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Deterioration of Various Cartridge Case Compositions in Selective Environments

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Abstract

Firearm and toolmark analysis has, as its primary function, to determine if a particular ammunition component was fired in, by, or from a particular firearm. Examiners in this discipline can be presented with components that have deteriorated over a period of time. This research sought to determine the likelihood of identification over time, the possibility of establishing a timeline based on different variables, and effectiveness of three restorative techniques, to aid examiners when dealing with corroded cartridge cases. This study includes several variables not tested in previous studies to add to the existing literature. Results indicate that the likelihood of identification is affected by time, firearm used, and cartridge case composition. Scanning electron microscope (SEM) data analysis suggests that a timeline may be possible, but a more extensive study is needed. In addition, the effectiveness of the three restorative techniques appear to be dependent on cartridge case composition, but statistical analysis indicates that Aqua Regia was the most effective reagent for steel cartridge cases.

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Introduction

Examiners in the discipline of firearm and toolmark analysis, or firearms identification, can encounter many different challenging situations in the course of their career. For example, ammunition components may be submitted in less than stellar conditions – corroded, caked with dirt and plant matter, or covered in blood and tissue – and the examiner must find a way to best clean and analyze the item. At this point in time, there is no standard practice concerning the most effective method of cleaning for such items, which indicates a lack of research into this area. This study was conducted to explore three possible cleaning methods to determine if any could be recommended for use in casework.

In order to understand the problem that examiners face when submitted corroded or debris-encrusted items, one must first have knowledge of the process that used to analyze ammunition components. Examiners in the area of firearm and tool mark analysis are trained to examine characteristics on evidence to determine the source of the evidence (i.e. the firearm from which the bullet or cartridge case was fired). These characteristics are divided into two categories: class characteristics and individual characteristics. Class characteristics are measurements and features of the bullet and cartridge case that are predetermined by the manufacturer (AFTE Glossary, 5th Ed.). These features are objective and relatively easy to determine – the evidence is weighed, the diameter and length are measured, and these measurements establish the caliber and brand of ammunition that may have been used. Individual characteristics are defined as random, accidental markings left by the manufacturing process or caused by use, damage, or corrosion that are unique to the firearm (AFTE Glossary, 5th Ed.). With fired ammunition, markings are imparted by the firearm's barrel, breach face, ejector, and extractor during the firing process. These markings, or striations, are known as individual characteristics, and are unique to the firearm, thus allowing examiners to identify the firearm that was used to fire the ammunition by comparing test-fired samples to evidence collected at the crime scene (i.e. known vs. questioned or known vs. unknown). Once imparted on the ammunition components, individual characteristics are permanent when the components are handled and stored properly. If left exposed to the elements, however, these characteristics can be marred by corrosion, or the components can be encased in plant matter, dirt, or tissue, which reduces the ability of the examiner to properly analyze the evidence (Larrison, 2006; Love, 1980; Gamboe, 1990; Chow et al, 2003). Although individual characteristics may be exposed after superficial cleaning, this method may not remove all of the foreign material from the surface if the evidence has been exposed for a long period of time. Examiners must then use chemical solutions and ultrasonic cavitation to remove the remaining material from the evidence. There is little research concerning the degradation of various ammunition components, and the few studies that are available do not take the composition of the components into account (Larrison, 2006; Booker, 1980; Smith et al, 1993). One study by Kerkhoff and colleagues (2014) did examine the differences of composition in relation to corrosion, but only exposed their small sample group to air – the samples were placed on glass plates on a rooftop, which only exposed them to the atmosphere. This is an unrealistic scenario that does not take into account the fact that cartridge cases will be exposed to soil and plant matter at the same time as the atmosphere.

The researcher sought to provide valuable data in relation to deterioration, as a diminishing factor, in the analysis of fired ammunition components within the field of firearm and tool mark analysis. The purpose of this study is threefold: 1) determine the likelihood of identification over time based on various factors present in the environments, 2) explore the possibility of establishing a timeline of deterioration for various cartridge case compositions in the selected environments based on the percentage of elements present, and 3) determine which of three selected restorative techniques are effective in restoring characteristics necessary to draw conclusions.

Statement of Problem

Limited research has focused on the deterioration of bullets and cartridge cases, and those that are available do not focus on the examiner's ability to identify the firearm that was used, but rather the changes in appearance of the samples (Kerkhoff et al, 2014; Bridgemon, 1986). The following studies documented the changes in color and development of corrosion on the samples, but did not examine the individual characteristics for any changes that occurred during the time of exposure. One study conducted by Shanahan (1977) delved into the issue by placing cartridge cases in soil to simulate the conditions from casework, and found that after 18 weeks of exposure, an examiner was still able to identify the samples to a control cartridge case fired from the same firearm.

The first question of this research investigated the hypothesis that, over time, a qualified examiner would be less likely to identify a cartridge case to a particular firearm, due to the factors that can potentially hinder the examination of individual characteristics of cartridge cases recovered from various environments. The examiner must have a clear view of the individual characteristics on the surface of the bullet or cartridge case in question in order to draw a conclusion about that bullet or cartridge case. If these characteristics are hidden or marred by deterioration of the metal's surface or debris from the environment, the examiner may not be able to come to a conclusion, which could cause that particular case to go "cold". This study sought to determine if it is possible to conduct an analysis on the samples prior to application of a restorative technique, and how likely an examiner would be able to draw a conclusion about the sample.

The second purpose concerns the analysis phase of an investigation. While it is possible to calculate the rate of corrosion for different metals in water, the formulas assume that corrosion is uniform and that the metals only come into contact with water (Callister, 2002). One environment does require that the samples be submerged in water, to which the corrosion rates would apply. However, samples will be subjected to little water in the other five environments when compared to the submerged samples, which renders the corrosion rates moot. The samples encountered dirt, wind, plant matter, animal tissue and fluids, in addition to water in the form of rain, ice, or snow. Established formulas do not take into account these environmental factors, and so no degradation timeline currently exists for these five environments. Through the use of a scanning electron microscope (SEM), the researcher sought to establish a timeline based on elements that were present on the cartridge cases and the amount in which they were present. By establishing a timeline for the selected environments, examiners in the field of firearm and tool mark analysis, as well as investigators, will be able to determine how long a piece of evidence may have been exposed in addition to identifying in which environment it was left.

The final purpose of the study sought to determine which, if any, of the three selected restorative techniques are effective in removing the deterioration or corrosion from the samples. If no conclusion can be rendered, the examiner may need to know which technique or solution is suitable to apply to the evidence, based on the composition of the cartridge case and the type of environment from which it was recovered. By removing the corrosion from the metal's surface, individual characteristics may be uncovered which would allow an examiner to analyze the evidence and draw a conclusion. These techniques have been shown to be effective in the literature, but only one of the articles names a specific composition of the bullet and cartridge case (Larrison, 2006; Randich et al, 2000; Booker, 1980). This research tested all three techniques on three cartridge case compositions to determine if their effectiveness is limited to one composition, or whether they can be utilized on samples of different compositions. If all three restorative techniques are shown to be effective in removing corrosion from multiple compositions, examiners will have more tools at their disposal in which to analyze deteriorated evidence as well as cold case investigations.

Background and Need

Battlefield archaeology has long encountered deteriorated ammunition components and firearm parts. Forensic examination of these ammunition components did not become prominent in battlefield archaeology until Douglas Scott utilized the techniques in his investigation of the Little Bighorn battlefield (Scott and McFeaters, 2011). It can be difficult to examine and analyze the components because they have often been left outside for decades or longer. However, after the components are cleaned, investigators are often able to distinguish between components that were fired in different firearms. Weber and Scott were able to examine 150- year-old percussion caps (components of the percussion firing system), identify a group of percussion caps that were used in one specific firearm, and map the movements of the firearm throughout the battlefield (2006). Through experimentation, the authors were able to show that percussion caps do acquire individual characteristics during the firing process, and those characteristics are persistent, meaning they are found in sequential firings of the firearm (2006). During an investigation in El Salvador, Douglas Scott and his team were only able to examine 34 out of the 245 cartridge cases found at the scene of a mass murder (2001). All of the cartridge cases were cleaned, but only a limited number still had discernible individual characteristics on the surface. The remaining cartridge cases were so corroded that the investigators were unable to view individual characteristics. As a result, it was not possible to determine if the cartridge cases matched any others already examined, or whether they belonged in a single group of their own. While archaeologists are able to examine the components without using a restorative technique, they are often hindered by the severity of corrosion. The proposed study will greatly benefit the discipline of battlefield archaeology if it is able to determine the effectiveness of restorative techniques in revealing or restoring individual characteristics on ammunition components. Utilizing these techniques would give archaeologists a greater chance of identifying the firearms used during a battle and tracking the movements of the participants.

Examiners in the field of firearm and tool mark analysis will greatly benefit from this research. They are occasionally presented with cartridge cases and bullets that have been recovered from a decomposing body, trees, or soil (Larrison, 2006; Love, 1980; Welch, 1985; Gamboe, 1990; Randich et al, 2000; Chow et al, 2003; Smith et al, 1993). By establishing a timeline using data collected by the SEM, examiners may be able to determine how long a cartridge case has been exposed to the elements in certain environments. In past casework, examiners would not be able to determine a time frame for a cartridge case that was discovered with a decomposing body. With this study, they may be able to give an approximate amount of time that the cartridge case had been in contact with the body, which could refute or confirm the suspect's story and possibly disprove or support the medical examiner's time frame for decomposition of the body. In addition, the study will show if the selected restorative techniques are of any value – if the solutions are able to remove corrosion and cause no further damage to the individual characteristics on the cartridge case, it will greatly increase the ability of an examiner to analyze evidence and draw a conclusion. The most effective technique could be applied to the same cartridge case that was imbedded in a tree, buried in soil or exposed to a decomposing body, which could then be matched to a firearm if one was found.

Purpose of the Study

The purpose of this study is threefold: 1) determine the likelihood of identification over time based on various factors present in the environments, 2) explore the possibility of establishing a timeline of deterioration for various cartridge case compositions in the selected environments based on the percentage of elements present, and 3) determine which of three selected restorative techniques are effective in restoring characteristics necessary to draw conclusions. With this research, examiners may be able to determine how long a cartridge case has been exposed by the elements present and in what percentages those elements are present, which could also indicate the environment in which the cartridge case was located prior to collection. The study will also provide examiners with possible techniques to utilize when attempting to restore degraded ammunition components.

