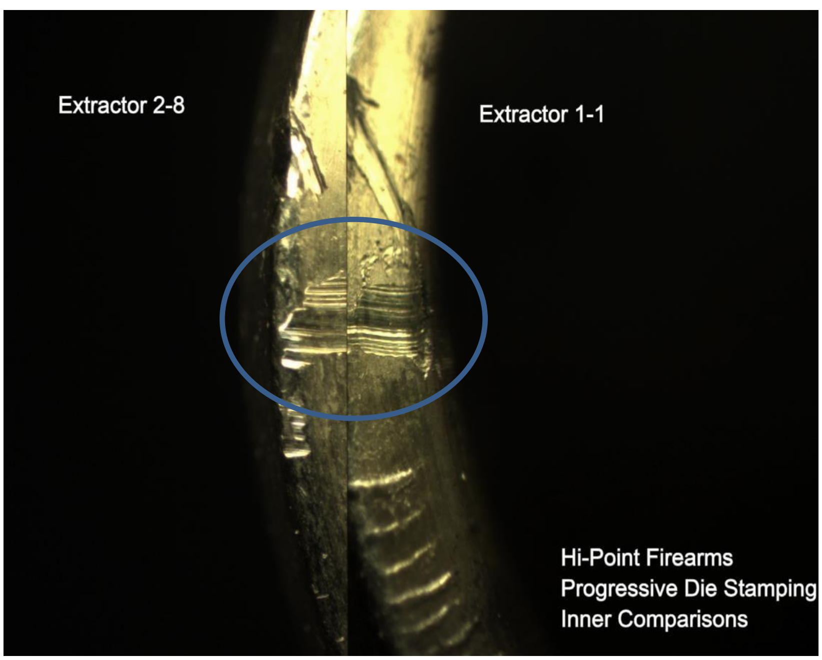
Figure 41: Inner comparisons on the markings produced by the Progressive Die Stamped extractors

Figure 41A: Inner comparisons conducted between Extractor 2-3 and Extractor 1-1



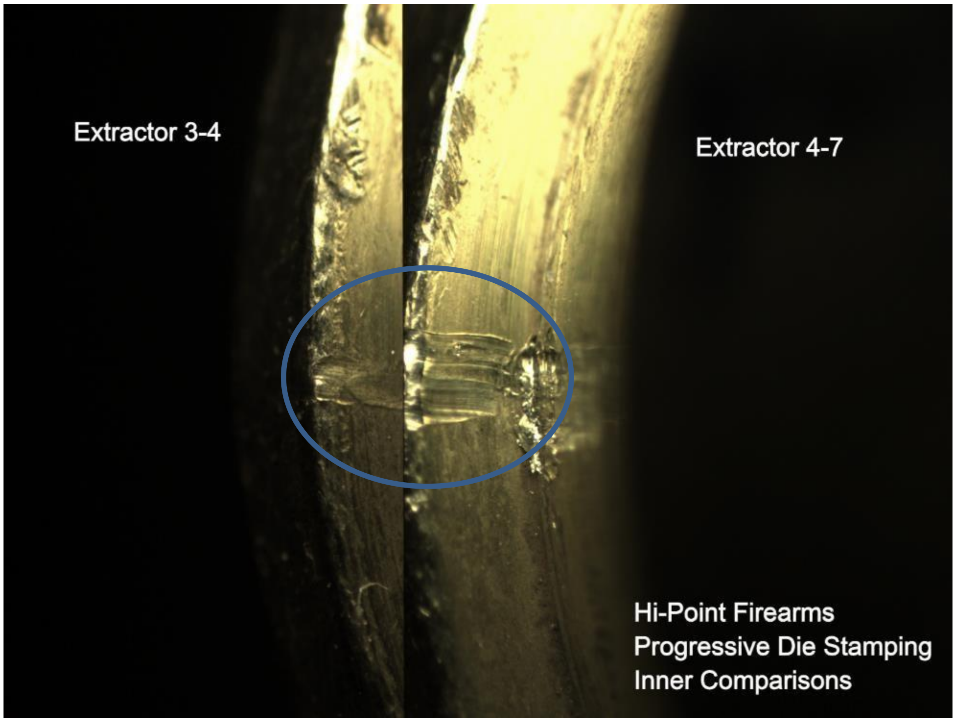
41A

Figure 41B: Comparisons conducted between Extractor 2-8 and Extractor 1-1



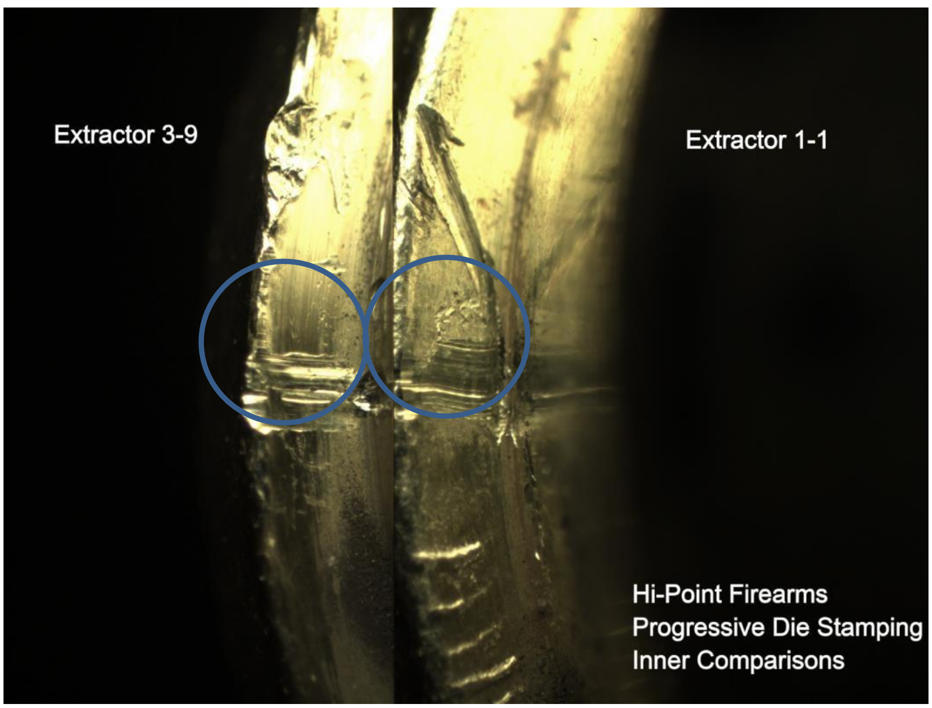
41B

Figure 41C: Comparisons conducted between Extractor 3-4 and Extractor 4-7



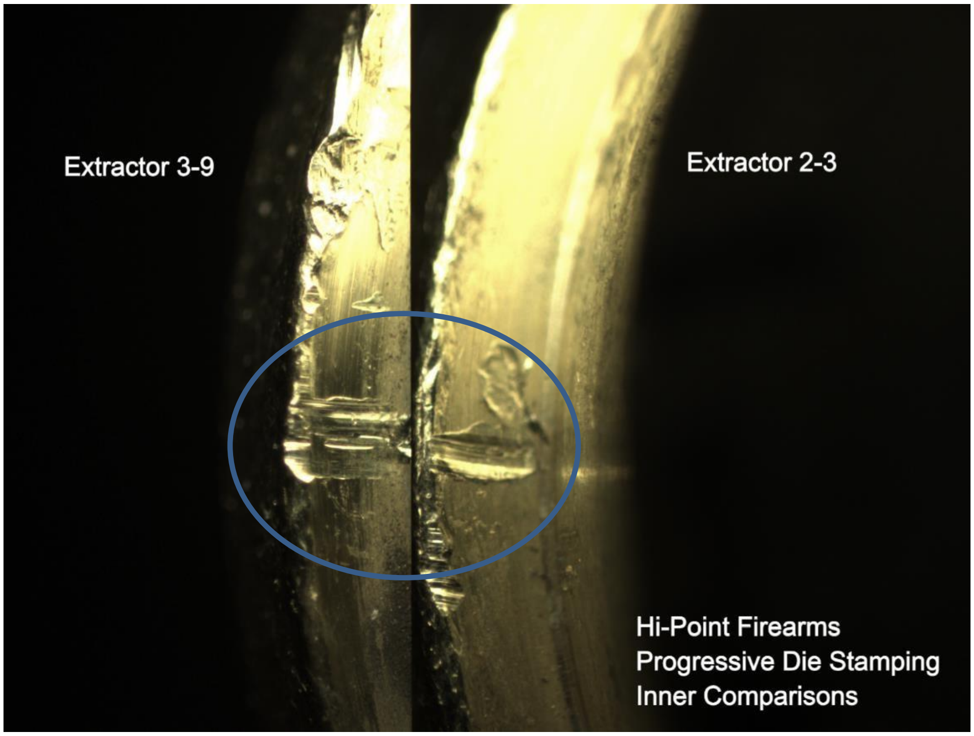
41C.