Previous studies have examined the degradation of bullets and largely ignored cartridge cases, so this research focused on examining cartridge cases of three different compositions. The fired cartridge cases were procured from the OSBI Forensic Science Center Firearms and Tool Mark Unit after a law enforcement officer and a faculty mentor prepared the specimen for use in this study. Two firearms were utilized to create unique characteristics that may be visible during the analysis phase of this research.. Once the cartridge cases were procured, they were placed in six different environments. A sample of 18 cartridge cases were collected from each environment for examination and chemical analysis every 31 days for twelve months. The collected samples were cleaned as needed using ultrasonic cavitation, then compared to control cartridge case samples to determine if any conclusions may be drawn in relation to the established research questions. If the deterioration of the cartridge case was so great that the observed characteristics diminished an examiner's ability to draw a conclusion, three restorative techniques were used to demonstrate their effectiveness in restoring these characteristics.

This study obtained data which indicates that more research into the elemental analysis of deteriorated cartridge cases is warranted to determine if a possible timeline can be developed. In addition, the research demonstrated the effectiveness of the three chosen restorative techniques in assisting examiners once it is established that deterioration hinders the analysis of a cartridge case. As expected, data gathered at the initial analysis of the samples showed that longer exposure time in the selected environments decreased the ability of the researcher and qualified examiner to identify a sample to one of the two firearms used in this study. However, the type of metal composition of the cartridge cases and the environment from which the samples were collected were shown to influence the likelihood of identification.

Research Questions

The first research question was to determine the likelihood of identification over time based on various factors present in the environments. During the course of one year, the researcher examined samples from six environments to see if any of the cartridge cases could be identified to one of the two firearms used in this study. It was hypothesized that, despite the various factors that may create corrosion on the samples, the researcher will be able to identify a majority of the samples to one of the two firearms. Data collected from the initial examination of the samples indicate that, while the likelihood of identification decreased over time, the majority of the samples were identified to one of the two firearms used in the study prior to the application of restorative techniques. In fact, all of the samples placed in one environment were identified to a particular firearm with no need for further cleaning. Additionally, the likelihood of reaching a conclusion of "identification" appeared to be affected by both type of metal composition and environment. For example, the researcher was 19.24 times more likely to identity brass cartridge cases left in a body of water than steel cartridge cases left in the same body of water for the same amount of time.

The second research question examined the possibility of creating a timeline based on the elements revealed through the use of the scanning electron microscope (SEM) and the percentage of those elements. It may be possible to establish a timeline through predictable amounts of certain elements over time in the selected environments. However, this timeline is contingent on the deterioration of the samples remaining consistent over time in each environment. It is possible that various factors could hinder or prevent the accumulation of elements in the form of rust. The results of the analysis conducted by the SEM indicate that more research is needed to fully answer this research question. While some elements did increase or decrease over time, the limited time frame prevented the researcher from determining if the change is consistent and useful to establish a timeline.

The third research question sought to determine if there are effective restorative techniques for various cartridge case compositions that have deteriorated due to exposure. To answer this question, the researcher chose three restorative techniques that have been used in previous studies with some success (Randich et al, 2000; Larrison, 2006; Booker, 1980). The techniques were shown to have success with a limited number of cartridge case compositions; therefore this study applied all three techniques to three different metal compositions. It was hypothesized that the chosen techniques would be effective in removing corrosion from the cartridge cases and would not damage the individual characteristics. After the application of all three techniques and the analysis of the samples following the application, the researcher found that the reagent Aqua Regia produced the best results when applied to steel cartridge cases from several different enviroments and aluminum cartridge cases left in a body of water, and the application of jewelry cleaner produced the worst results. Results for the third restorative technique were not significantly different from either Aqua Regia or jewelry cleaner. Therefore, when faced with a cartridge case that is corroded or covered in dirt, plant matter, or tissue, examiners can use a solution that is already on hand for serial number restoration.

Significance to the Field

Compared to preceding studies, the research included several previously overlooked variables which will supply the field of firearm and tool mark analysis with valuable information and new resources beneficial for training purposes.

Previous studies have examined cartridge cases and bullets alike, but sample sizes have never been large – the largest sample found by the researcher contained approximately 63 bullets. Research examining cartridge cases have equally small or smaller sample sizes. This particular study examined over 1,200 cartridge cases. By increasing the sample size, the researcher increased the ability to generalize the results, and increased the external validity of the study. In addition, only one study that looked at deterioration used several metal compositions in their sample. With more empirical data on the different rates of deterioration according to composition, examiners may be able to refute or support arguments in court when testifying to cartridge cases collected long after a crime has been committed.

Another improvement upon previous studies is the addition of multiple environments. Several studies used only one environment or gathered samples from an area they knew to contain ammunition components. One study chose four different environments, but used a dog carcass instead of a pig carcass (Larrison, 2006). The same study hung samples from monofilament, or fishing wire, and left them exposed only to air and precipitation, which is not an incredibly realistic scenario. This research collected data from six realistic environments where cartridge cases could be found, thereby yielding realistic results. Another advantage to placing the samples in the environments on purpose is the ability to monitor the conditions to which the samples are exposed. Temperatures, wind, precipitation, and other environmental factors were documented and recorded to determine in which ways these variables affected the samples.

Limitations of Study

This study has a few limitations that could be addressed with future research. One of the larger restrictions on generalization of the results is the setting – the study takes place in the state of Oklahoma. Due to the differences in soil and water pH levels, the researcher is not able to generalize the results garnered from the research to vast locations throughout the United States. The extreme temperatures and weather changes often experienced in Oklahoma also limit generalizability of the data. In order to counter this constraint, future studies could replicate the methodology in other geographic regions of the United States.

Another limitation is the sample group itself. In this study, the sample group consists of only cartridge cases of three different compositions. There are several different compositions for cartridge cases and all should be tested to provide a greater pool of knowledge. Exchanging bullets for cartridge cases as the experimental sample would also yield valuable data. The scenarios in this study could be used in a similar study with bullets as the sample, and it is possible that the bullets will react differently to the different environments. Bullets are also made of numerous materials, so future studies should take both the type of ammunition component and the possible compositions of that component into account.

Time is a restriction in all research. In this study, the data collection will take place over the course of one year. In reality, cartridge cases and bullets could be left exposed for several years, possibly decades. This time restraint limits the ability of an examiner to estimate the length of time that a cartridge case has been exposed. Future studies could expand the amount of time that samples are exposed to different environments to offset this limitation.

For battlefield archaeology, the establishment of a timeline for deterioration will be of lesser value. Because the discipline deals with artifacts that are much older than a year, any developed timeline as a result from this study will only allow investigators to state that the artifact has been left in the environment for longer than a year. However, the timeline can provide a starting point for archaeologists and eliminate any components that were recently added to the environment. Several sites are not preserved and people still use the land to farm, build, or hunt. These activities can introduce new items into the environment. The addition of new ammunition components can skew results and interpretations, so the investigators will need to be able to determine whether the found artifact was indeed part of the battle in question.

Review of the Literature

The issue at hand is one that many forensic science disciplines face – the lack of scientific research. In this study, valuable information will be provided to the field of firearm and tool mark analysis, specifically in three areas. The research will seek to classify stages of deterioration of various cartridge case compositions in several different environments, determine if analysis of cartridge cases can be conducted prior to the use of a restorative technique, and establish the effectiveness of three different restorative techniques in aiding analysis of deteriorated cartridge cases. Not only will this study provide new tools for firearm and tool mark examiners, but will also give battlefield archaeologists another tool. Testing the three restorative techniques will provide archaeologists assistance in studying ammunition components if the techniques are able to remove corrosion without damaging the individual characteristics. By using these techniques, archaeologists will be able to identify with certainty the movements of combatants during a battle, and possibly identify which firearm was used if they have access to the original firearms.

Battlefield Archaeology

When considering battlefield archaeology, one must first know what it is. The term is generally given to the discipline of conflict archaeology, and is slightly misleading (Scott and McFeaters, 2011). Those involved in the field examine artifacts left on the field of battle to determine the context in which battles take place and track the movement of individuals through the course of a specific battle. It focuses on the archaeology of the event or battle rather than the ground where it took place, therefore the phrase 'the archaeology of battle' is more precise (Sutherland, 2005).

This area of study is a relatively new field – the investigations that paved the way occurred in the late 1950s and 1970s. In England, Edward Fitzgerald used artifacts from the Battle of Naseby to interpret the nature of the battle in the mid-19th century, but the importance of his work was not recognized at the time (2005). In the United States, Scott and Fox drove the development of battlefield archaeology with their investigation on the Battle of Little Bighorn in the 1980s. Several advances were made during this study – the investigators developed a systematic approach to searching the battlefield with metal detectors, recorded precise locations of artifacts, and applied "modern firearms identification techniques to the firearms components, cartridge cases, and bullets" (Scott and McFeaters, 2011). Through similar investigations, the field has improved in the analysis and interpretation of historic battlefields.

Battlefield archaeology and forensic science are similar to one another in many ways. Like forensic scientists, the archaeologists do not know what evidence is relevant until the scene of the battle has been completely examined. They must examine all of the found artifacts and map their locations to find patterns to properly interpret the battle. Archaeologists also rely on cultural references ascertained by examining the artifacts to determine the context in which the battle took place. Crime scene investigators must follow the same methodology when investigating a crime scene. In addition, the battlefield is searched systematically using techniques similar to those used during forensic investigations (Lees, 2002; Sivilich, 1996; Scott and McFeaters, 2011). Because a battlefield is usually a large area, the only way to search properly is to use a line search. This method is used by investigators when searching the site of a plane crash, or a large open area where a homicide victim might have been left (Gardner, 2005). A line search involves a group of people that are stationed in a line across the search area and instructed to search a specific zone in front of them. The boundaries for each searcher can be marked with flags or rope. The searchers move across the area together, maintaining the line as they go. Once a search has been completed, another group searches the same area but starting from a different direction. In the case of battlefield archaeology, this second group is often equipped with metal detectors to aid in the search efforts (Sivilich, 1996; Scott and McFeaters, 2011). This ensures that the likelihood of overlooking evidence is reduced.