Figure 41D: Comparisons conducted between Extractor 3-9 and Extractor 1-1



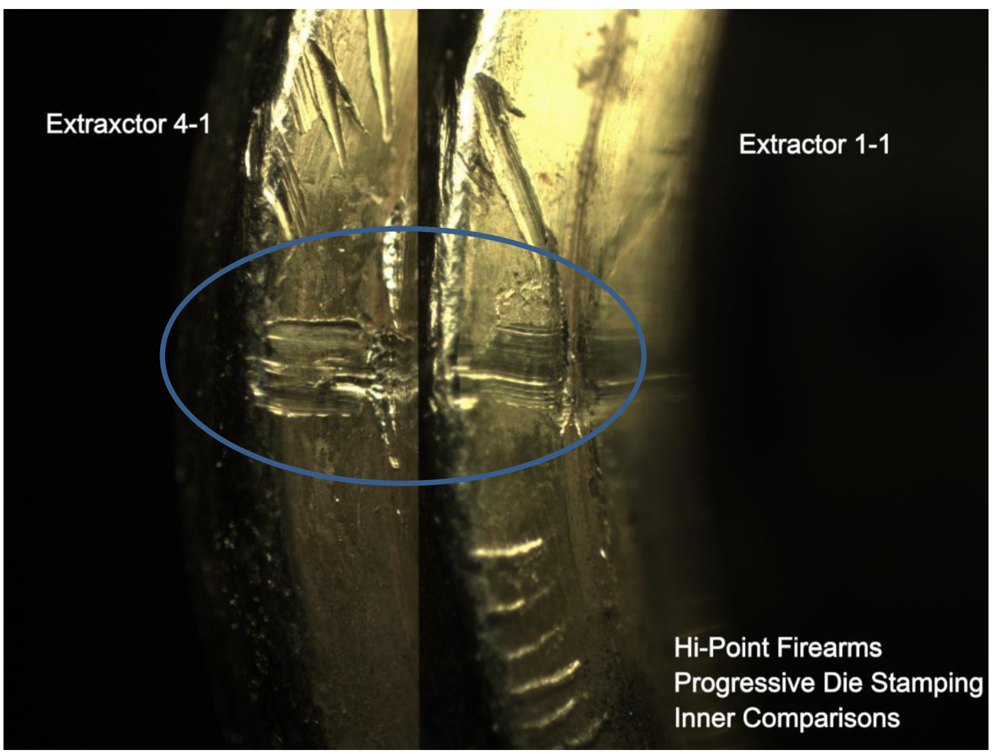
41D

Figure 41E: Comparisons conducted between Extractor 3-9 and Extractor 2-3



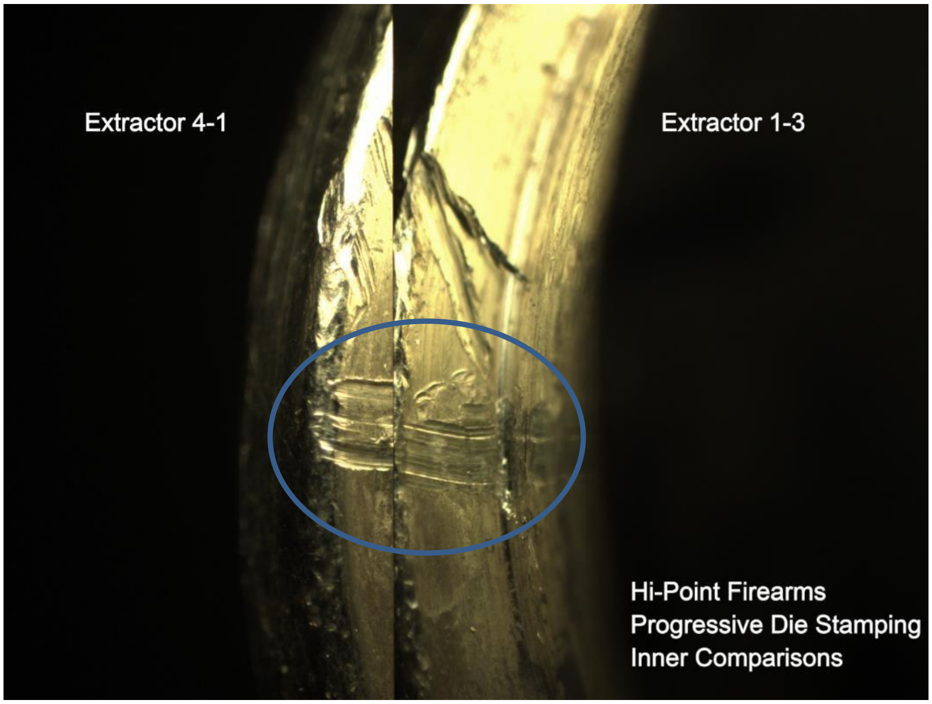
41E

Figure 41F: Comparisons conducted between Extractor 4-1 and Extractor 1-1



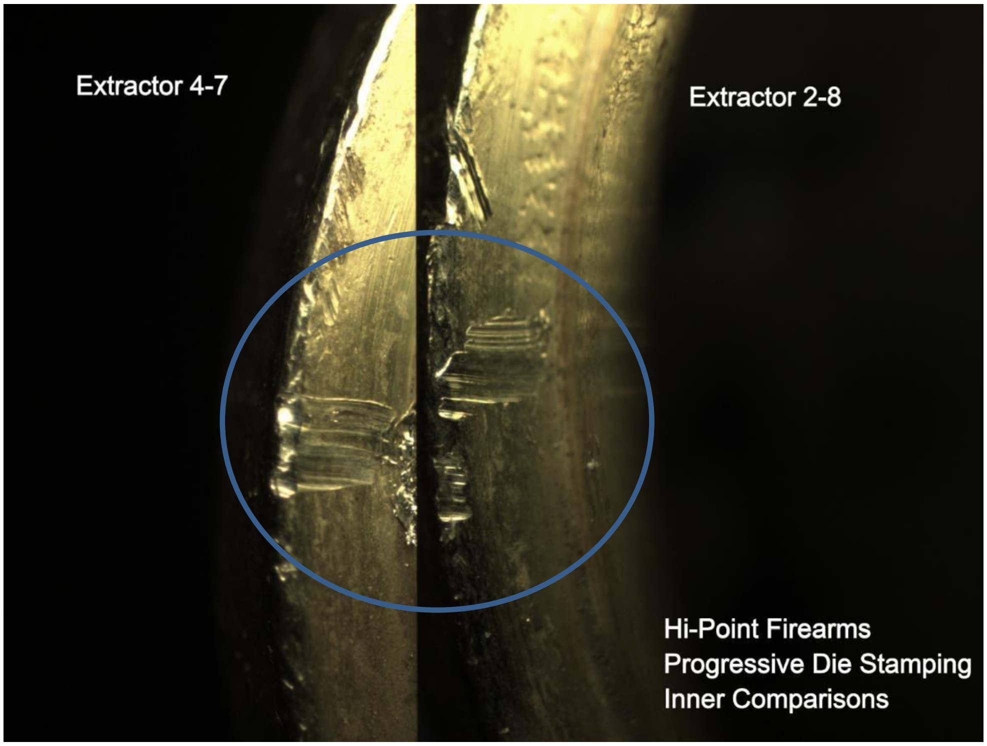
41F

Figure 41G: Comparisons conducted between Extractor 4-1 and Extractor 1-3



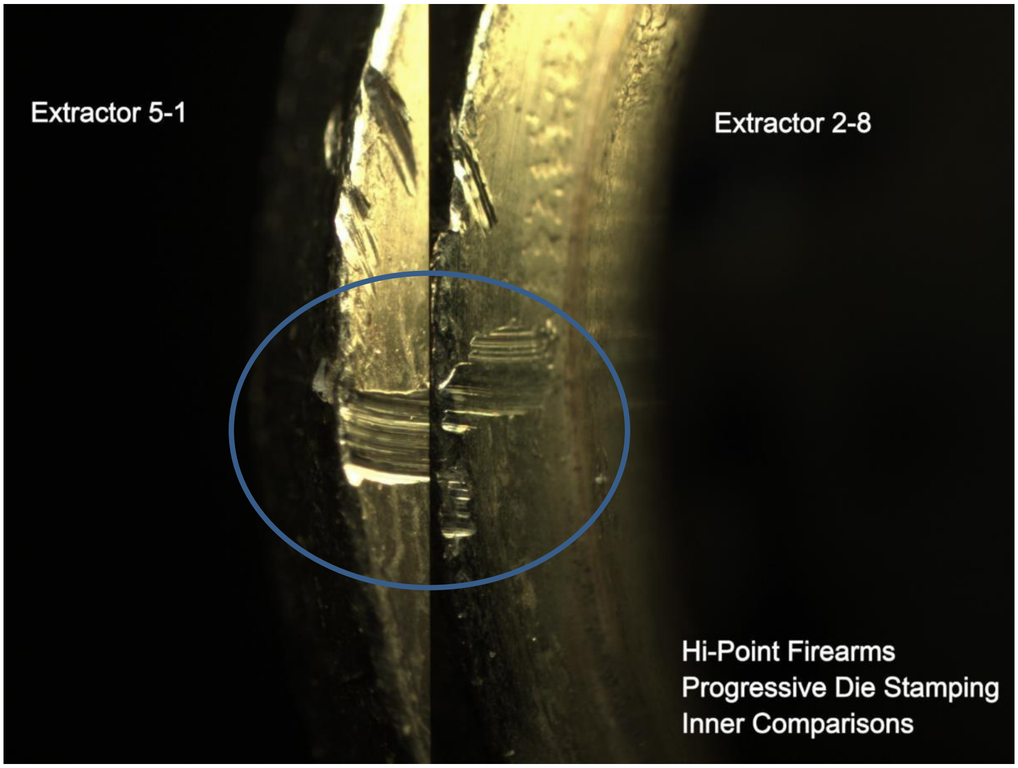
41G

Figure 41H: Comparisons conducted between Extractor 4-7 and Extractor 2-8



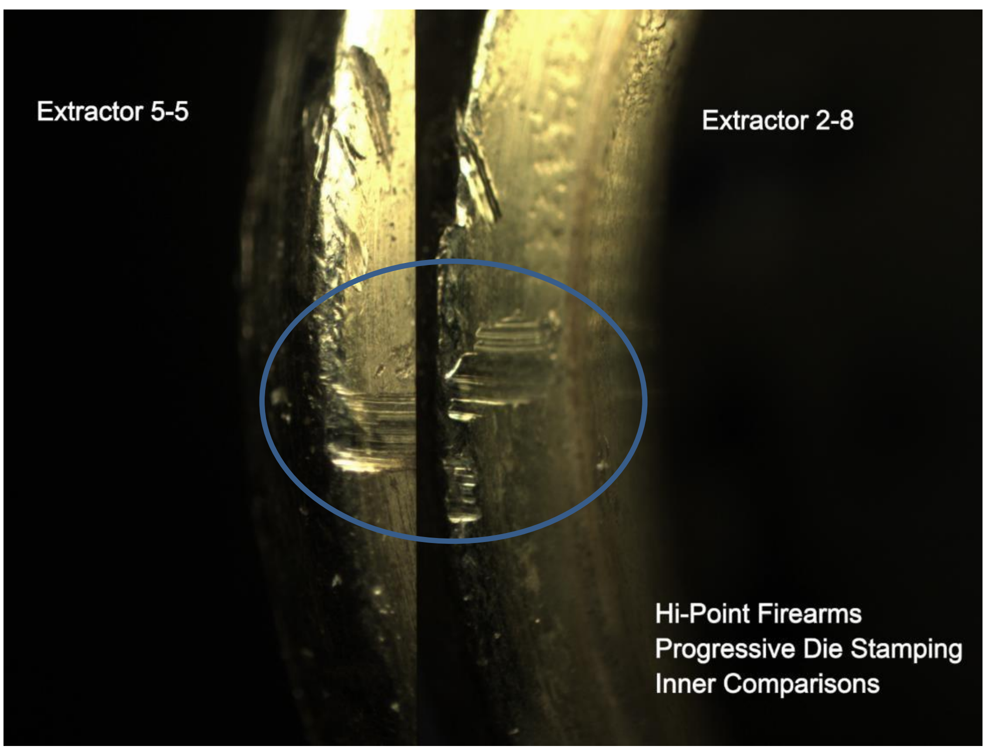
41H

Figure 41I: Comparisons conducted between Extractor 5-1 and Extractor 2-8



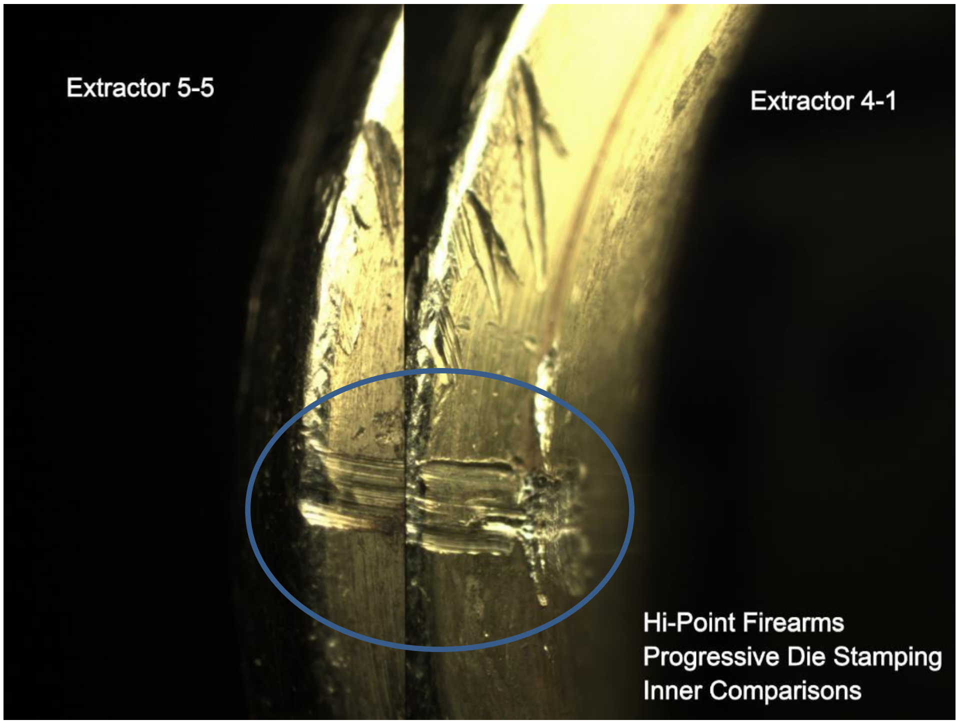
41I

Figure 41J: Comparisons conducted between Extractor 5-8 and Extractor 2-8



41J

Figure 41K: Comparisons conducted between Extractor 5-5 and Extractor 4-1



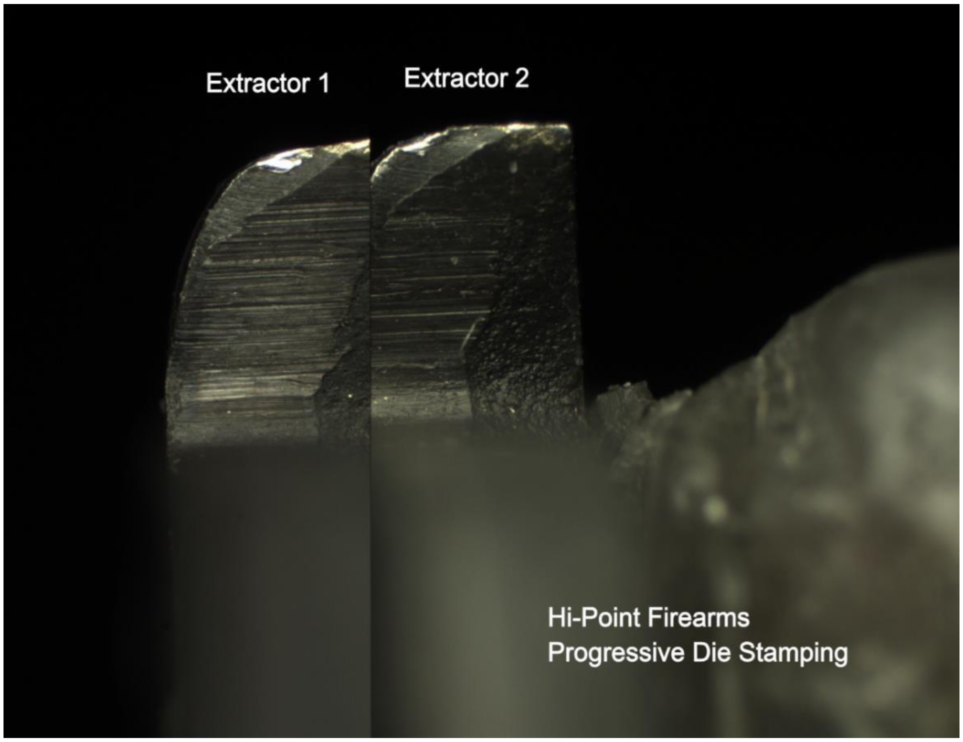
41K

It should be noted that there were similarities and differences seen throughout this inner comparison process. Figure 41G shows a “match” comparison conducted between the two cartridge cases while Figure 41H shows a “non-match” comparison conducted between the two cartridge cases. This was because Extractor 2-8 displayed no reproducible markings like those found on Extractor 4-7. Among the “matched” comparisons, it was observed that although similar markings were seen on both pieces of evidence, there were times in which only partial identifying markings were identified and could be compared. These markings used for partial comparisons can be observed in Figure 41C and 41K. To determine the reason behind this observation, it was concluded that the extractor did not exert enough force on the cartridge during its removal process. Hence, the presence of partial Progressive Die Stamped extractor markings.

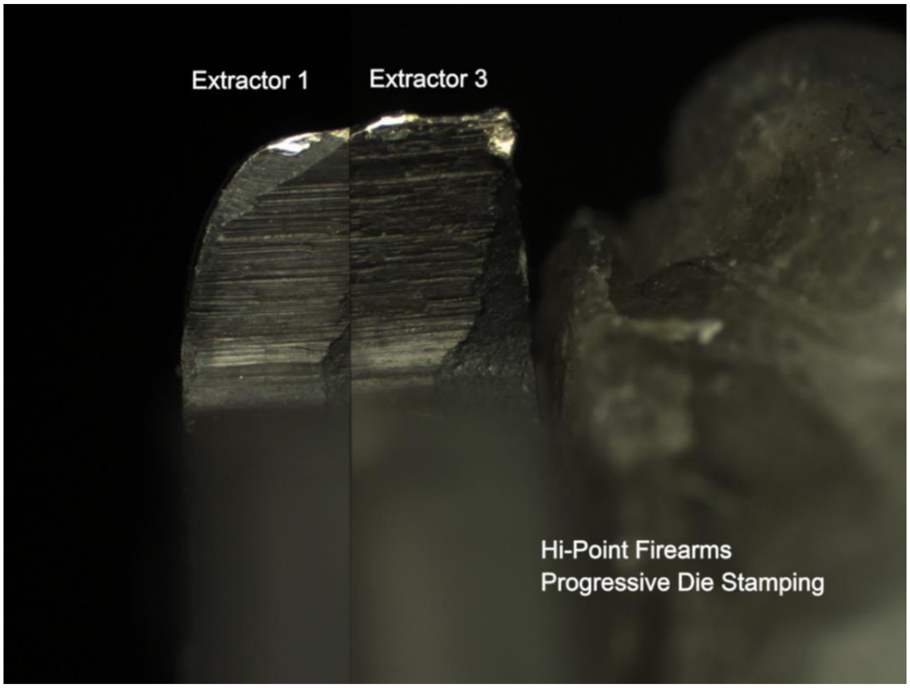
Comparisons of the inside and outside working surfaces of the Progressive Die Stamped extractors was also regulated and can be seen in Figure 42. All images taken of the extractors themselves were obtained at a magnification of 15X. It should be noted that the inside working surfaces as well as the outside working surfaces of the extractors can be viewed below. The inside working surfaces are the first set of images to be displayed. Although both inside and outside working surfaces of the extractors were obtained, it was determined that because the inside working surfaces of the extractors contacted the cartridge cases directly, conclusions would only be drawn based on the inside working surfaces.