Another similarity between the two disciplines is the comparison of physical evidence to documents, witness statements, and any available photographs (Scott and McFeaters, 2011). During a crime investigation, the opinions rendered by examiners are compared to the statements given by those involved in the crime and any relevant documents like a phone call log, receipts, video surveillance, etc. Archaeologists compare the artifacts found at a battlefield to diary entries of those who participated in the battle, any photographs taken after the battle, and any other document that describes the event. By comparing artifacts to historical documents, archaeologists can support or disprove the statements and opinions given at the time of the battle, much like forensic science examiners can support or disprove theories and eyewitness statements about a crime.

Using firearm identification techniques is a relatively new addition to battlefield archaeology. The application of these techniques did not become prevalent until the investigation of the Battle of Little Bighorn as previously mentioned. Once archaeologists realized these techniques could provide rich new data about the firepower of the combatants and the movements of individual soldiers, they began to use the techniques regularly. One such example is the study by Daniel Sivilich; he and his team analyzed musket balls in order to provide more information about a Revolutionary War site in New Jersey (1996). The investigators were there to look for old coins around a house on a property called the Neuberger Farm, but found 45 musket balls in addition to other artifacts. Twenty five of these musket balls were made available for analysis by the local park system along with musket balls from a 1992 excavation, for a total of 52 musket balls.

The weight, diameter, and surface characteristics of the musket balls were analyzed and recorded. By doing so, the investigators were able to categorize the musket balls by firearm type and whether they were fired or simply dropped. The surfaces of the majority of analyzed musket balls were covered with a patina or tarnish, which prevented a thorough examination. However, the absence of certain markings told the investigators that some of the musket balls had not been fired and therefore were dropped or discarded at some point in the battle. Others contained molar impressions on the surface, which are "usually associated with field surgery to help bear pain …. 'bite the bullet'" (1996). The deep impressions on two of the five chewed musket balls indicate that someone had been wounded and needed assistance in dealing with the pain. The other three had shallow marks, indicative of lesser pain, boredom, or the need to promote salivation. Mapping the locations of the musket balls resulted in a linear pattern, suggesting a military formation. The author also noted circular indentations on the surface of the musket balls. These indentations suggested that the musket balls were "stored in contact with each other at some point, subjected to vibration and compaction" (1996).

By examining the musket balls, the author was able to determine that the site was likely a British camp associated with the aftermath of a specific battle. The diameters of the musket balls and certain surface characteristics were indicative of the use of Brown Bess muskets, and the possible transportation of ammunition overseas (1996). Without the knowledge of firearms and the techniques necessary to determine the type of firearm used, the author might have arrived at a different conclusion.

Another example of the usefulness of firearm techniques concerns the evidence of a mass execution in El Salvador which occurred on December 11, 1981. The investigators wanted to evaluate the firearm evidence to determine if the incident was a result of combat related operations, or a mass execution (Scott, 2001). On December 10, The El Salvadoran Army's Atlacatl Battalion questioned the villagers of El Mozote about the guerrilla presence in the area, and then ordered the residents to remain in their houses until the next day. After spending the night in El Mozote, the soldiers separated the villagers and locked them up in different locations – the church, convent, and several houses. They took the men outside, interrogated them again, and then executed them. The women were then separated from their children and killed. Finally, the children were shot down, some inside the convent. After the villagers were killed, the soldiers set the buildings on fire. On December 12, the soldiers moved to Los Toriles and repeated their actions. Fortunately, some of the villagers there were able to escape.

Despite the evidence and testimonies to the contrary, authorities in El Salvador denied that the massacre had taken place. Once criminal proceedings began and testimonies were given by eyewitnesses, the court ordered the exhumation of the remains of the victims. The investigation began in 1992 in El Mozote with the examination of the convent. The evidence found there supported the testimonies from the eyewitnesses – the remains were placed in the area at the same time, the events were unlikely to have occurred later than 1981, and that numerous people had been shot, crushed, or burned. The number of individuals killed in the event is unknown due to postmortem damage, commingling of the skeletons, and complete cremation of infants' remains (2001). Most of the victims found in the convent were children, substantiating witness reports that the soldiers locked children inside the convent before shooting them. The firearms evidence found in the convent also indicated that the victims were shot inside the building.

In addition, the investigation found large amounts of bullets and cartridge cases, which were examined to determine the type of weapons used, and the minimum number of possible shooters involved in the incident. A total of 245 cartridge cases were found and associated with the convent. All of the cartridge cases were examined, then cleaned with a 3% solution of acetic acid or vinegar to remove oxidation (2001). While the solution removed most of the hindering material, only 34 cartridge cases were examined using the comparison microscope. Using the comparison microscope, the investigators were able to group bullets and cartridge cases according to the firearm from which they were fired, and determined that a minimum of 24 individual shooters were present.

In his article, Scott described a concept called "artifact wear pattern analysis", which he compares to firearms identification techniques (2001). Archaeologists are able to interpret the pattern of wear on an artifact and attribute that pattern to certain human behaviors. He also described class and individual characteristics of firearms, which are used in a similar fashion as the wear pattern on an artifact. With this knowledge, the investigators were able to identify the weapons used at the convent, the minimum number of shooters present, and where and when the ammunition was made. The firearms evidence, along with the remains and testimonies, proved that the events at El Mozote were not related to combat operations, and could only have been a mass murder.

One study by Weber and Scott demonstrates that experimentation with firearms is necessary even in battlefield archaeology (2006). Over a hundred percussion caps were found in New Mexico where the Battle of Cieneguilla took place in 1854. Five of the caps were determined to be of the variety more suitable for use in a pistol (known as pistol or common caps), and the remainder were found to be top hat or musket caps. All of the caps were made of copper and did not contain any ignition component, even though several were unfired. Despite the fact that the percussion caps had been buried or exposed to the elements for almost 150 years, they were in good condition and required little cleaning (2001). For those that needed to be cleaned, the caps were soaked in a commercial jewelry cleaner, then scrubbed lightly to remove oxidation. The pistol caps were all unfired, so no individual characteristics were found on their surfaces. One of the caps did display a manufacturer's mark, indicating that it was made by a French manufacturer. Unfortunately, the company name could not be identified. Examination of the musket caps revealed that 41 caps had been fired and 64 caps were unfired. Nine of the fired percussion caps contained distinct patterns, allowing the investigators to match some of the caps to others as being fired in the same musket. As a group, the fired caps indicated that there were a minimum of 34 different firearms present during the battle where the caps were found.

At the time of the article, percussion caps were not used much to identify the number of firearms or to determine the movements of an individual. In their study, Weber and Scott discussed the development, use, and manufacturing process of the percussion cap; they also pointed out that the small components could be dropped or lost while reloading during a battle, which could explain why so many were found (2006). Even though percussion caps are found in great quantities on Civil War battlefields, few studies have been done regarding their value as evidence. Lucien Haag conducted some experiments which determined that the marks imprinted on the caps were unique, but no other studies, forensic or archaeological, existed (2006). To validate the methods used and show that percussion caps are valuable to battlefield archaeology, Weber and Scott conducted two tests. A blind study using modern percussion caps was performed to validate the methods of examination. The authors were able to group 15 fired percussion caps correctly without knowing the number of firearms used or having the firearms in their possession (2006). They also examined markings on percussion caps that were created by several different firearms, and determined that each firearm imparted identifiable individual characteristics on the caps. These tests support the methods used and the conclusions reached about the percussion caps from the Battle of Cineguilla.

By using firearm examination and identification techniques, the authors in the aforementioned investigations were able to provide physical evidence that refuted previous interpretations of a battlefield, supported other evidence and testimonies in regards to a mass execution, and demonstrated the number of individuals present in different scenarios. They were also able to place the events in context by using these techniques. Chewed musket balls, for example, told a story about pain and wounded soldiers, while numerous spent cartridge cases spoke of several individuals involved in a massacre. Studies like these indicate that the techniques developed by the field of firearm and tool mark analysis are of great use to other disciplines, especially to battlefield archaeology.

Deterioration of Bullets and Cartridge Cases

In the field of firearm and tool mark analysis, examiners often come across bullets and cartridge cases that have been damaged by corrosion. These ammunition components can be found inside the body of a victim, on or below the ground at an older crime scene, embedded in a tree or other plants, or in the midst of a burned building (Love, 1980; Welch, 1985; Gamboe, 1990; Gerber and Marsanopoli, 2005; Marsanopoli et al, 2008). Even though examiners encounter such damaged items frequently, there are few studies about the effects certain environments can have on the bullet or cartridge case, and the prevention of analysis due to corrosion.

Previous studies focused on deterioration out of need – for example, the researcher had a case where the bullet or cartridge case was so deteriorated that they had to develop a cleaning solution to remove the corrosion hindering the analysis (Love, 1980; Gamboe, 1990; Gerber and Marsanopoli, 2005; Marsanopoli et al, 2008; Randich et al, 2000). Other studies were conducted due to curiosity and the lack of information about the deterioration of ammunition components (Welch, 1985; Smith et al, 1993; Chow et al, 2003; Larrison, 2006). The older studies did not discuss previous literature, and the methodology was sparse – the articles only consisted of three to four pages of information. One example of this type of study is an article by Edard Love that sought to determine the effect that prolonged exposure to blood would have on a bullet (1980). He based the study on the fact that he had encountered blood-soaked bullets in his work and had wondered if there was a corrosive effect from the blood that hindered analysis. He showed that bullets left in blood and exposed to the elements (while eliminating rain) deteriorated much faster than bullets placed in a vial of blood and refrigerated. He speculated as to why one sample group deteriorated more rapidly than the other, but never continued the research to determine why the rate of deterioration was greater for one group (1980). Another study by Gamboe demonstrates the same characteristics (1990). To examine bullets encapsulated in body tissue, he felt it was necessary to develop a new technique for removing the tissue. His previous encounter with such a bullet had resulted in an unsuitable specimen after cleaning the bullet with an ultrasonic cleaner (1990). The method he used in this article resulted in a bullet with clear individual characteristics, suitable for analysis. While he determined the new method was more effective in removing tissue, he never explained why it was better than the ultrasonic cleaner.