Figure 42: Inner comparisons were also conducted on the extractors

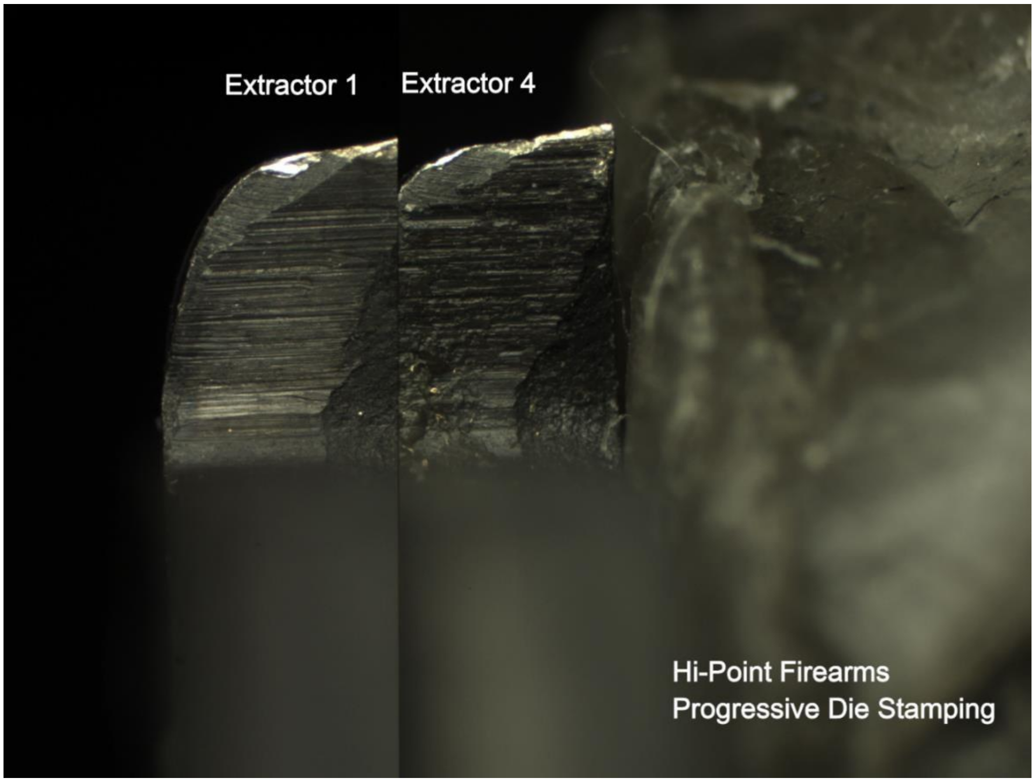
42A; Inside Working Surface



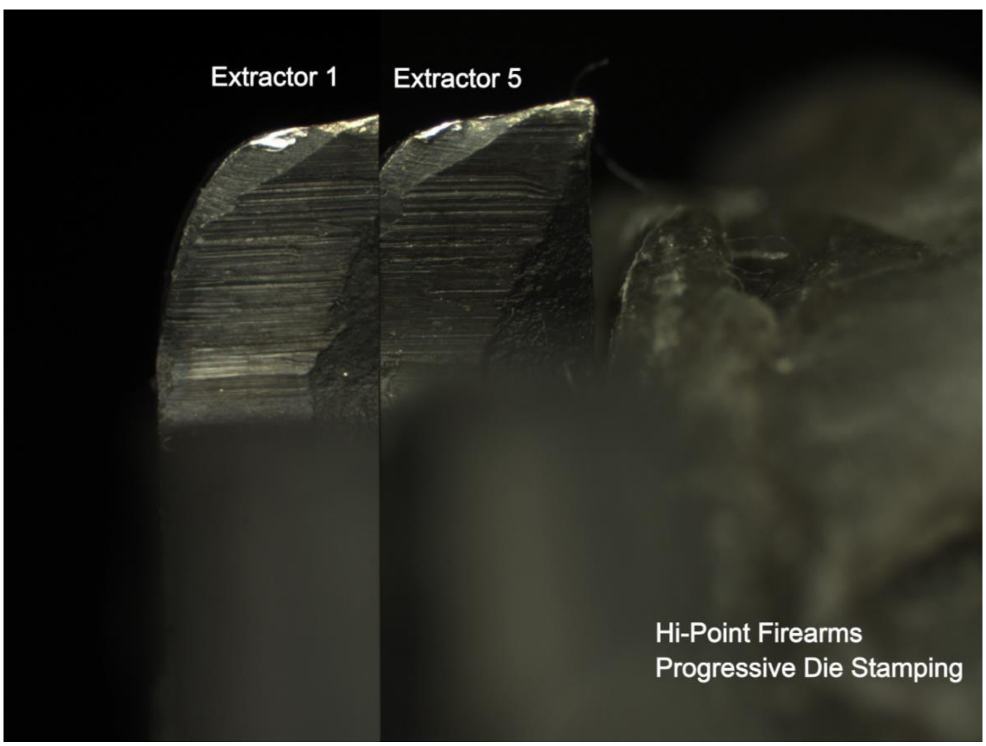
42B; Inside Working Surface



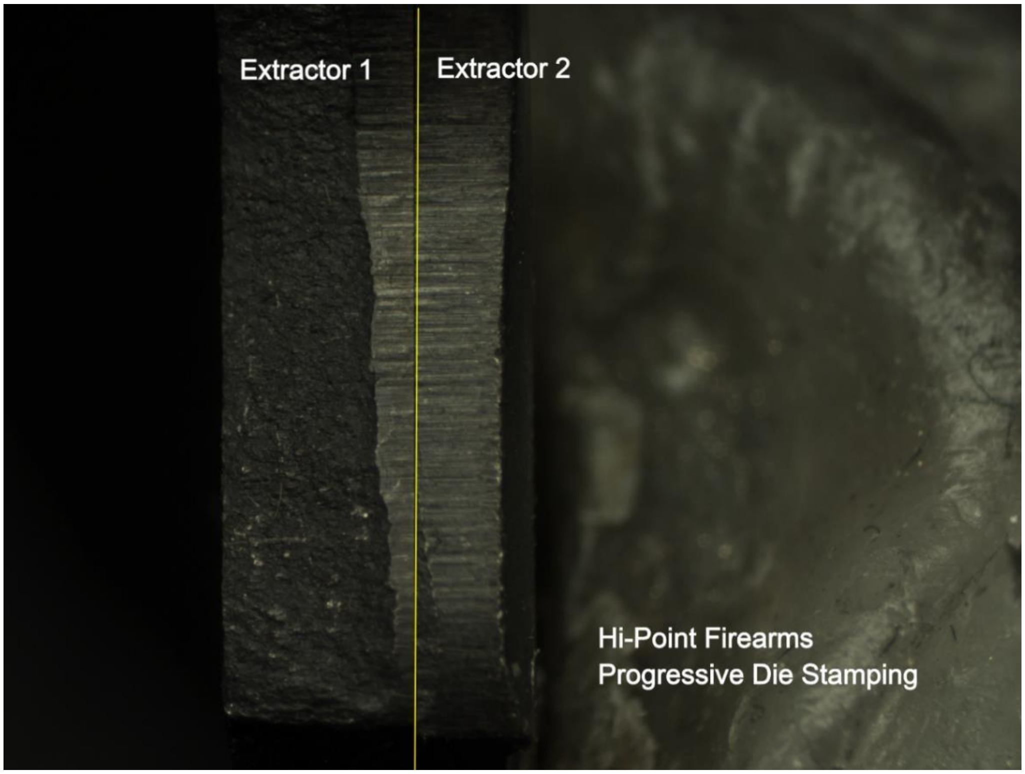
42C; Inside Working Surface



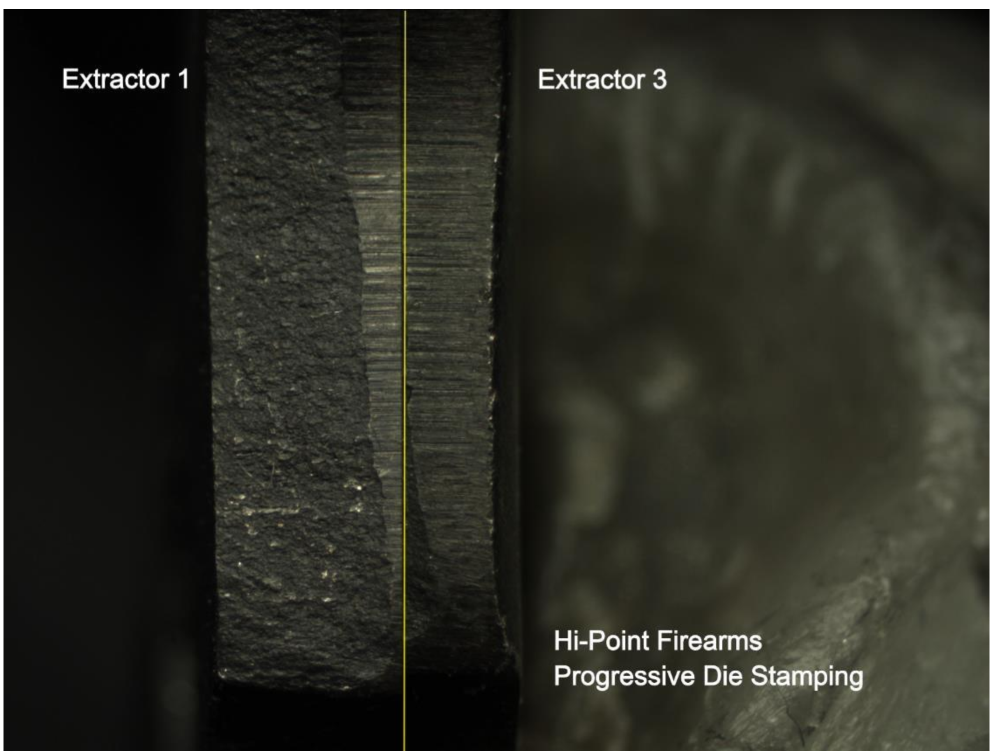
42D; Inside Working Surface



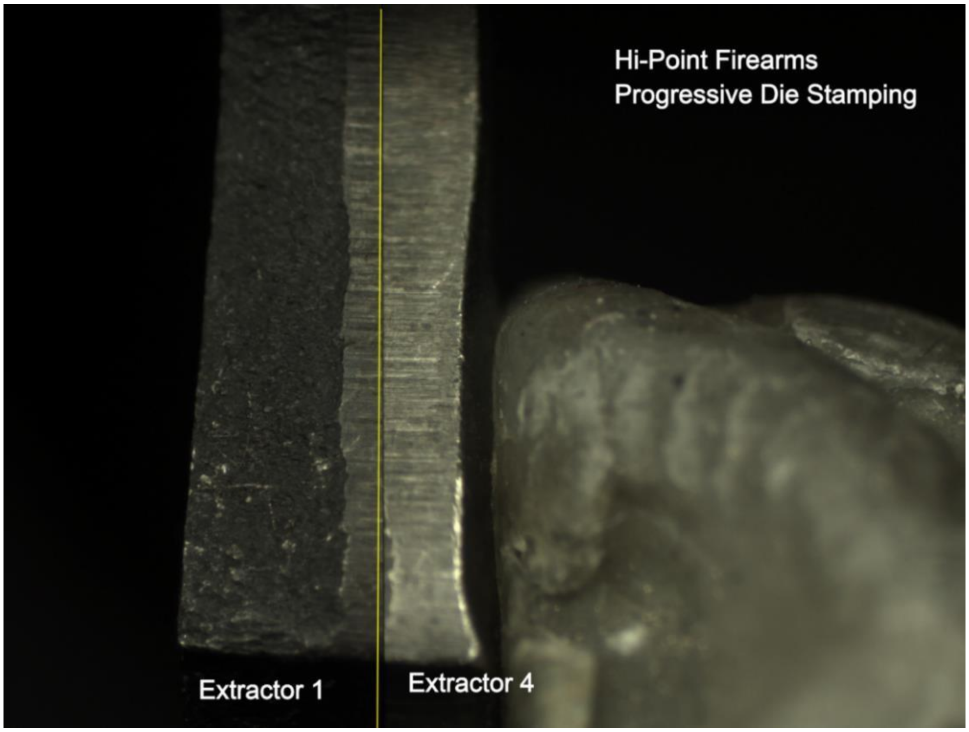
42E; Outside Working Surface



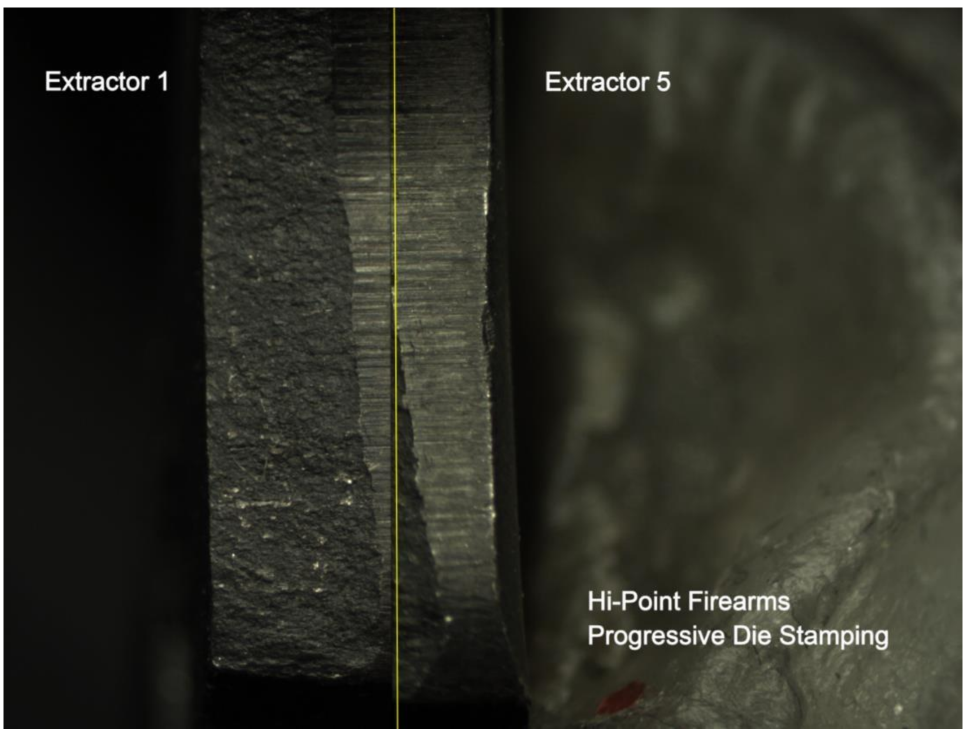
42F; Outside Working Surface



42G; Outside Working Surface



42H; Outside Working Surface



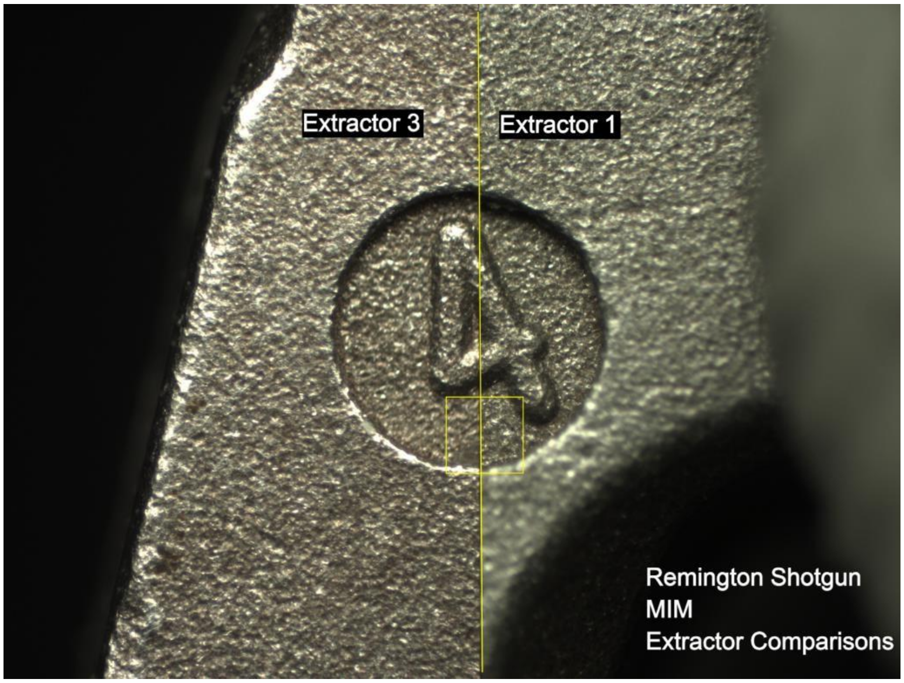
FINDINGS/CONCLUSION

The firing and comparison of markings on cartridge cases and shotshells made by Progressive Die Stamped extractors and Metal Injection Molded extractors was completed. The extractors were first analyzed. Microscopic comparisons between the markings produced by the extractors was also conducted to determine if enough individual characteristic markings for identification of fired evidence were present.