The study by Randich and colleagues used evidence involved in a criminal investigation, but the authors were extremely detailed in their documentation of the methods used to restore the bullets and cartridge cases (2000)1. During the investigation, cartridge cases were found on the ground around the suspect's house and bullets were discovered embedded in a palm tree used for target practice (2000). The examiners determined that chemical treatments were needed to remove the corrosion and plant matter from the evidence, but specifically avoided wiping or scrubbing tactics to prevent damaging any individual characteristics present on the surface. After testing several solutions on "well-corroded but non-evidentiary exemplars" or representatives of the evidence, the authors were able to develop a methodology that cleaned while avoiding further damage to the individual characteristics (2000). To verify the preservation of the stria by the solutions, the authors applied the procedure they had developed to two of four test-fired bullets and cartridge cases of the same caliber as the evidence they had found. When the treated and untreated test-fires were compared to each other by an experienced examiner, the individual characteristics were still present on the treated specimens and a match could be made (2000). The bullets lodged in the palm tree were unfortunately too damaged by years of exposure to the plant material, but the cartridge cases proved much more useful. The examiners were able to match four cartridge cases found at the suspect's house to those found at the crime scene, effectively showing that the suspect was present and fired his weapon (2000).

More recent studies have elaborated on the techniques used in the aforementioned research, but rather than use evidence collected from a crime scene, the researchers created their own scenarios to observe the effects of deterioration on bullets and cartridge cases. In one such study, Chow and colleagues were interested in the effects of putrefaction or decomposition of a body on bullets and constructed two scenarios based on the seasonal weather changes (2003). To simulate the decomposition of a human body, the authors used four pig carcasses in the first phase of the study and five carcasses in the second phase. Taking place in Indiana, the first phase was conducted during late winter and early spring, and the second phase ran from late summer to early fall (2003). In the first phase of the study, four types of bullets were used to show any differences between the compositions, and one pig carcass was assigned to each bullet type. Once the bullets had been fired into the pig carcasses, the pigs were left in an outdoor environment. Due to the disturbance of the pigs by a predator, some of the bullets in the first phase were never recovered, and the setting had to be adjusted to prevent any further damage to the pigs. The same settings were used for the second phase, but a few changes were made – the bullets were placed in the pigs rather than fired into them, a control pig body was added to determine if firing into the bodies increased the rate of deterioration, and the control bullets were placed in a cloth bag to aid in recovery (2003).

Once the bullets had been collected, they were cleaned following the method used by Gamboe and allowed to dry (2003). One of three conclusions was drawn when the experimental bullets were compared to the control bullets: unsuitable, meaning the bullet is too damaged for analysis, inconclusive, or identification. After examining the bullets collected from the pig carcasses, the authors were able to identify several of them. In addition, the authors created a scale with which to describe the state of deterioration of the experimental bullets, not unlike the stages proposed in the present study. However, the authors failed to provide photographs or objective criteria of the different levels or states of deterioration, which the proposed research will include.

Another recent study by Larrison created several different scenarios in which bullets and cartridge cases could be found (2006). The study took place in the state of Michigan, and the author chose four different environments in which to place bullets and cartridge cases: open air, soil (buried), water, and carcass. The open air test consisted of attaching bullets and cartridge cases to insulated wire and hanging them from a structure outside (2006). This scenario is a bit unrealistic as no bullet or cartridge case will simply remain in the air without contact with another surface. The other environments consisted of placing samples in three inches of soil, submerging in water, and inserting into a dog carcass that was then wrapped and laid in a shallow pit (2006). It was noted that the carcass was covered with chain link fence to prevent any disturbance, but it is unclear whether it was buried.

The bullets and cartridge cases chosen for this study were of different compositions and calibers, fired through firearms made by two different manufacturers. A total of 48 bullets and 32 cartridge cases were utilized in the study, which lasted over a period of two years (2006). Every six months, two cartridge cases and three bullets were removed from each environment and examined for individual characteristics. Those samples that could not be identified were cleaned with water, scrubbed with a toothbrush, and then examined again. If this cleaning had not removed all of the material from the surface, the author applied different chemical solutions that included jewelry cleaner and an acetic acid solution (2006).

The results obtained from this study showed that identification of bullets and cartridge cases left in open air and soil is possible even after two years of exposure. Minimal cleaning was needed for these samples, indicating that the rate of deterioration in these environments is slow when compared to the samples from other environments. While not all of the bullets and cartridge cases contained individual characteristics after being subjected to water or a decomposing body, this study demonstrated that one should always attempt restoration. After applying the restorative solutions to the samples, Larrison found that “small areas of identification still survived” under the corrosion (2006). The author also found that solutions like acetic acid should only be applied in short durations to avoid damaging the individual characteristics hidden by layers of corrosion.

The aforementioned studies and similar research are greatly beneficial to the field of firearm and tool mark analysis, not to mention battlefield archaeology and law enforcement. These studies provide examiners and investigators information on casework and aid archaeologists in examining weathered ammunition components and other artifacts found during the course of their research.

Use of SEM in Firearm and Toolmark Analysis

The scanning electron microscope (SEM) has been available and used to examine evidence related to firearms identification since the early 1970s. One of the first articles published about the use of the SEM for forensic science states the microscope was developed by a group of scientists over 30 or more years (Korda et al., 1971). The first commercial SEM became available in 1965, and was quickly put to use examining forensic evidence by 1970 (Korda et al, 1971; Scanlan and Reinholz, 2013; Mann et al, 1992). Items that are able to conduct electricity can be scanned by the SEM without issue, but non-conductive items have to be coated with a thin layer of aluminum in or some other conductive material in order for the SEM to obtain an image (Korda et al, 1971). Several papers followed on the utilization of the SEM to analyze firing pin impressions and extractor marks on cartridge cases and individual characteristics on bullets (Mann et al, 1992). One paper even analyzed the striations found on finger nail clippings with the SEM and found that some clippings could be identified as having come from the same source, even though they had been collected a year apart (Korda et al, 1971).

The advantages that the scanning electron microscope provides to the examiner are greater depth of field, greater magnification, and images of better quality (Mann et al, 1992). The equipment made it easier for an examiner to see the shallow detail, narrow marks, and other features present on ammunition components and toolmarks that would be difficult to see using the conventional comparison microscope (Scanlan and Reinholz, 2013). This level of detail can make a difference if an examiner feels that there is some consistent individual characteristics between the evidence and test fires, but not enough for them to reach a conclusion of "identification". Greater magnification can also assist in rendering conclusions – the range of the SEM exceeds the range of the comparison microscope by several thousand (Scanlan and Reinholz, 2013). Images produced by the SEM are also clearer than those obtained with a comparison microscope. With no light source, the pictures from the SEM do not contain the glare often seen on cartridge cases or bullets when positioned on the comparison microscope (Scanlan and Reinholz, 2013).

One major disadvantage of the SEM was the inability to compare two specimens at the same time. In the beginning, one item had to be placed in the chamber, photographs were taken, then the item was swapped for another, and photographs were taken of that item (Mann et al, 1992; Goebel et al, 1983). The photographs were then enlarged so the examiner could compare the images. This system proved time consuming and very difficult – it was nigh impossible to photograph each specimen with the same lighting and magnification (Goebel et al, 1983). Eventually, technology improved enough that the image of the first item was temporarily stored on a computer and the examiner could then compare that image to the live image of the second item in the SEM (Mann et al, 1992). However, this was still problematic because if the right area of the first item was not captured the first time, the examiner had to place the first item in the

SEM again and capture more images. Special stages had been created by this time for the examination of ammunition components, which meant that the stage already in the SEM had to be replaced (Scanlan and Reinholz, 2013; Mann et al, 1992). There are two different versions of this new stage, one of which required the installation of other pieces of equipment, which required money, technical knowledge, and time to install (Mann et al, 1992). The additions could also create an issue when trying to capture the image of an item – the coil that had to be installed would increase the distance between the final lens and the item, comprising the quality of the image (Mann et al, 1992). The other version of the stage took the place of the standard SEM stage with no other modifications; it is with this stage that the image is captured and stored for a short time so it can be compared with the live image of the second item (Mann et al, 1992).

Over time, the Compare Scan system was developed. Similar to the comparison microscope, this system combined two SEMs with a single viewing screen, which was a color TV monitor (Mann et al, 1992; Goebel et al, 1983). The two microscopes were synchronized electronically with one another, but could still be operated individually, allowing the examiner to move each specimen without removing it from the chamber (Mann et al, 1992; Goebel et al, 1983). Special stages were created to hold cartridge cases and bullets in the correct orientation for examination (Goebel et al, 1983). Elegant in its design, this system was also extremely expensive, which meant that very few laboratories could afford to purchase it. In fact, few laboratories could afford a single SEM for the use of firearms examiners alone – there rarely arises a time when the SEM is needed to analyze ammunition components or toolmarks, which did not justify the cost of equipment and maintenance of an SEM (Giverts et al, 2013). One study suggested that the SEM is not a replacement for the comparison microscope, but rather a tool to complement the work done on the comparison microscope, and to aid in reaching a conclusion when more magnification is needed (Scanlan and Reinholz, 2013).

New equipment and technologies have been developed recently that add to the capabilities to the scanning electron microscope. In the 80s, studies were conducted to determine if a more "natural" state could be achieved in the chamber of the SEM (Katterwe et al, 2009). The SEM required a vacuum-sealed chamber in order to analyze the sample; in addition, the sample had to be cleaned of any dirt or debris and had to be able to conduct electricity in order for the SEM to create quality images (Scanlan and Reinholz, 2013). These requirements restricted the type of samples that could be analyzed by the microscope, so research was done to determine if they were necessary. The first SEM that could create an "environmental chamber" caused those using the machines to be suspicious of its abilities, but it has advantages over the conventional SEM (Katterwe et al, 2009). The Variable Pressure-SEM, or VP-SEM, differs from the SEM only in the presence of gas in the chamber – the gas acts as a conductor which allows non-conductive material to be analyzed (Katterwe et al, 2009). Furthermore, the gas reduces the charge that can be created on the surface of the sample and facilitate the detection of the signal that produces the image (Katterwe et al, 2009). In time, two VP-SEMs were combined into a Comparison-VP-SEM, which is essentially a Comparison-SEM or CSEM, but it can analyze non-conductive materials (Katterwe et al, 2009). A recently developed alternative to the SEM is the virtual microscope. Forensic Technology, Inc. produces a virtual microscope that uses confocal microscopy to scan the specimen placed in the instrument, and the software can then render a 3D image of the surface (Giverts et al, 2013). Once the area has been scanned and saved on the computer, the examiner can remove or add surface texture, lighting, and other features that can make the comparison easier (Giverts et al, 2013). There are a couple of drawbacks – it can take a while to acquire the image, and the image is only a small portion of the specimen, not the whole surface (Giverts et al, 2013). A major advantage is the ability to gain a second opinion from an examiner without having them examine the actual evidence – the images can be sent to the examiner for comparison (Giverts et al, 2013). More testing will be needed to make sure that the same results would be obtained with comparing images and comparing actual evidence to test fires, but there is potential to reduce the time needed for verification. In addition, the virtual microscope could be incorporated into IBIS, or the Integrated Ballistics Information System, which could increase the likelihood of generating hits when searching older cases (Giverts et al, 2013).