Upon analysis of the Metal Injection Molded extractors led to the confirmation that these three extractors were created using the same mold cavity. After injection of the feedstock into a mold, the produced part can either be removed or broken off the mold cavity. As such, any reproducing markings/patterns on the Metal Injection Molded extractor would only be transferable if there was a defect or an identifiable marking in the mold cavity. These defects or identifiable markings would then be transferred to the shot shells as the two items contacted each other. The inside working surfaces of the extractors were “smooth” and produced no signs of additional process as a finishing procedure as was seen with the Progressive Die Stamped extractors. Upon analysis of the same areas of different extractors, the presence of similar markings on the Metal Injection Molded extractors was visible. These similarities were referenced in Figure 33 and was further explained in Figure 43 below.

Figure 43: Extractor comparisons for Metal Injection Molded extractors with zoomed examples

Figure 43A shows the comparison of the extractors

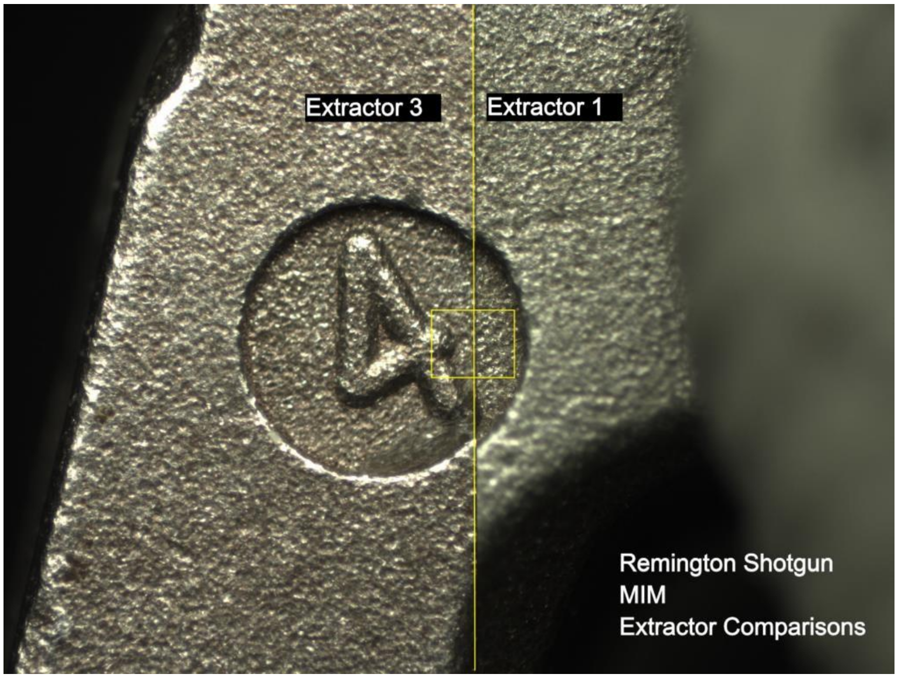


43A

Figure 43B shows a similar pattern seen among the two extractors with zoomed examples being compared identified in the orange outline

43B

Figure 43C shows the comparison of the extractors



43C

Figure 43D shows a similar pattern seen among the two extractors with zoomed examples being compared identified in the orange outline

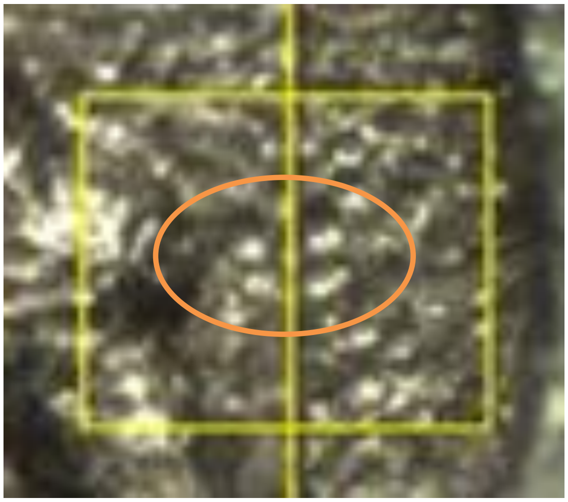
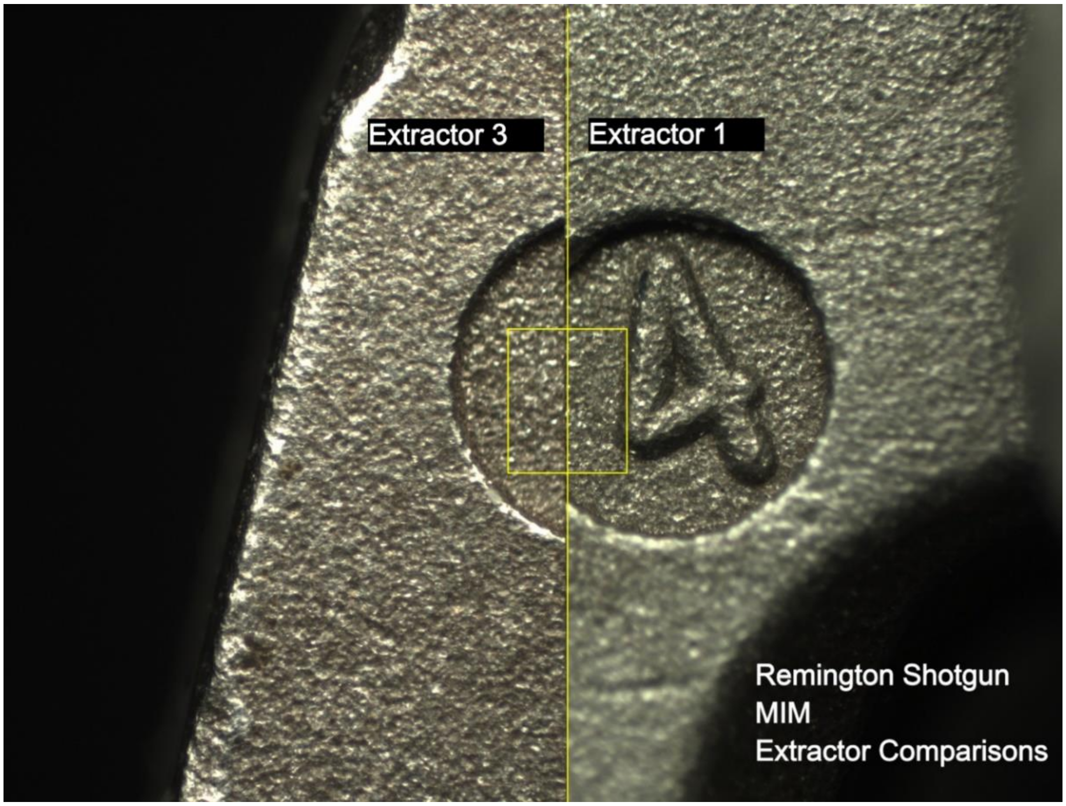
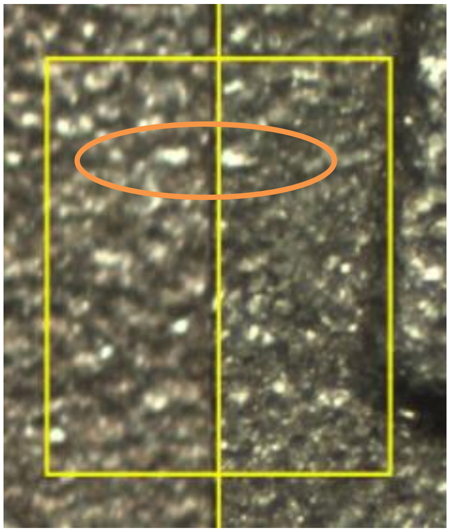

43D

Figure 43E shows the comparison of the extractors



43E

Figure 43F shows a similar pattern seen among the two extractors with zoomed examples being compared identified in the orange outline



43F

Because these markings were not produced by the inside working surface of these extractors, this could help to explain why these markings were not transferred on the shot shells after discharge. Again, having identical striations on the machined parts prove the consecutive nature of the MIM'd extractors, thus an increased possibility of having similar markings transferred on the shot shells if they were to contact each other.

When referring to the Metal Injection Molded extractor markings themselves, it was believed that the extraction process did not occur with a lot of force. This was because these extractor markings on the shot shell were not as profound as the markings produced by the Progressive Die Stamped extractors. After analysis of these markings, there were more similarities and minor differences when referencing the within and inner comparisons that was conducted. This conclusion was drawn after the presence of what was identified as an "equal mark" which was seen amongst most comparisons as well as the presence of other identifiable markings. An example of this marking can be seen in Figure 44 below.

Figure 44A; within comparison showcasing the “equal mark”

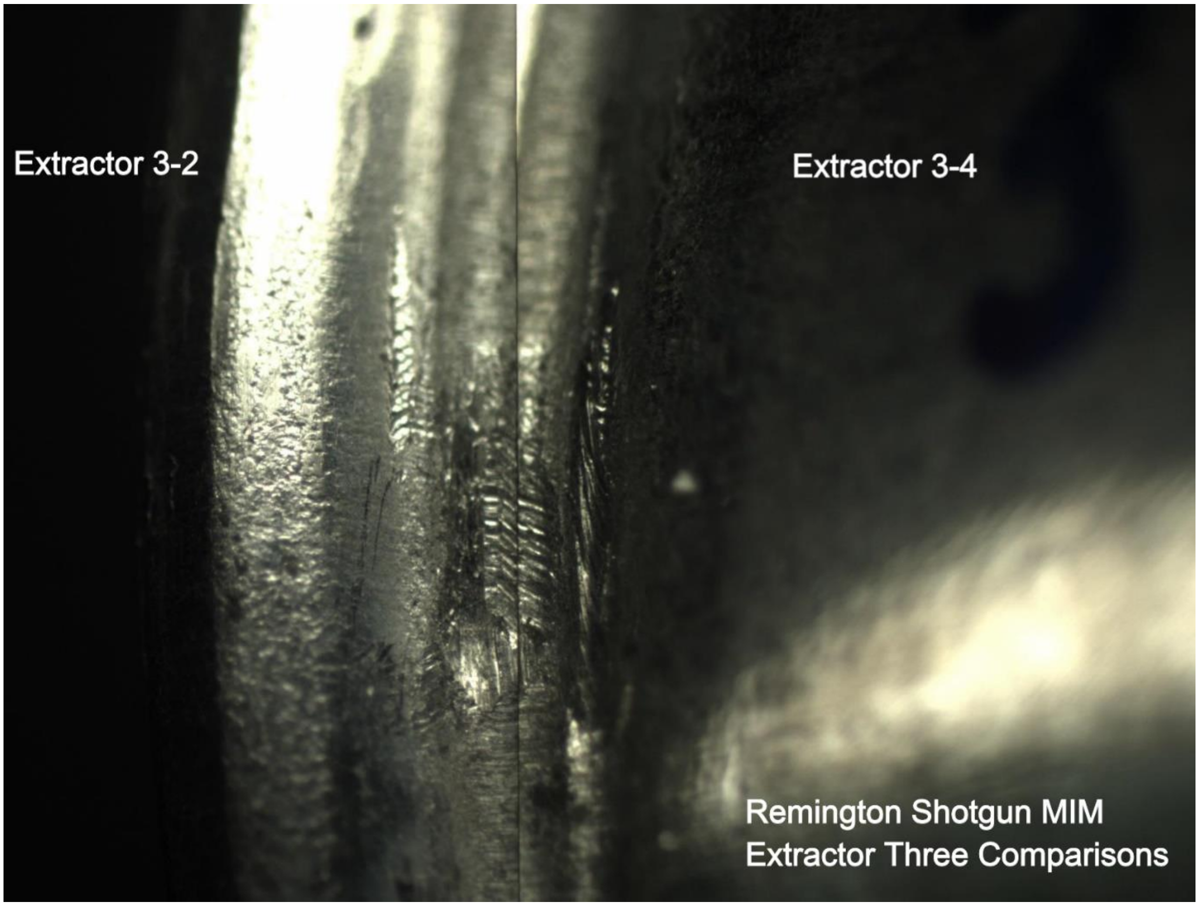
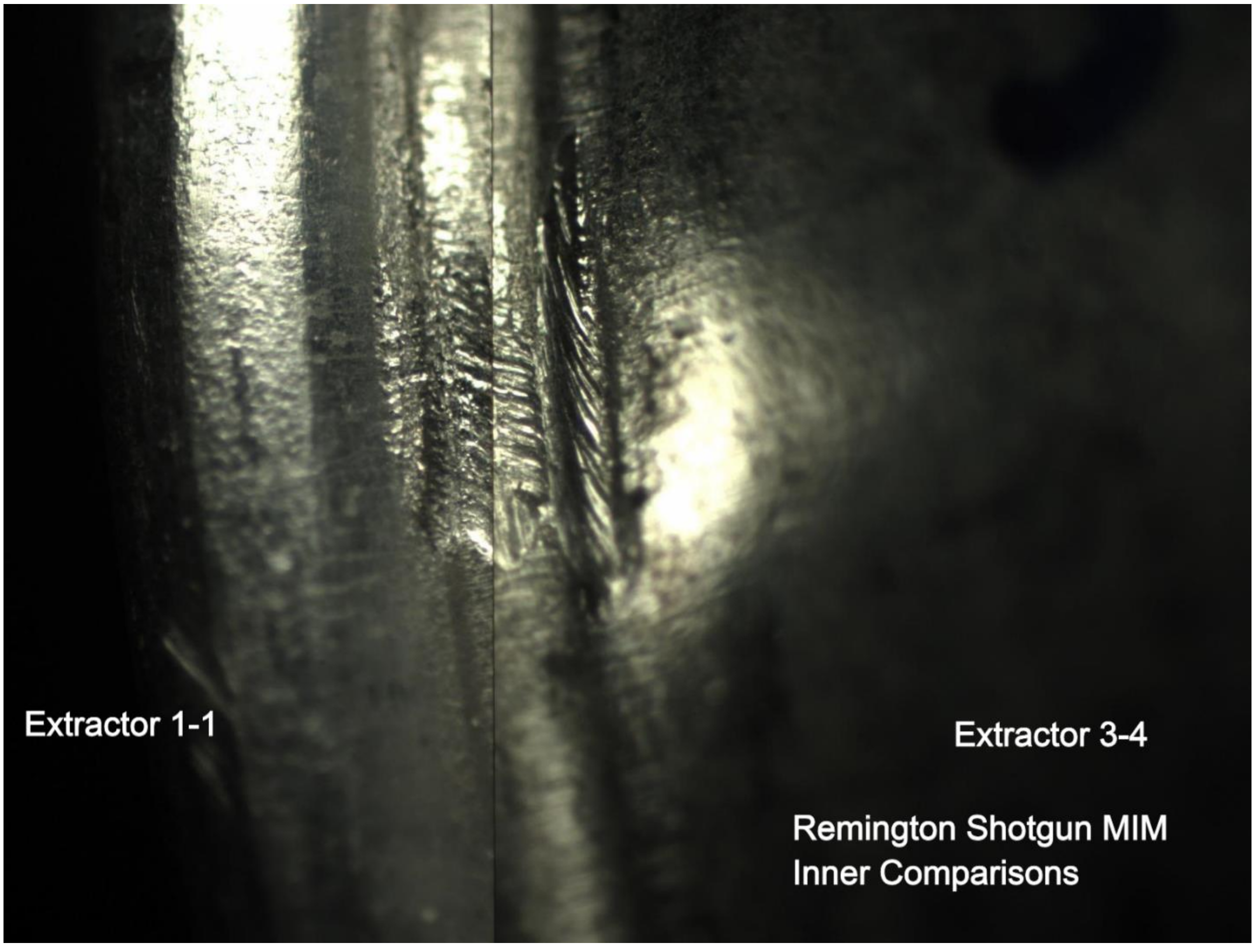