As mentioned earlier, the scanning electron microscope is used to analyze marks on cartridge cases, bullets, and striations within finger nails. When applied to ammunition components, generally the components are so damaged that examining them with the comparison microscope does not provide the examiner with enough information (Mann et al, 1992). In contrast, the components may be in good condition, but there is only a small area that holds individual characteristics – in either situation, the magnification of the SEM is very useful in detecting enough detail for the examiner to fully analyze the components. One study applied the advantages of the SEM to non-toxic shot in order to differentiate between types and manufacturers (Stevens and Gallant, 2006). One of the operations of the SEM is to identify elemental composition of the item being scanned as well as providing a detailed view of the surface; this operation was applied to non-toxic shot to determine if it could be used in casework to decide what type of shot was used and possibly the manufacturer of that shot (Stevens and Gallant, 2006). At 50x magnification, the authors were able to differentiate the types of shot used in the study, and greater magnification did not result in new information; however it could prove useful if the pellets were too damaged to be viewed with a simple stereoscope or comparison microscope (Stevens and Gallant, 2006). In addition, the elemental analysis of the shot used indicated that this process could be used in casework to determine the type of shot that was used (Stevens and Gallant, 2006). This information could be helpful if a suspect or suspects were found to be in possession of the same type of shot.

One of the most common uses of the SEM in the firearm and toolmark section of a forensic laboratory is the gunshot residue (GSR) analysis. To collect samples from the suspect or garment, it is possible to simply apply adhesive tape to the area in question and then place the tape in the SEM for analysis (Warlow, 2005). The inorganic material present in GSR is detected by the SEM. One study compared the three methods used to identify GSR and found that while it can be time consuming, the SEM will identify with certainty the presence of GSR (Portis and Tilley, 1981). When combined with one of the other methods, the examiner can obtain identification of GSR from the SEM as well as good quantitative data from the other method (Portis and Tilley, 1981).

Another use for the SEM on the rise in regards to GSR is determining particle density in distance determination examinations (Heard, 2008). The SEM can detect GSR particles at muzzle-to-target distances of 15 feet or more; the experimentation, collection, and analysis does require a great deal of time (Heard, 2008). Samples are collected from test garments that have been shot at predetermined distances, and the particle density is calculated from those samples – results are then compared to the density found on the evidence garment and an approximate distance or range is determined (Heard, 2008). A crucial piece of information, that is required before testing begins, is the GSR distribution created by the combination of the suspect ammunition and firearm (Heard, 2008). Samples from bullet holes can also be evaluated using the SEM to determine which is the entry hole and the possible bullet type used (Warlow, 2005; Heard, 2008). Using tape, fragments of the bullet left on the garment are placed in the SEM to determine if they consist of lead or some kind of jacketing material specific to a bullet type or country of origin (Portis and Tilley, 1981). In addition, the SEM can also detect elements specifically found in tracer rounds (Warlow, 2005; Haag et al, 2014). One article from 1976 details the use of the scanning electron microscope to examine possible individual characteristics found on flakes of smokeless powder (Vandiver, 1976). The author believed that it might be possible to distinguish one batch or lot or powder from others based on markings created when the powder was extruded and cut (Vandiver, 1976). However, little research has been done to indicate such an association can be made between flakes of gunpowder and a particular batch or lot.

Research undertaken by Klees applied the abilities of the scanning electron microscope and X-ray mapping to the detection of obliterated laser-etched markings on firearms (Klees, 2009). The author sought to determine if the SEM and X-ray mapping could detect changes in the metal's structure beneath the markings, differences in texture from the etching process, or differences in the composition of the metal (Klees, 2009).These changes or differences could potentially be used to recreate the markings that had been removed from the metal surface. Both methods were quite capable of detecting the characters before they were obliterated, which was done by removing very thin layers with a Dremel tool (Klees, 2009). However, once the characters were removed, neither the SEM nor X-ray mapping could discern any differences between the area where the characters were once located and the metal around it (Klees, 2009).

This research applied an instrument that has already found a use in the field of firearm and toolmark analysis to determine if a new resource can be developed to aid examiners.

Depending on future research, examiners may find themselves using the SEM to analyze corroded ammunition components in the future.

Restorative Techniques

There are a variety of tools and techniques available to law enforcement today, and restorative techniques such as serial number restoration are included in that category. Criminals attempt to hide their activities and any possible evidence by removing serial numbers from firearms, part numbers from tools, VIN numbers from cars, etc. With developed chemical solutions, examiners are able to restore these numbers. These solutions do not restore the numbers to their original state, however, but merely cause the numbers to be visible again. This is possible due to the molecular changes that occur when a metal is subjected to great force and pressure (Polk and Giessen, 1989; Massiah, 1978). The molecular structure beneath the surface of the metal is resistant to the new shape up to a point, but when the "elastic limit" or limit of resistance is surpassed, the metal takes on the new shape permanently (Polk and Giessen, 1989). When enough force is applied, the new shape persists deep beneath the surface and can only be removed with great effort (Gardner 2005; Houck and Siegel, 2010; Polk and Giessen, 1989; Massiah, 1978). To restore an obliterated number, the area in question is first filed or polished to a smooth and level finish, then an acid is applied. The acid can react with the deformation of the metal's structure beneath the serial number in two ways (Houck and Siegel, 2010). First, the stamped or deformed metal can become denser and therefore dissolve more slowly than the surrounding metal, which causes the serial number to appear raised above the faster dissolving metal. The other reaction causes the serial number to appear pressed into the metal, because the compressed metal dissolves at a faster rate than the surrounding metal. Examiners must be careful when applying the acid to the surface to ensure that it does not dissolve the metal too much and obscure the numbers.

In this study, the researcher will be using the serial number restoration technique in an attempt to reveal individual characteristics on the cartridge case. Massiah and others state that the surface must be polished before any solution is applied, but this could damage or remove the markings that the researcher needs to analyze (Massiah, 1978; Polk and Giessen, 1989; Houck and Siegel, 2010; Gardner, 2005; Booker, 1980). The use of ultrasonic cavitation or agitation will remove rust, corrosion, metal, dirt, or any other material left on the surface of the cartridge cases (Barabash and Fahey, 1977; Randich et al, 2000). This step will replicate the recommended scrubbing or filing of the metal surface. Therefore, the samples for this study will be cleaned to remove corrosion, but will not be scrubbed or polished before the application of the chemical solutions.

Jewelry cleaner and acetic acid have been used in previous studies, but not much research has been conducted regarding their effects. The proposed study will determine the extent of the usefulness and duration of application of these two solutions. By applying the solutions to several metal compositions, the research will also show the level of effectiveness of the two solutions on different metals. The method by Randich et al was developed for copper and copper alloy compositions (2000). However, this research will apply the technique to several compositions in order to demonstrate its usefulness with other metals.

Some restorative techniques have proven to be useful in revealing evidence without further damaging it. However, these techniques have yet to be applied to several metal compositions from different environments. This research supplied this much needed information and demonstrated the effectiveness of the chosen solutions.

Research Methodology

This study sought to determine the likelihood of identification over time based on factors in the different environments, to establish a timeline based on elements present, and to establish the effectiveness of three restorative techniques in aiding examiners to draw a conclusion. With the creation of a timeline according to the degradation observed on the cartridge cases, examiners in firearm and tool mark analysis will be able to testify to a specific time frame in which the cartridge case was exposed to certain environments. By determining the effectiveness of the restorative techniques, those working in the disciplines of firearm and tool mark analysis and battlefield archaeology will be able to conduct a more thorough analysis of weathered cartridge cases they may encounter during investigations.

The cartridge cases were fired through two guns, placed in six different environments, and left for a period of one year. Every 31 days, the researcher collected a sample of 18 cartridge cases from each environment, examined them using a comparison macroscope, and compared the samples to a control group. Samples were also analyzed using a scanning electron microscope. If necessary, restorative techniques were applied and the samples were re-examined to document the results. A photographic log was kept of all the samples through the use of image capture on the comparison macroscope. All weather changes were noted by utilizing the Corps of Engineers' monthly lake reports, which record rainfall for the area in which the samples will be placed, and through the use of a Tiny Tag device that hourly records the temperature and humidity.

This study utilized a pig carcass, which was donated to the university by the Medical Examiner's Office. The use of this carcass has been approved under IRB IACUC #10007.

Setting

The following six environments were chosen: open area or field, shaded area or woods, buried in open area, buried in shaded area, water, and buried under a pig carcass. These environments represent real-life scenarios in which evidence has been left or the suspect tried to hide the evidence. All locations were in or around Lake Arcadia in the state of Oklahoma. Samples of the soil and water to which the samples will be exposed in the study were tested to determine pH levels and prevalent chemicals or elements at the Soil, Water and Forage Analytical Laboratory located at the Oklahoma State University.

A frame of PVC pipe was created to contain the samples in a small area. A drill press was utilized to create small holes close to the mouth of the cartridge cases, away from the area of interest (i.e. the breechface and headstamp regions), which enabled the researcher to place the cartridge cases onto monofilament, or fishing line. To separate the cartridge cases and prevent possible interaction, plastic tubing was placed on the fishing line between each cartridge case. The fishing line was then attached to the frame with zip ties. To collect a sample group, the researcher simply cut the zip ties holding the fishing line in place on the frame. All sample groups, except those left in the water, were covered with a plastic mesh material held down with metal stakes, to prevent animals from disturbing the research area, and the locations were then marked with brightly colored flags.