Figure 44B; within comparison showcasing the “equal mark”



Statistical findings for the Metal Injection Molded extractor within comparisons can be found below. In Table VI below, an example of the "p-values" greater than and less than 0.05 that was generated by the markings produced using the Metal Injection Molding extractors can be observed.

Table VI:

	Extractor 1-1	Extractor 1-2	Extractor 1-3	Extractor 1-4	Extractor 1-5	Extractor 1-6	Extractor 1-7	Extractor 1-8	Extractor 1-9	Extractor 1-10
Extractor 1-1	N/A	0.001566956	0.083351782	1.16139E-20	0.004304862	0.254135088	0.271476865	0.000239298	0.230808576	8.30925E-13
Extractor 1-2	0.001566956	N/A	0.709698381	5.89521E-38	0.746696549	0.001499453	6.87014E-05	0.102656999	0.317198284	2.0205E-06
Extractor 1-3	0.083351782	0.709698381	N/A	1.48863E-11	0.857735969	0.072982378	0.02302239	0.504613451	0.426802358	0.02068099
Extractor 1-4	1.16139E-20	5.89521E-38	1.48863E-11	N/A	1.0228E-31	7.07156E-14	3.19987E-19	4.49716E-28	3.24731E-11	1.08168E-31
Extractor 1-5	0.004304862	0.746696549	0.857735969	1.0228E-31	N/A	0.005449565	0.001775067	0.402821872	0.331150353	0.003102414
Extractor 1-6	0.254135088	0.001499453	0.072982378	7.07156E-14	0.005449565	N/A	0.73479544	0.000416616	0.003687258	2.10108E-12
Extractor 1-7	0.271476865	6.87014E-05	0.02302239	3.19987E-19	0.001775067	0.73479544	N/A	1.29837E-06	0.02932587	8.39564E-16
Extractor 1-8	0.000239298	0.102656999	0.504613451	4.49716E-28	0.402821872	0.000416616	1.29837E-06	N/A	0.101608643	1.69211E-05
Extractor 1-9	0.230808576	0.317198284	0.426802358	3.24731E-11	0.331150353	0.003687258	0.02932587	0.101608643	N/A	2.1772E-05
Extractor 1-10	8.30925E-13	2.0205E-06	0.02068099	1.08168E-31	0.003102414	2.10108E-12	8.39564E-16	1.69211E-05	2.1772E-05	N/A
Extractor 2-1	0.603762188	0.008371087	4.70999E-15	5.20528E-06	0.009800981	0.869750238	0.947838945	5.3381E-06	0.393939222	1.65374E-06
Extractor 2-2	0.000254086	7.3119E-10	4.81929E-19	0.166736557	1.92785E-11	0.003823278	0.001216425	7.17482E-14	0.00178114	1.02784E-11
Extractor 2-3	0.858880702	0.00208973	6.06924E-05	2.2852E-15	0.006457171	0.774110704	0.567333692	2.5952E-10	0.435091144	4.05779E-09
Extractor 2-4	0.000198455	7.28923E-14	1.3297E-15	2.41074E-05	1.59741E-09	0.010447873	0.003698478	3.18654E-33	0.002999217	4.17503E-21
Extractor 2-5	9.16126E-07	1.9673E-13	5.76995E-08	2.38324E-07	1.16215E-15	0.000948765	0.000178429	2.02845E-16	0.00039994	9.95965E-17
Extractor 2-6	4.23579E-13	0.015584911	0.282707274	1.50525E-29	0.079751227	1.59124E-18	1.22301E-13	0.200874563	3.05731E-05	0.083354879

Extractor 2-7	1.64799E-10	3.08644E-06	0.00024922	1.49853E-37	0.001651136	1.10002E-08	2.01744E-13	8.4208E-10	0.000543802	0.906959738
Extractor 2-8	0.07686058	2.40206E-06	0.00675692	9.2348E-17	0.000112573	0.512931665	0.668680206	1.23085E-07	0.053264932	4.84422E-14
Extractor 2-9	0.064850149	2.27719E-08	0.009563374	6.25692E-20	6.76383E-06	0.706532026	0.926147219	5.00348E-08	0.107248667	8.49801E-18
Extractor 2-10	0.046014814	0.681321565	0.636978142	1.27485E-13	0.631982763	0.001637965	0.008098596	0.261018167	0.236101882	0.000549137
Extractor 3-1	1.5578E-06	7.6752E-14	0.000123627	6.4539E-10	1.79989E-06	0.000482852	0.000608468	6.25796E-19	7.33472E-05	3.56838E-42
Extractor 3-2	0.022394208	0.898243041	0.68892343	3.01565E-24	0.914957146	0.011357882	0.000128259	0.121238219	0.345319712	0.000340081
Extractor 3-3	4.36922E-18	4.75126E-33	7.47173E-59	3.31535E-05	1.13082E-28	1.7129E-12	1.5783E-16	2.99702E-51	4.46891E-11	3.08623E-32
Extractor 3-4	0.07195455	3.92686E-06	6.66435E-12	2.3813E-06	9.64282E-07	0.254892642	0.240015976	3.17251E-10	0.08693499	2.36189E-09
Extractor 3-5	8.29179E-09	1.28655E-15	3.22707E-09	0.160667217	1.75282E-08	1.44171E-07	2.4162E-09	2.49635E-30	6.53835E-09	2.77759E-62
Extractor 3-6	1.82324E-16	3.37599E-12	1.71469E-05	7.52267E-51	1.00301E-06	4.89374E-12	1.21058E-16	2.00183E-12	4.67623E-05	0.252379034
Extractor 3-7	3.24793E-27	1.94784E-46	2.11644E-33	4.11471E-11	9.04758E-38	2.68549E-22	3.04927E-35	3.31027E-54	5.60728E-19	1.48358E-39
Extractor 3-8	6.66384E-23	8.27494E-24	6.957E-12	0.000421878	1.3058E-22	1.24486E-22	1.75274E-25	6.90983E-22	2.36958E-23	6.55312E-26
Extractor 3-9	3.97884E-10	1.38835E-21	4.91742E-07	2.84747E-07	1.11862E-31	2.1661E-05	1.58478E-05	4.91793E-15	3.94291E-05	5.93319E-18
Extractor 3-10	6.89237E-12	1.09984E-23	2.87499E-67	0.005270036	2.80522E-18	5.57638E-09	1.85237E-12	1.94843E-41	1.10523E-08	4.94783E-27

The table displayed above shows the "p-values" obtained that are less than and greater than the alpha value of 0.05. By obtaining such a wide range of "p-values," this would suggest that the extractor markings may or may not be statistically different from each other after being compared by firearm examiners.

The table below, Table VII, shows an example of the Metal Injection Molded extractor markings obtained for the within comparison with "p-values" less than or equal to an alpha value of 0.05.

Table VII:

	Extractor 1-1	Extractor 1-2	Extractor 1-3	Extractor 1-4	Extractor 1-5	Extractor 1-6	Extractor 1-7	Extractor 1-8	Extractor 1-9	Extractor 1-10
Extractor 1-1	N/A	0.001566956	N/A	1.16139E-20	0.004304862	N/A	N/A	0.000239	N/A	8.31E-13
Extractor 1-2	0.001566956	N/A	N/A	5.89521E-38	N/A	0.001499453	6.87014E-05	N/A	N/A	2.02E-06
Extractor 1-3	N/A	N/A	N/A	1.48863E-11	N/A	N/A	0.02302239	N/A	N/A	0.020681
Extractor 1-4	1.16139E-20	5.89521E-38	1.48863E-11	N/A	1.0228E-31	7.07156E-14	3.19987E-19	4.5E-28	3.25E-11	1.08E-31
Extractor 1-5	0.004304862	N/A	N/A	1.0228E-31	N/A	0.005449565	0.001775067	N/A	N/A	0.003102
Extractor 1-6	N/A	0.001499453	N/A	7.07156E-14	0.005449565	N/A	N/A	0.000417	0.003687	2.1E-12
Extractor 1-7	N/A	6.87014E-05	0.02302239	3.19987E-19	0.001775067	N/A	N/A	1.3E-06	0.029326	8.4E-16
Extractor 1-8	0.000239298	N/A	N/A	4.49716E-28	N/A	0.000416616	1.29837E-06	N/A	N/A	1.69E-05
Extractor 1-9	N/A	N/A	N/A	3.24731E-11	N/A	0.003687258	0.02932587	N/A	N/A	2.18E-05
Extractor 1-10	8.30925E-13	2.0205E-06	0.02068099	1.08168E-31	N/A	2.10108E-12	8.39564E-16	1.69E-05	2.18E-05	N/A
Extractor 2-1	N/A	0.008371087	4.70999E-15	5.20528E-06	N/A	N/A	N/A	5.34E-06	N/A	1.65E-06
Extractor 2-2	0.000254086	7.3119E-10	4.81929E-19	N/A	1.92785E-11	0.003823278	0.001216425	7.17E-14	0.001781	1.03E-11
Extractor 2-3	N/A	0.00208973	6.06924E-05	2.2852E-15	N/A	N/A	N/A	2.6E-10	N/A	4.06E-09
Extractor 2-4	0.000198455	7.28923E-14	1.3297E-15	2.41074E-05	1.59741E-09	0.010447873	0.003698478	3.19E-33	0.002999	4.18E-21

Extractor 2-5	9.16126E-07	1.9673E-13	5.76995E-08	2.38324E-07	1.16215E-15	0.000948765	0.000178429	2.03E-16	0.0004	9.96E-17
Extractor 2-6	4.23579E-13	0.015584911	N/A	1.50525E-29	N/A	1.59124E-18	1.22301E-13	N/A	3.06E-05	0.083355
Extractor 2-7	1.64799E-10	3.08644E-06	0.00024922	1.49853E-37	0.001651136	1.10002E-08	2.01744E-13	8.42E-10	0.000544	N/A
Extractor 2-8	N/A	2.40206E-06	0.00675692	9.2348E-17	0.000112573	N/A	N/A	1.23E-07	0.053265	4.84E-14
Extractor 2-9	N/A	2.27719E-08	0.009563374	6.25692E-20	6.76383E-06	N/A	N/A	5E-08	N/A	8.5E-18
Extractor 2-10	0.046014814	N/A	N/A	1.27485E-13	N/A	0.001637965	0.008098596	N/A	N/A	0.000549
Extractor 3-1	1.5578E-06	7.6752E-14	0.000123627	6.4539E-10	1.79989E-06	0.000482852	0.000608468	6.26E-19	7.33E-05	3.57E-42
Extractor 3-2	0.022394208	N/A	N/A	3.01565E-24	N/A	0.011357882	0.000128259	N/A	N/A	0.00034
Extractor 3-3	4.36922E-18	4.75126E-33	7.47173E-59	3.31535E-05	1.13082E-28	1.7129E-12	1.5783E-16	3E-51	4.47E-11	3.09E-32
Extractor 3-4	N/A	3.92686E-06	6.66435E-12	2.3813E-06	9.64282E-07	N/A	N/A	3.17E-10	N/A	2.36E-09
Extractor 3-5	8.29179E-09	1.28655E-15	3.22707E-09	N/A	1.75282E-08	1.44171E-07	2.4162E-09	2.5E-30	6.54E-09	2.78E-62
Extractor 3-6	1.82324E-16	3.37599E-12	1.71469E-05	7.52267E-51	1.00301E-06	4.89374E-12	1.21058E-16	2E-12	4.68E-05	N/A
Extractor 3-7	3.24793E-27	1.94784E-46	2.11644E-33	4.11471E-11	9.04758E-38	2.68549E-22	3.04927E-35	3.31E-54	5.61E-19	1.48E-39
Extractor 3-8	6.66384E-23	8.27494E-24	6.957E-12	0.000421878	1.3058E-22	1.24486E-22	1.75274E-25	6.91E-22	2.37E-23	6.55E-26
Extractor 3-9	3.97884E-10	1.38835E-21	4.91742E-07	2.84747E-07	1.11862E-31	2.1661E-05	1.58478E-05	4.92E-15	3.94E-05	5.93E-18
Extractor 3-10	6.89237E-12	1.09984E-23	2.87499E-67	0.005270036	2.80522E-18	5.57638E-09	1.85237E-12	1.95E-41	1.11E-08	4.95E-27

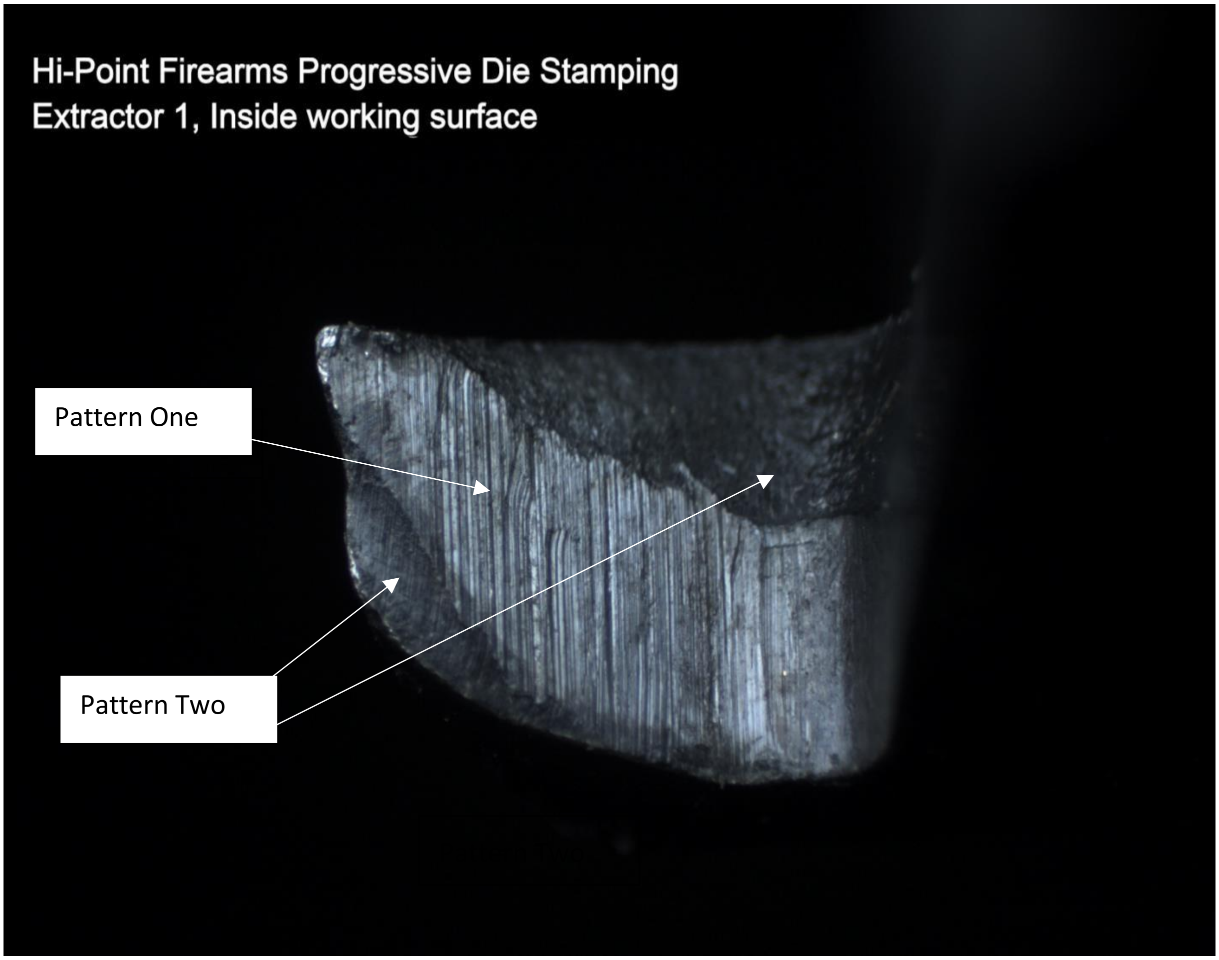
The table above displays all the “p-values” that are less than or equal to the alpha value of 0.05. As mentioned before, having “p-values” less than the alpha value of 0.05 states that there is a significant difference between the markings being compared. By comparing the “p-values” that are less than or equal to 0.05, this would suggest that mass produced parts by modern manufacturing processes can be differentiated by firearm examiners after comparing fired evidence.

Upon further investigation of Progressive Die Stamped extractors, there was evidence that the extractors went through a finishing process after manufacture. Confirmation of this finishing process was provided when two pattern types were observed on the inside working surfaces of the Progressive Die Stamped extractors. The first pattern; referred to as “Pattern One” was identified as the result of the extractor being cut from the remaining metal strip. The second pattern; referred to as “Pattern Two” was a representation of the extractors’ final finishing process and it was concluded that the pattern type produced was a result of the use of sandpaper- to ensure a smooth part. Both patterns were observed in all five Progressive Die Stamped extractors and can be observed in Image 45 below.

It should be noted that a surface finish of 0.8 micromoles is usually achievable on Progressive Die Stamped parts. A surface finish of 0.3 to 0.5 micromoles is also possible as well. A surface finish is helpful as it usually allows the produced part to maintain a smooth surface and plays a role in the size and chemistry of powders used. Surface finish is often used in the manufacture of various components as having a rough surface can, however, negatively affect a surface finish based on the tooling used (Heaney).

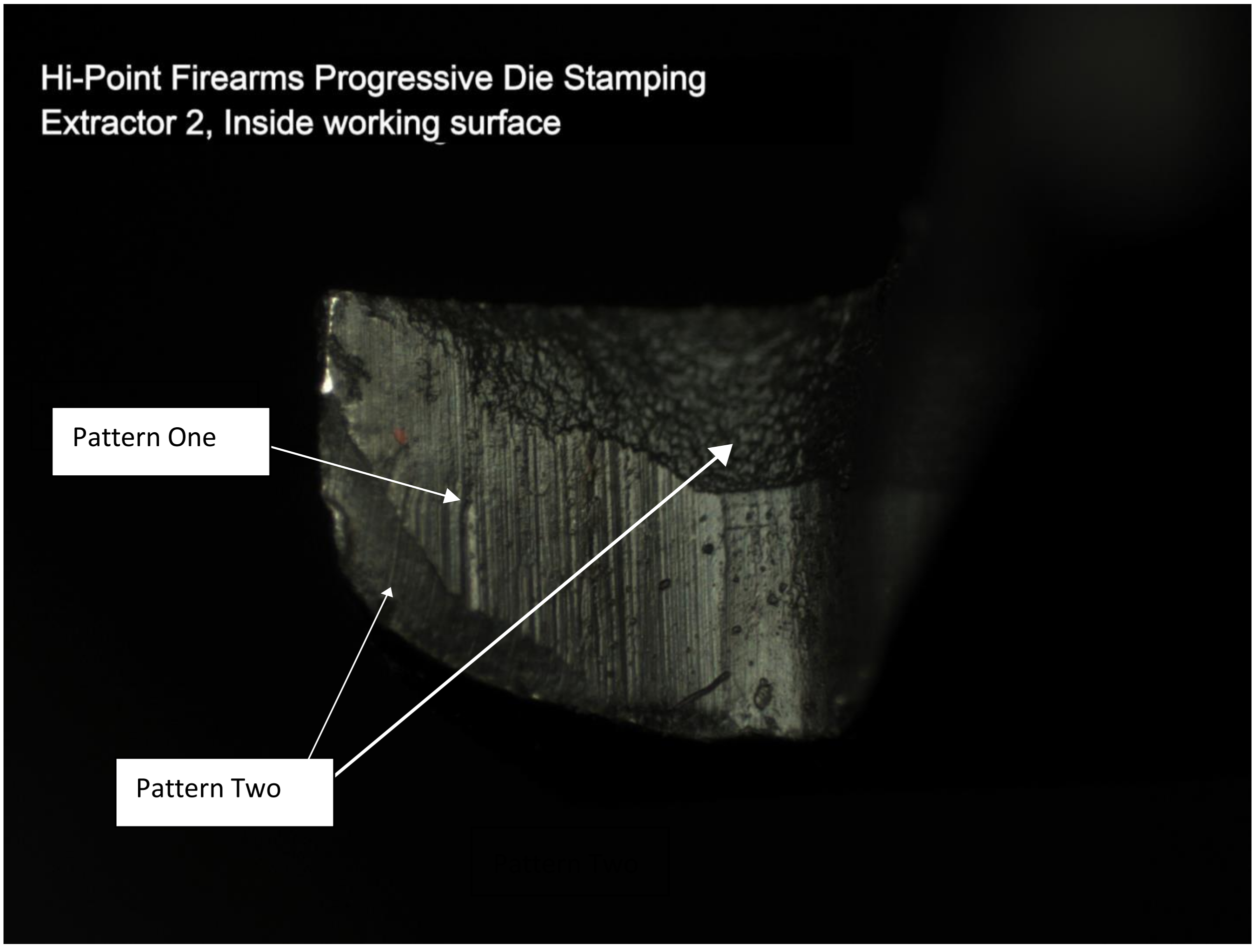
Figure 45: Visual documentations of the two visible patterns seen on the Progressive Die Stamped extractors