Materials

The author collected a total of 1,308 spent cartridge cases at the beginning of the study; there were 436 brass cartridge cases, 436 steel cartridge cases, and 436 aluminum cartridge cases. Half of each composition was fired from a 9mm Beretta pistol and the other half was fired from a 9mm Hi Point. Two cartridge cases of each composition, each fired by a different firearm, were chosen at random to serve as the control cartridge cases for comparison. For example, of the two brass cartridge cases chosen to be controls for comparison, one was fired from the Beretta, and the other was fired from the Hi Point. Thus, the researcher had a total of six (6) controls from comparison purposes. The same method was used to choose a control group to determine if there was any interaction between the cartridge cases and the fishing line or plastic tubing. This sample group was left undisturbed in a drawer for the length of the study. The remaining cartridge cases were randomly assigned to the environments. The sample groups were established by using the following guidelines: three (3) cartridge cases of each composition were needed to test the 3 restorative techniques, which meant that nine (9) cartridge cases fired from each firearm were needed in each sample group. Therefore, a total of eighteen (18) cartridge cases are needed for one environment for one month (9 cartridge cases x 2 firearms). Six environments have been selected for this study, which meant that 108 cartridge cases were needed for all six environments for one month of research (18 cartridge cases x 6 environments). Sample groups were collected every 31 days after being placed in the environments for the period of one year; there were a total of twelve (12) collections that took place. As a result, the total sample size for this research was 1,296 cartridge cases (108 cartridge cases x 12 sample collections).

Two firearms were used to create the individual characteristics on the cartridge cases: a 9 mm Hi Point model C9 pistol and a 9 mm Beretta model 92 FS pistol. The Hi Point was chosen for its ability to create distinct markings that could potentially be less affected by corrosion. The Beretta was chosen because the markings it creates are possibly more likely to be marred or damaged by corrosion. Choosing firearms that differ in this manner serves to demonstrate how different individual characteristics can be affected by the deterioration of the cartridge cases.

Once collected, the samples were cleaned with water combined with ultrasonic cavitation, if deemed necessary by the researcher. Ultrasonic cavitation has been shown to be effective in removing materials from the marking grooves of obliterated serial numbers and effective method of restoration (Larrison, 2006; Massiah, 1978). This method removed corrosion, plant matter, dirt, or biological fluids from the samples with no assistance from the researcher. Those samples collected from water and from under the pig carcass were cleaned using a solution of water and bleach with ultrasonic cavitation, then cleaned further with a germicidal cleaner and deodorant called Disolv®. This step was taken to ensure that anyone handling the samples would not be at risk of dangerous bacteria. Once cleaned, Rem® Oil was added to the area of interest on each cartridge case to prevent further corrosion from developing. Each cartridge case was then placed in a coin envelope and assigned a number for documentation purposes. The envelopes were kept in bags, separated according to environment.

Once cleaned and numbered, the researcher then analyzed each cartridge case using the Leeds 1600 comparison macroscope, and compared the unknown cartridge case to a known cartridge case to determine if a conclusion of "identification" could be made. If the sample was identified to one of the two guns used in this study, photographs were taken, and the sample was not cleaned further. If the researcher was not able to identify the sample to either firearm, photographs were taken to document the condition of the sample compared to the control cartridge case, and the sample was set aside for further cleaning.

The three restorative techniques required specific concentrations of different chemicals. One technique was developed by Randich and colleagues and required deionized water, trichloroethylene (TCE), acetone, sodium metasilicate, ethylene glycol monobutyl ether, and a sulfuric acid-based cleaning solution that contains sulfuric acid, thiourea, and sodium lauryl sulfate (2000). See Appendix 1 for concentrations and procedure. Each step in the procedure requires ultrasonic agitation for two minutes, except step 5 – for severely corroded samples, it is recommended to sonicate in solution for one minute, for less corroded samples, no sonication is required. This step can also be repeated if corrosion is still present on the sample, which will be determined through examination with a comparison microscope. The final step in this procedure is to ensure the chemicals used on the samples cease all activity and do not damage the sample. This technique was developed for copper and copper-alloy bullets and cartridge cases, but the researcher used the technique on all of the chosen compositions to determine if it can be effective in cleaning other compositions.

The second technique or procedure used was the serial number restoration technique, which has been utilized for several years by examiners in firearm and tool mark analysis. Only one reagent called Aqua Regia was chosen, which is considered a universal reagent for serial number restoration (Rymer, n.d.). Aqua Regia was chosen to reduce the number of factors that could affect the cleaning of the cartridge cases. If only one reagent is used for cartridge cases collected from the same environment, the differences in reactions may be due to the composition of the cartridge case itself.

The final technique to be tested was used by Larrison when he examined the degradation of bullets and cartridge cases (2006). While he used several different chemical solutions, this study will only use one of those solutions – jewelry cleaner. The researcher chose only of these solutions to test in this study because jewelry cleaner yielded the best results in the study by Larrison and investigations of the sites of the Battle of Cieneguilla and the mass execution in El Salvador (2006; Weber and Scott, 2006; Scott, 2001). However, Larrison states that the jewelry cleaner could only be used for a short time (2006). With no specific time listed in the article, the researcher relied on the instructions found on the container of the jewelry cleaner and limited the exposure for all samples to ten seconds.

Monofilament, or fishing line, was utilized for retrieval purposes, in addition to shovels for creating sites in which to place the samples. A pig carcass was needed to simulate a decomposing human body. It has been established that the pig is an appropriate model to use when studying human decomposition, which is why the pig was chosen for this study (Chow et al, 2003). PVC pipe was also used to construct a frame that would hold all of the samples for one environment to reduce the area that was needed. Thus the disturbance to the environment was minimized to the size of the frame.

Data Collection

The samples were procured using the water tank in the OSBI Firearm and Tool Mark Laboratory, and the outdoor range at Midwest City, Oklahoma. The cartridge cases were fired though either a 9 mm Hi Point model C9 pistol or a 9 mm Beretta model 92 FS pistol, which a law enforcement officer or faculty member handled. The samples were then grouped according to their composition and the firearm from which they were fired, and assigned to one of six environments. One sample collection from one environment contained 18 cartridge cases (6 cartridge cases for each composition), and a collection from all six environments had 108 cartridge cases.

A pig carcass was utilized to simulate a decomposing human body and the effects such decomposition can have on cartridge cases and individual characteristics. The buried samples were placed no further than three inches below the surface, and the samples buried with the pig carcass were placed two feet from the surface. A protective structure of plastic mesh screening was made to contain the cartridge cases left in the open area and shaded area, preventing an animal or person from disturbing the samples. The pig carcass was also covered by plastic mesh screening to prevent any predators from disturbing the carcass. The water samples were submerged in a nearby body of water located at Arcadia Lack, with the PVC pipe frame anchored to a stationary object on land.

All of the samples were placed in their various environments on June 18, 2012. Counting that day as day 1, the researcher collected the first group of samples after 31 days. This pattern was continued for the period of one year, until June 24, 2013, at which time the last group of samples and materials were collected from each environment.

Once a sample group was collected, it was cleaned using water and ultrasonic cavitation, if it was deemed necessary. Sample groups collected from the water and under the pig were cleaned with a solution of bleach and water with ultrasonic cavitation, then cleaned further with Disolv®-Germicidal Foaming Cleaner. This step was taken to ensure that anyone handling the samples would not be at risk of dangerous bacteria. Once cleaned, Rem® Oil was added to the area of interest on each cartridge case to prevent further corrosion from developing. Each cartridge case was then placed in a coin envelope and assigned a number for documentation purposes. The envelopes were kept in bags, separated according to environment.

Once cleaned and numbered, the researcher examined each cartridge case using the Leeds 1600 comparison microscope and compared them to the control group acquired at the same time as the experimental samples. If the researcher was able to analyze the samples and draw a conclusion identifying the source of the cartridge case (which firearm), no restorative techniques were used. Photographs were taken to document the individual characteristics seen on sample cartridge case in comparison to those seen on the control or known cartridge case. If the cartridge case was not able to be identified to the satisfaction of the researcher and a qualified examiner who verified the conclusions, it was put aside.

Before the cartridge cases were cleaned further, those collected at the 3-month, 6-month, 9-month, and 12-month marks were analyzed using the scanning electron microscope (SEM) to determine the basic elements that were present, and the percentage of those elements. This step provided data that was evaluated if there is indication that the elements and the amount of those elements appear in a predictable manner. If predictable, examiners may be able to determine the amount of time a cartridge case was left in a particular environment.

Once the data using the SEM was compiled, the list of cartridge cases not positively identified to a particular firearm was narrowed down to a select group to be cleaned further with the chosen restorative techniques. The cartridge cases were randomly assigned to one of the three restorative techniques in a manner that maximized the statistical significance of the data to be collected. The cartridge cases were cleaned with the assigned technique, after which they were examined using the comparison microscope. This last step was to evaluate the appearance of the breechface area of the cartridge case and determine if it could now be identified to a particular firearm.

The E-Z-Est® jewelry cleaner was applied in the following manner: a small amount of cleaner was placed in a shallow plastic dish, the base of the cartridge case was placed in the cleaner for 10 seconds (average time recommended by the manufacturer), and then rinsed with water. A thin coat of Rem® Oil was applied after the cartridge case was rinsed to prevent further corrosion from developing. Aqua Regia was swabbed onto the area of interest, similar to the method used in serial number restoration, until the debris was removed and the area of interest was more visible. The cartridge case was then rinsed and Rem® Oil was applied. For the method developed by Randich and colleagues, see Appendix 1 – the solutions are listed in the order in which they should be used. Due a mistake by the researcher, the solutions were applied to the sample group from the shaded buried environment in the incorrect order. However, the area of interest was cleaned enough that the researcher was able to analyze the area with the comparison microscope. Future research may reveal a better method or order to follow when using these solutions.

The conclusions reached by the researcher, both before and after restorative techniques were applied, were later verified by a qualified examiner. Any inconsistencies between the examiner and the researcher were reanalyzed and discussed before a final conclusion was recorded.

Results

Analysis of Likelihood of Identification

The first research question dealt with the likelihood of an examiner reaching a conclusion of identification based on the composition of the cartridge case, the environment to which it was exposed, and the time it was left in that environment. The shaded buried environment did not affect the cartridges cases enough to prevent an identification. While the individual characteristics were not as distinct as those seen on the control cartridge cases, the researcher and examiner agreed that all of the samples would be identified to the control cartridge case if they were received in real casework.