Figure 45A; two patterns on Extractor 1



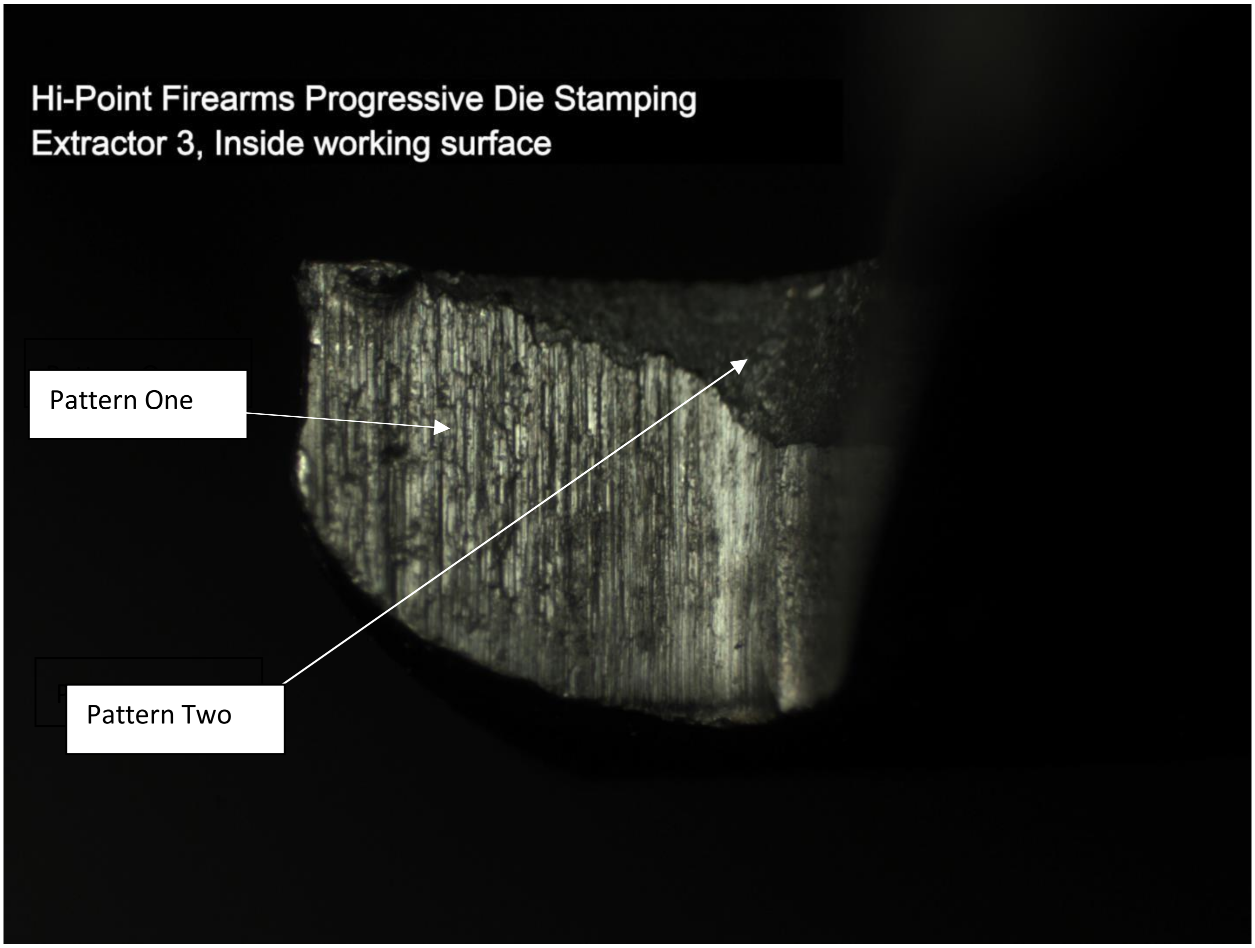
45A

Figure 45B; two patterns on Extractor 2



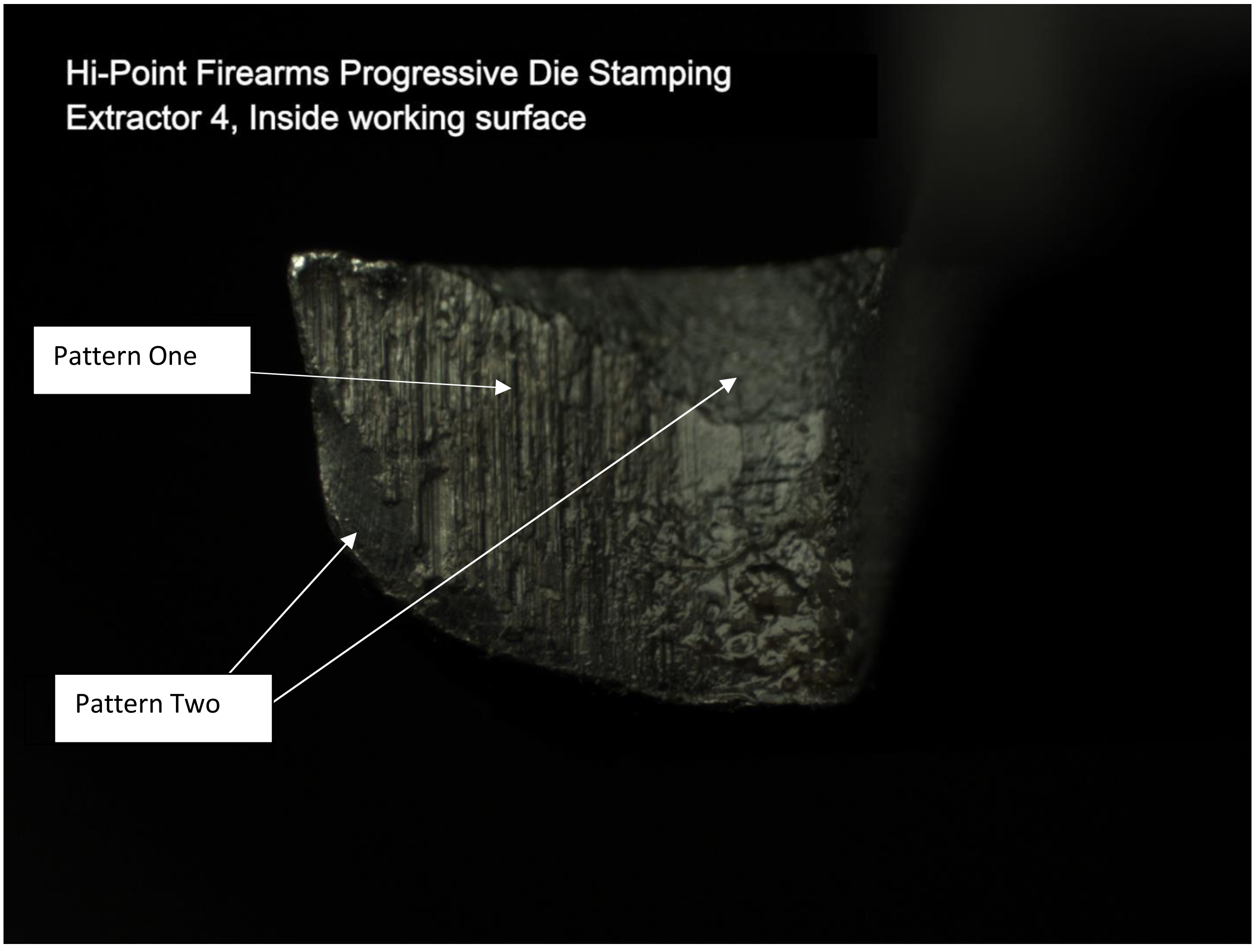
45B

Figure 45C; two patterns on Extractor 3



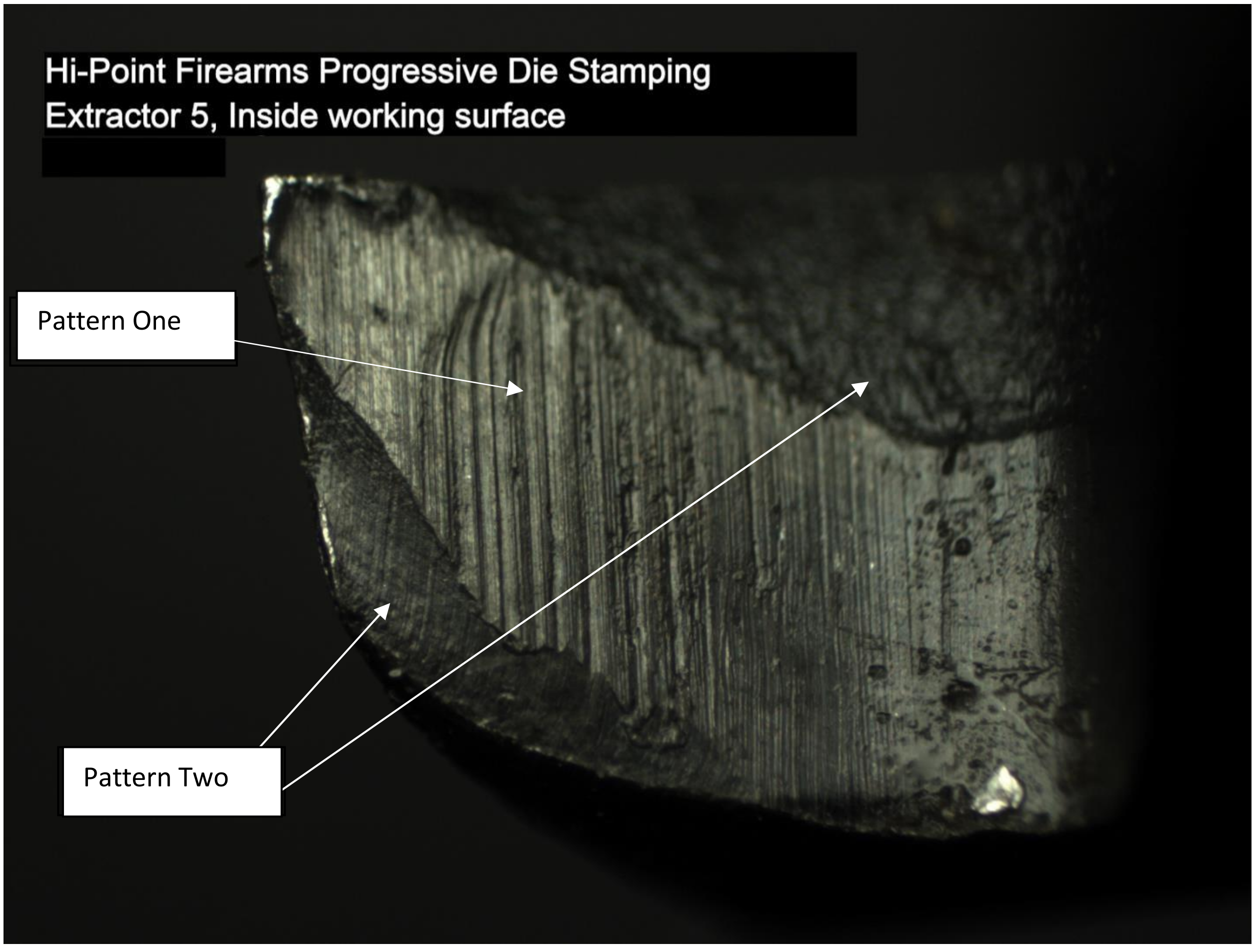
45C

Figure 45D; two patterns on Extractor 4



45D

Figure 45E; two patterns on Extractor 5



45E

When referring to the Progressive Die Stamped markings themselves, it was believed that the extraction process occurred with a lot of force. This was because these extractor markings on the cartridge were very profound. The overall pattern seen after analyzing the extractor markings from the within comparison revealed significant agreement by these five extractors. When conducting the inner comparisons of the extractor markings, similarities existed amongst the markings, but the overall pattern needed for identification was amiss. The markings from different Progressive Die Stamped extractors could be differentiated.

An example of the first table for the Progressive Die Stamped extractor within comparison with "p-values" greater than and less than an alpha value of 0.05 can be found below in Table VIII.

Table VIII:

	Extractor 5-1	Extractor 5-2	Extractor 5-3	Extractor 5-4	Extractor 5-5	Extractor 5-6	Extractor 5-7	Extractor 5-8	Extractor 5-9	Extractor 5-10
Extractor 1-1	4.83154E-21	3.44535E-18	0.026632494	6.15248E-16	4.2306E-32	1.34826E-17	1.29117E-09	7.89706E-51	1.61964E-13	1.29605E-45
Extractor 1-2	6.56515E-09	1.38907E-07	0.46341235	7.31628E-06	1.9251E-15	5.84778E-26	0.004472754	3.21338E-22	0.02559007	2.34228E-18
Extractor 1-3	1.30904E-23	6.58861E-21	0.008593783	3.50908E-18	1.55228E-31	9.68947E-18	7.65592E-11	7.78312E-49	1.66531E-13	5.91768E-37
Extractor 1-4	3.32085E-68	4.518E-40	0.003464283	2.29872E-26	9.94556E-19	7.13715E-11	3.66403E-21	5.77139E-27	0.131169041	4.46989E-09
Extractor 1-5	6.66155E-15	3.72582E-13	2.32779E-09	1.0714E-06	7.31278E-06	1.54208E-17	0.007452066	5.86396E-10	0.005021144	0.07687385
Extractor 1-6	6.66155E-15	3.72582E-13	2.32779E-09	1.0714E-06	7.31278E-06	1.54208E-17	0.007452066	5.86396E-10	0.005021144	0.07687385
Extractor 1-7	1.39459E-21	1.11516E-17	0.027947938	1.72118E-14	1.15851E-22	2.86316E-36	8.81062E-05	1.90959E-38	0.000596568	1.8395E-09
Extractor 1-8	0.009434995	2.01317E-09	3.33425E-37	4.81252E-11	0.20585534	3.47494E-36	6.66403E-14	0.920965017	5.54148E-16	0.000126426
Extractor 1-9	0.000240437	0.010160484	0.005312227	0.088105336	4.59087E-14	7.78734E-31	0.4788598	3.11978E-10	1.20344E-05	0.021059636
Extractor 1-10	1.51163E-15	6.40585E-11	0.005158084	4.68067E-07	5.79924E-23	6.38146E-40	0.004157812	8.96735E-28	0.000241564	7.9781E-07
Extractor 2-1	9.96404E-23	1.46562E-22	0.00334719	1.38786E-21	5.01844E-22	5.69982E-11	1.76374E-13	1.76659E-26	0.009305648	2.31472E-12
Extractor 2-2	3.44908E-05	2.66775E-09	1.23543E-17	3.49101E-12	3.33707E-06	3.69216E-55	3.50872E-10	0.000266125	1.32193E-51	1.38007E-22
Extractor 2-3	6.88108E-05	0.000972402	0.340213018	0.008313306	2.14319E-09	2.24287E-18	0.091488694	1.53235E-11	0.034214989	2.29768E-07
Extractor 2-4	4.24553E-09	4.05704E-13	9.58466E-23	1.16472E-16	2.08388E-19	1.59959E-78	8.7857E-14	2.18325E-14	9.93642E-61	1.80889E-46
Extractor 2-5	5.38575E-12	4.92111E-14	0.115690839	3.68308E-12	2.91548E-09	1.4495E-14	2.06226E-05	1.50972E-13	0.234257459	0.000274434
Extractor 2-6	0.506199633	0.268759439	5.08358E-12	0.006170863	0.310812622	1.68573E-41	0.002246316	0.007455336	9.73709E-21	0.005364028

Extractor 2-7	0.003463716	0.032299543	0.050560793	0.132295182	1.01872E-06	2.39908E-20	0.486118136	3.4452E-07	0.000407099	0.023315281
Extractor 2-8	0.395850344	0.001022322	2.26342E-15	1.63576E-06	0.57428569	6.16671E-56	6.66869E-06	0.124983996	1.42815E-39	1.11096E-09
Extractor 2-9	3.34986E-08	4.34242E-12	7.61861E-20	1.73075E-14	7.17762E-15	7.93067E-67	1.35655E-12	1.79277E-10	6.93507E-57	7.16749E-39
Extractor 2-10	2.60491E-25	1.39873E-20	0.303032686	3.60168E-16	8.0395E-14	1.34996E-12	6.06327E-14	8.93466E-17	0.844574442	4.32211E-05
Extractor 3-1	0.237771067	0.346025712	2.61361E-17	0.001569516	0.077516309	4.34854E-39	0.000160064	0.000424742	1.44491E-16	0.018011689
Extractor 3-2	0.004218892	4.01871E-08	7.05795E-19	1.26906E-12	0.005965002	2.40401E-55	8.21128E-10	0.152721491	2.68164E-44	2.86224E-15
Extractor 3-3	0.082830429	0.410064591	0.001323687	0.996305027	0.007229414	2.36576E-28	0.528434117	4.67892E-05	4.52126E-14	0.764156732
Extractor 3-4	0.050218007	0.410880634	6.99222E-05	0.863764889	0.000452904	1.43773E-40	0.369717696	6.40778E-07	3.51087E-21	0.379226655
Extractor 3-5	0.516779795	0.020215893	5.42555E-20	8.11104E-05	0.675868306	2.91755E-31	3.65955E-06	0.352258893	1.45561E-12	0.003774145
Extractor 3-6	3.1296E-20	6.06321E-19	0.000589975	3.44748E-19	5.72699E-16	2.10854E-06	1.08223E-15	1.52688E-17	0.094797751	2.19815E-07
Extractor 3-7	0.881517419	0.012700986	1.40951E-17	5.15603E-05	0.502736127	4.38265E-52	1.36076E-05	0.000132745	3.16226E-24	1.28347E-05
Extractor 3-8	7.47928E-22	8.53255E-27	0.597060467	1.75106E-24	4.98854E-16	8.04415E-15	5.02969E-11	7.71784E-26	0.490369975	1.21605E-09
Extractor 3-9	3.55987E-21	3.21587E-19	0.008125873	9.53727E-16	1.60533E-35	5.10586E-25	7.65857E-10	1.48824E-38	3.55042E-10	2.33957E-33
Extractor 3-10	0.335610575	2.66775E-09	1.23543E-17	3.49101E-12	3.33707E-06	3.69216E-55	3.50872E-10	0.000266125	1.32193E-51	1.38007E-22
Extractor 4-1	1.1017E-07	0.007104435	1.49533E-11	0.466839154	0.002687283	3.6185E-22	0.305589166	4.40512E-07	4.05123E-06	0.875184605
Extractor 4-2	1.87212E-22	1.52224E-14	0.053218329	2.89759E-10	1.0207E-15	3.42892E-16	3.4025E-07	1.39004E-16	0.439238462	0.000126708
Extractor 4-3	8.02228E-10	1.52224E-14	0.053218329	2.89759E-10	1.0207E-15	3.42892E-16	3.4025E-07	1.39004E-16	0.439238462	0.000126708

Extractor 4-4	5.58967E-07	6.67271E-05	0.274015664	0.001622985	8.20562E-16	1.03342E-30	0.04407163	9.79059E-18	0.009691456	5.26613E-12
Extractor 4-5	0.20542766	0.025273839	1.24434E-07	0.002795006	0.086109349	9.34557E-38	0.001675298	0.697139105	7.1499E-25	5.28057E-11
Extractor 4-6	0.081406004	0.654400259	8.45863E-07	0.537819156	0.000185373	6.89181E-41	0.185194903	2.45306E-05	1.78217E-13	0.246880312
Extractor 4-7	0.123549549	0.598944216	0.000183413	0.779716274	0.002650434	5.40055E-30	0.373778874	0.000424296	9.82539E-10	0.496955613
Extractor 4-8	0.091815163	0.505081796	1.77313E-33	0.041826531	0.240523138	3.32535E-25	0.000199495	0.018528984	2.19995E-07	0.183345948
Extractor 4-9	2.18699E-20	6.05059E-17	0.001700561	1.83553E-15	1.51792E-35	1.08924E-08	7.74472E-11	2.23765E-27	0.000376673	8.83192E-15
Extractor 4-10	1.88599E-05	0.127559953	3.04842E-18	0.862674453	0.002015415	3.79651E-28	0.107563085	8.0565E-06	8.50355E-07	0.769447311
Extractor 5-1	N/A	0.000570855	5.99614E-27	5.87758E-06	0.754444305	3.65147E-36	1.22067E-08	0.024866149	1.6817E-14	0.004538083
Extractor 5-2	0.000570855	N/A	5.9083E-22	0.007424594	0.049029106	7.10733E-34	0.000202724	7.0584E-05	2.97555E-12	0.162292945
Extractor 5-3	5.99614E-27	5.9083E-22	N/A	2.59252E-14	7.65173E-13	5.27731E-12	1.66709E-13	4.63365E-16	0.918528904	3.88686E-05
Extractor 5-4	5.87758E-06	0.007424594	2.59252E-14	N/A	0.001365957	1.20489E-29	0.077888459	4.06106E-08	5.58616E-10	0.825415246
Extractor 5-5	0.754444305	0.049029106	7.65173E-13	0.001365957	N/A	1.06847E-51	0.000311283	0.025587723	1.19694E-24	9.42496E-07
Extractor 5-6	3.65147E-36	7.10733E-34	5.27731E-12	1.20489E-29	1.06847E-51	N/A	3.60416E-21	3.81013E-56	7.46419E-34	1.46748E-48
Extractor 5-7	1.22067E-08	0.000202724	1.66709E-13	0.077888459	0.000311283	3.60416E-21	N/A	1.34139E-07	8.05049E-05	0.491632082
Extractor 5-8	0.024866149	7.0584E-05	4.63365E-16	4.06106E-08	0.025587723	3.81013E-56	1.34139E-07	N/A	7.35738E-39	9.96295E-15
Extractor 5-9	1.6817E-14	2.97555E-12	0.918528904	5.58616E-10	1.19694E-24	7.46419E-34	8.05049E-05	7.35738E-39	N/A	6.9056E-35
Extractor 5-10	0.004538083	0.162292945	3.88686E-05	0.825415246	9.42496E-07	1.46748E-48	0.491632082	9.96295E-15	6.9056E-35	N/A

The table displayed on the previous page shows the “p-values” obtained that are less than and greater than the alpha value of 0.05. By obtaining such a wide range of “p-values,” this would suggest that the extractor markings may or may not be statistically different from each other after being compared by firearm examiners.