The average temperature, average humidity, and total rainfall were recorded for each month of the experiment using a Tiny Tag device or the Corps of Engineers' monthly lake reports. These variables were transformed for this portion of the analysis. The temperature and humidity were averaged over the entire period that the cartridge cases were at the locations, rather than just the months in which they were collected. Similarly, rainfall was summed over the entire period that the cartridge cases were at the locations.

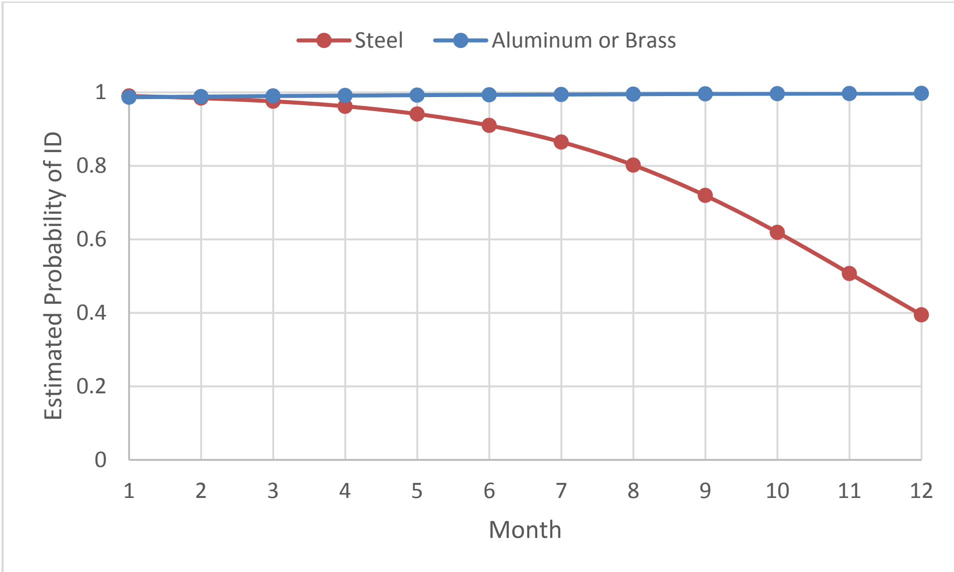
A logistic regression model was developed for each location to determine which factors are significantly related to the probability of correctly identifying a cartridge case. The model building recommendations of Hosmer and Lemeshow (2000) were followed in developing these models. Factors considered for inclusion in the models (except for the water location) were composition, gun, month, average temperature, average humidity, and total rainfall. At the water location, the cartridge cases were submerged in the water, so air temperature and humidity were irrelevant. Month, temperature, humidity, and rainfall were highly collinear. Consequently, the best non-collinear subset of these variables was selected for each location. At all locations, pH could not be considered for inclusion because the pH remains the same at each location throughout the entire experiment. No model was developed for the shaded exposed location since all cartridge cases at that location were correctly identified. Similarly, at the shaded buried, open exposed, and open buried locations all of the aluminum cartridge cases were correctly identified, so the aluminum category could not be modeled separately. Since aluminum and brass were most similar with respect to the proportion of cartridge cases correctly identified, these two categories were combined for the analysis at these locations. SAS v. 9.3 was used for this portion of the analysis.

The resulting models are displayed graphically in Figure 1 with the corresponding mathematical model below each graph. The estimated probability of making a correct identification can be found by calculating

$$\frac{\exp\left(\widehat{\text{logit}}(p_i)\right)}{1+\exp\left(\widehat{\text{logit}}(p_i)\right)}$$

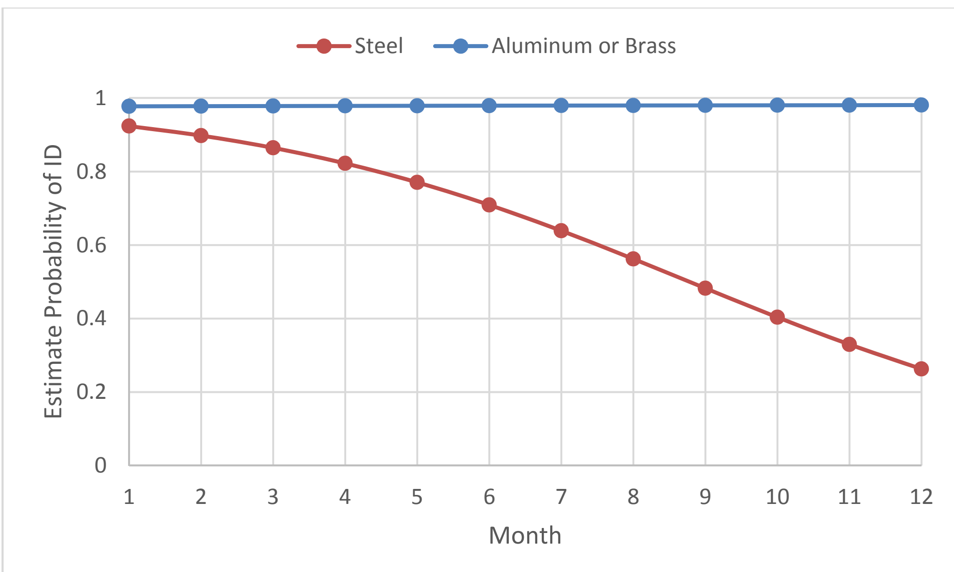
These estimated probabilities are displayed in the following graphs.

Figure 1. Logistic regression models for each location.
Shaded Buried



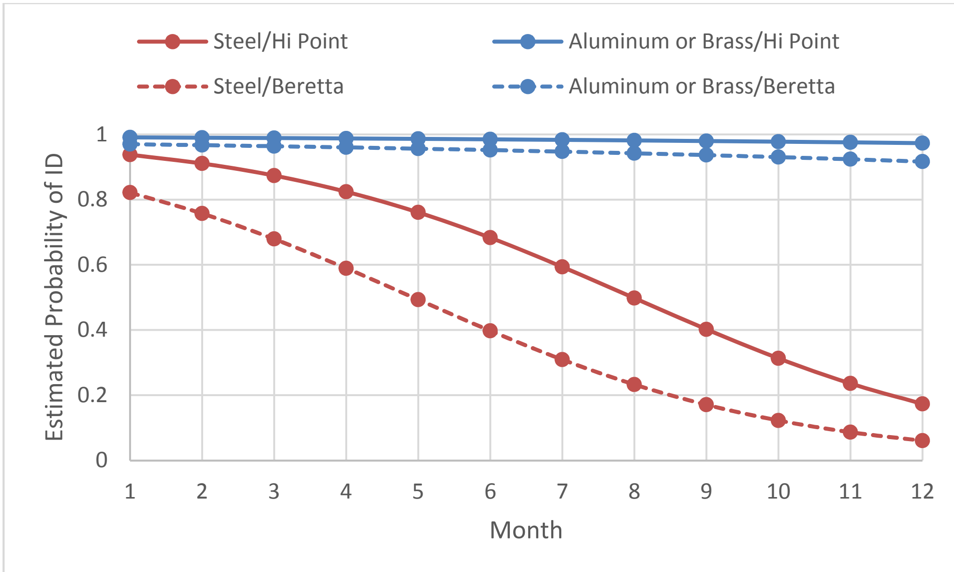
$$\widehat{\text{logit}}(p_i) = 4.1668 + 0.8849 \text{ steel} + 0.1370 \text{ month} - 0.5937 \text{ steel} * \text{month}$$

Open Exposed



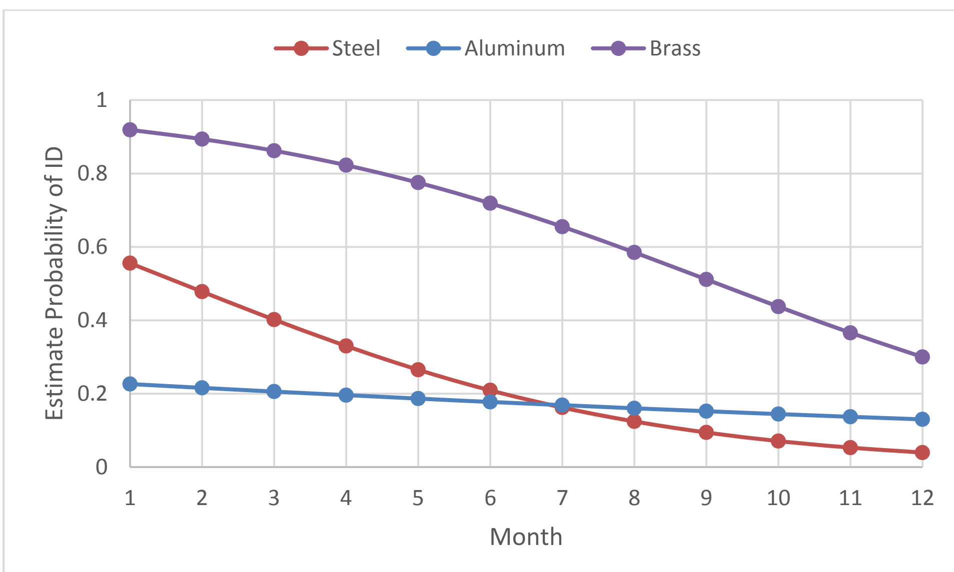
$$\widehat{\text{logit}}(p_i) = 3.7584 - 0.9462 \text{ steel} + 0.0143 \text{ month} - 0.3346 \text{ steel} * \text{month}$$