An example of the second table for the Progressive Die Stamped extractor within comparison with “p-values” less than and equal to an alpha value of 0.05 can be found below in Table IX.

Table IX:

	Extractor 5-1	Extractor 5-2	Extractor 5-3	Extractor 5-4	Extractor 5-5	Extractor 5-6	Extractor 5-7	Extractor 5-8	Extractor 5-9	Extractor 5-10
Extractor 1-1	4.83154E-21	3.44535E-18	0.026632494	6.15248E-16	4.2306E-32	1.34826E-17	1.29117E-09	7.89706E-51	1.61964E-13	1.29605E-45
Extractor 1-2	6.56515E-09	1.38907E-07	N/A	7.31628E-06	1.9251E-15	5.84778E-26	0.004472754	3.21338E-22	0.02559007	2.34228E-18
Extractor 1-3	1.30904E-23	6.58861E-21	0.008593783	3.50908E-18	1.55228E-31	9.68947E-18	7.65592E-11	7.78312E-49	1.66531E-13	5.91768E-37
Extractor 1-4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractor 1-5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.008915155	N/A
Extractor 1-6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.008915155	N/A
Extractor 1-7	0.013631027	N/A	0.020233695	0.036693063	0.052919355	N/A	0.029058291	N/A	0.037363049	N/A
Extractor 1-8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.029294478	N/A
Extractor 1-9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.041670812	N/A
Extractor 1-10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.024115116	N/A
Extractor 2-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.023585432	N/A
Extractor 2-2	N/A	N/A	0.050617643	N/A	N/A	N/A	N/A	N/A	0.036685546	N/A
Extractor 2-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.039356069	N/A
Extractor 2-4	N/A	N/A	0.045464189	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractor 2-5	0.000855619	N/A	0.003702418	0.003308203	0.00334236	0.026807176	0.005636879	0.011810879	N/A	0.004079161
Extractor 2-6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.004901884	N/A

Extractor 2-7	0.000788973	N/A	0.003488539	0.003160372	0.003031792	0.024785978	0.005318822	0.011139651	N/A	0.003629056
Extractor 2-8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.010319222	N/A
Extractor 2-9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.002630632	N/A
Extractor 2-10	N/A	N/A	0.045938165	N/A	N/A	N/A	N/A	N/A	0.005911645	N/A
Extractor 3-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.020330353	N/A
Extractor 3-2	0.000768517	N/A	0.003432895	0.003088551	0.002949455	0.024269143	0.005236344	0.010897697	N/A	0.003516661
Extractor 3-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.008678298	N/A
Extractor 3-4	0.004583432	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.01118896	N/A
Extractor 3-5	0.022482241	N/A	0.03063116	0.042145806	N/A	N/A	0.043128348	N/A	N/A	N/A
Extractor 3-6	N/A	0.013314293	N/A	N/A	0.047287143	N/A	N/A	N/A	0.000733372	0.012551824
Extractor 3-7	N/A	0.024399806	N/A	N/A	N/A	N/A	N/A	N/A	0.001278349	0.037962097
Extractor 3-8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00526742	N/A
Extractor 3-9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractor 3-10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.036685546	N/A
Extractor 4-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.023842968	N/A
Extractor 4-2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractor 4-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Extractor 4-4	N/A	0.053790947	N/A	N/A	N/A	N/A	N/A	N/A	0.002564481	0.018797545
Extractor 4-5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.011192453	N/A
Extractor 4-6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.014293634	N/A
Extractor 4-7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.008801133	N/A
Extractor 4-8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.010163256	N/A
Extractor 4-9	N/A	0.032380392	N/A	N/A	N/A	N/A	N/A	N/A	0.000601049	N/A
Extractor 4-10	N/A	0.010296535	N/A	N/A	0.018711443	N/A	N/A	N/A	0.000339643	0.011264561
Extractor 5-1	N/A	0.040244326	N/A	N/A	N/A	N/A	N/A	N/A	0.000766241	N/A
Extractor 5-2	0.040244326	N/A	0.040102586	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Extractor 5-3	N/A	0.040102586	N/A	N/A	N/A	N/A	N/A	N/A	0.003426664	0.027013097
Extractor 5-4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.003080555	N/A
Extractor 5-5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00294032	N/A
Extractor 5-6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.024211486	N/A
Extractor 5-7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.005227104	0.042445131
Extractor 5-8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.010870729	N/A
Extractor 5-9	0.000766241	N/A	0.003426664	0.003080555	0.00294032	0.024211486	0.005227104	0.010870729	N/A	0.003504229
Extractor 5-10	N/A	N/A	0.027013097	N/A	N/A	N/A	0.042445131	N/A	0.003504229	N/A

The table on the previous page shows the comparison table of all the “p-values” that are less than or equal to the alpha value of 0.05. By comparing the “p-values” that are less than or equal to 0.05, this would suggest that mass produced parts by modern manufacturing processes can be differentiated by firearm examiners.

Researching the effect of characteristics marks on extractors from two manufacturing techniques; Metal Injection Molding (MIM) and Progressive Die Stamping, brought about an interesting result. After comparing Metal Injection Molded extractors and their markings produced after discharging a Remington shotgun also revealed similarities among the extractor markings within each group of shotshells fired from the same set of extractors. More similarities than differences among extractor markings produced from different extractors; inner comparisons, among this manufacturing processes was also detected. Although there were more similarities amongst the markings produced by different extractors when conducting an inner comparison, these markings can statistically and microscopically be differentiated. It has, thus, been proven that these Metal Injection Molded markings can be differentiated one from another.

The findings after comparing the Progressive Die Stamped extractors and the markings produced after discharging a Hi-Point Firearm, similarities among the extractor markings were identified within each group of cartridges tested from the same set of extractors. When comparing extractor markings from differing groups, there were, in contrast, more differences among the markings than similarities.

I concluded that the manufacturing processes conducted on the Progressive Die Stamped extractors displayed more individual characteristic markings for microscopic identification when compared to Metal Injection Molded extractors. This can be attributable to the two patterns displayed on the inside working surfaces of the Progressive Die Stamped extractors and the more profound extractor markings seen on the cartridge cases when compared to those seen on the shotshells.

When referring to the results obtained at the conclusion of the statistical analysis conducted; differences between the two manufacturing processes; Progressive Die Stamping and Metal Injection Molding, was found. It can be concluded that mass produced parts by modern manufacturing methods can be differentiated by firearm examiners after comparing fired evidence. This conclusion was generated after analyzing the results obtained from the microscopic comparisons as well as the results obtained from the statistical analysis.

Forensically, firearm and toolmark examiners should be able to microscopically identify and differentiate these markings produced on fired evidence should the extractors be manufactured by either the Progressive Die Stamped or Metal Injection Molded manufacturing process.

FUTURE STUDIES

Additional research can be done to compare the markings produced by extractors in a firearm produced by other manufacturing processes such as Machining and Joining to determine whether similarities and or differences exist between markings.

Markings produced by different parts within a firearm can also be compared.

APPENDIX

The following are copies of consent forms obtained for the copyright of images used throughout this research paper.

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Forensic Sciences Program (MC 865)
Biopharmaceutical Sciences
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Dmitri Kopeliovich

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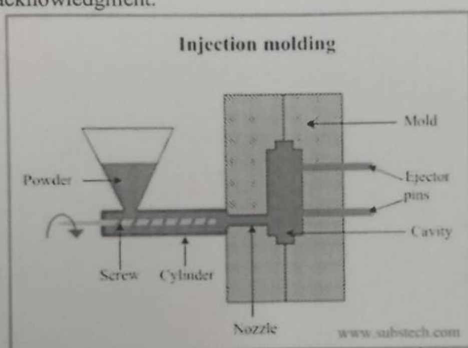

A copy of this letter is included for your records. Thank you for your kind consideration of this request.

Sincerely,

Deanna-Kaye Daley
516 S Coolidge Street,
Chicago Heights, IL 60411

The above request is approved.

Approved by: Dmitri Kopeliovich　　Date: 25th July 2019

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July 25, 2019

Hans Bergmark

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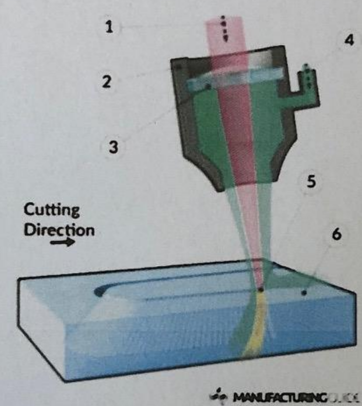

A copy of this letter is included for your records. Thank you for your kind consideration.

Sincerely,

Only to be used in your thesis. Not for commercial use.

Deanna-Kaye Daley
516 S Coolidge Street,
Chicago Heights, IL 60411

The above request is approved.

Approved by: ______________________ Date: 5Aug 2019

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Forensic Sciences Program (MC 865)
Biopharmaceutical Sciences
College of Pharmacy
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August 16, 2019
Leeds Precision Instruments Incorporated

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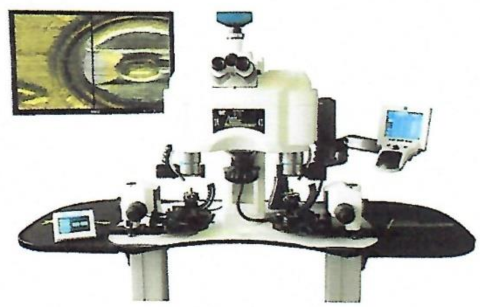

A copy of this letter is included for your records. Thank you for your kind consideration.

Sincerely,

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The above request is approved.

Approved by: Margaret Bender Date: 8/21/19

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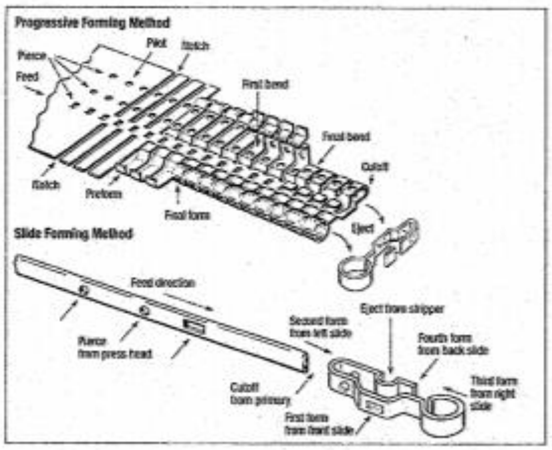
August 16, 2019

Peter Ulintz

I am writing to request permission to use the following material from your website "Metal Forming Magazine" in my thesis on firearm and toolmark analysis and manufacturing processes. This material will appear as originally published. Unless you request otherwise, I will use the conventional style of the Graduate College of the University of Illinois at Chicago as acknowledgment.



A copy of this letter is included for your records. Thank you for your kind consideration.

Sincerely,

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The above request is approved.

Approved by: Peter J Ulintz Date: 08/20/2019

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Forensic Analysis of Trash Bags Part One: Discrimination of Trash Bags Utilizing Photomicrography

American Chemical Society (ACS) National Conference
April 3rd, 2017

Forensic Analysis of Trash Bags Part One: Discrimination of Trash Bags Utilizing Photomicrography
Oral Presenter at the American Academy of Forensic Science National Conference
February 17th, 2017

Forensic Analysis of Trash Bags Part One: Discrimination of Trash Bags Utilizing Photomicrography
McNair Research Scholar Showcase
October 19th, 2016

Forensic Analysis of Trash Bags Part One: Discrimination of Trash Bags Utilizing Photomicrography
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Detection of Small Molecules with Signaling Capabilities
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ABSTRACTS:

Point-of-care systems require highly sensitive, quantitative and selective detection platforms for the real-time multiplexed monitoring of target analytes. To ensure facile development of a sensor, it is preferable for the detection assay to have minimal chemical complexity, contain no wash steps and provide a wide and easily adaptable detection range for multiple targets. Current studies involve label-free detection strategy for relevant clinical molecules such as heme using G-quadruplex based self-assembly. We have explored the measurement of binding and kinetic parameters of various G-quadruplex/heme complexes which are able to self-associate to form a DNAzyme with peroxidase mimicking capabilities and are critical to nucleic acid research. The detection strategy includes immobilizing the G-quadruplex sequences within a polymer matrix to provide a self-assembly based detection approach for heme that could be translated towards other clinically relevant targets.

PUBLICATIONS:

Hughes, Natalie, Nguyen, Nancy, **Daley, Deanna-Kaye**, Grennell, Justin, Gee, Amira, Ali, Mehnaaz F; Comparison of DNAzyme activity for the development of an immobilized Heme sensor; MRS ADVANCES; 2017.