Open Buried



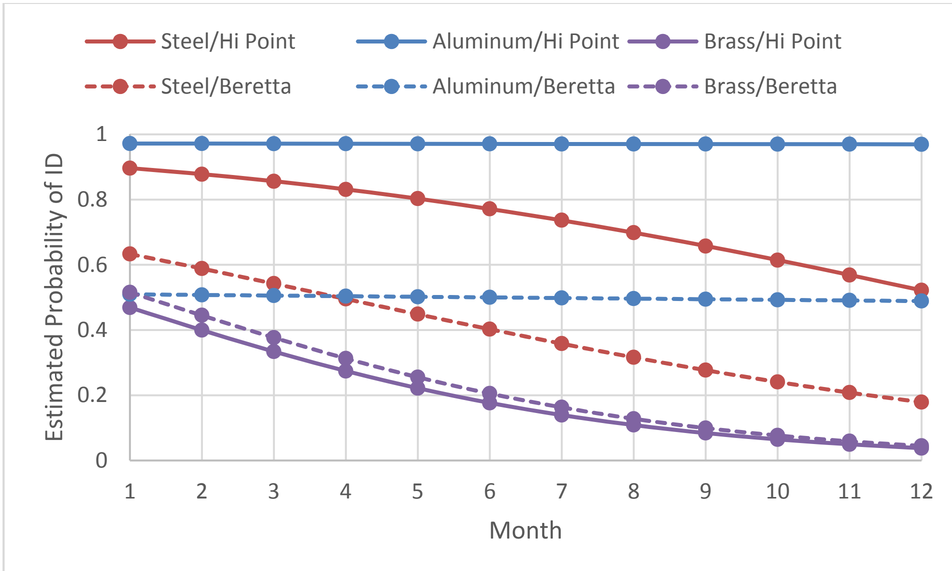
$$\widehat{\text{logit}}(p_i) = 3.5830 - 1.6676\ \text{steel} + 1.1838\ \text{gun} - 0.0987\ \text{month} - 0.2898\ \text{steel} * \text{month}$$

Water



$$\widehat{\text{logit}}(p_i) = 0.5341 - 1.7021\ \text{aluminum} + 2.1915\ \text{brass} - 0.3108\ \text{month} + 0.2497\ \text{aluminum} * \text{month} + 0.0130\ \text{brass} * \text{month}$$

Pig Buried

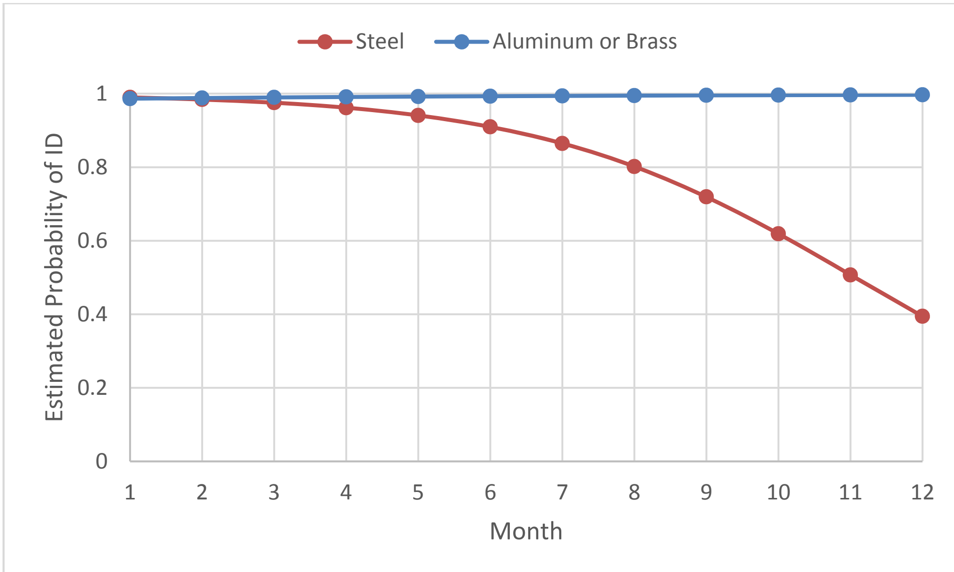


$$\widehat{\text{logit}}(p_i) = 0.7354 - 0.6895 \text{ aluminum} - 0.3894 \text{ brass} + 1.6106 \text{ gun} - 0.1882 \text{ month}$$
$$+ 1.8874 \text{ aluminum} * \text{gun} - 1.7975 \text{ brass} * \text{gun} + 0.1807 \text{ aluminum*month}$$
$$- 0.0945 \text{ brass*month}$$

The following graphs in Figure 2 represent the factor that most affected the likelihood of identification in each environment. Month, temperature, humidity, and rainfall were highly collinear, and so the best non-collinear subset of these variables was selected for each location. At the pig buried location, both temperature and humidity were significant; consequently, two graphs are given. The first graph displays the estimated probability of making a correct identification versus temperature with humidity fixed at 57.2%. The second graph displays the estimated probability of making a correct identification versus humidity with temperature fixed at 71.7°F. These values were the average humidity and temperature, respectively, at the pig buried location.

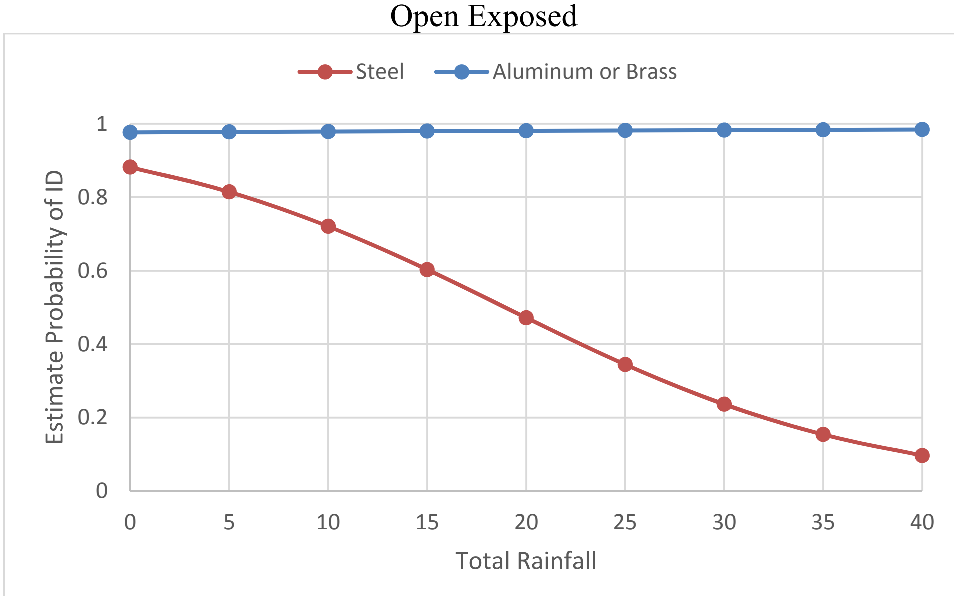
Figure 2. Logistic regression models for most influential factor in each environment

Shaded Buried



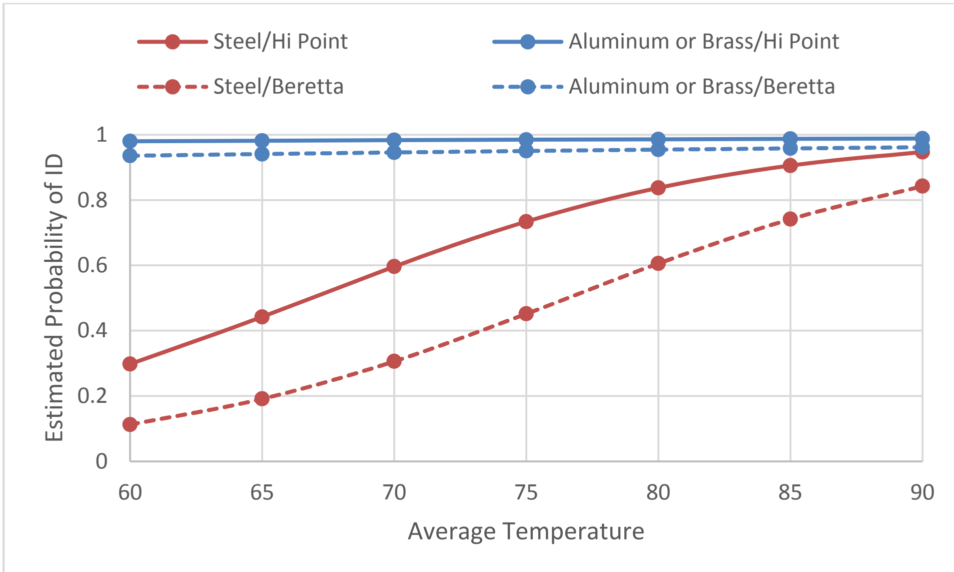
$$\widehat{\text{logit}}(p_i) = 4.1668 + 0.8849 \text{ steel} + 0.1370 \text{ month} - 0.5937 \text{ steel} * \text{month}$$

Open Exposed



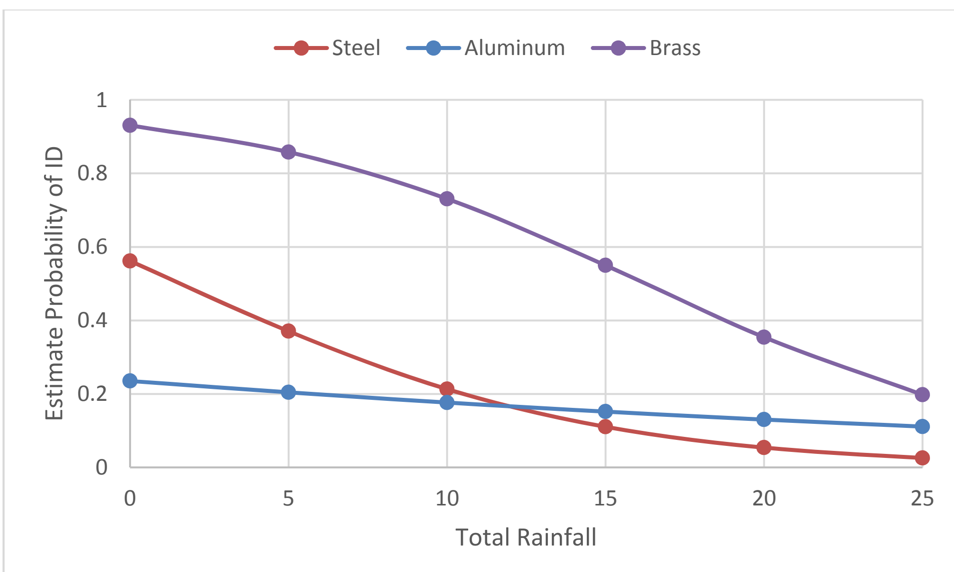
$$\widehat{\text{logit}}(p_i) = 3.7257 - 1.7171 \text{ steel} + 0.0101 \text{ rainfall} - 0.1162 \text{ steel} * \text{rainfall}$$

Open Buried



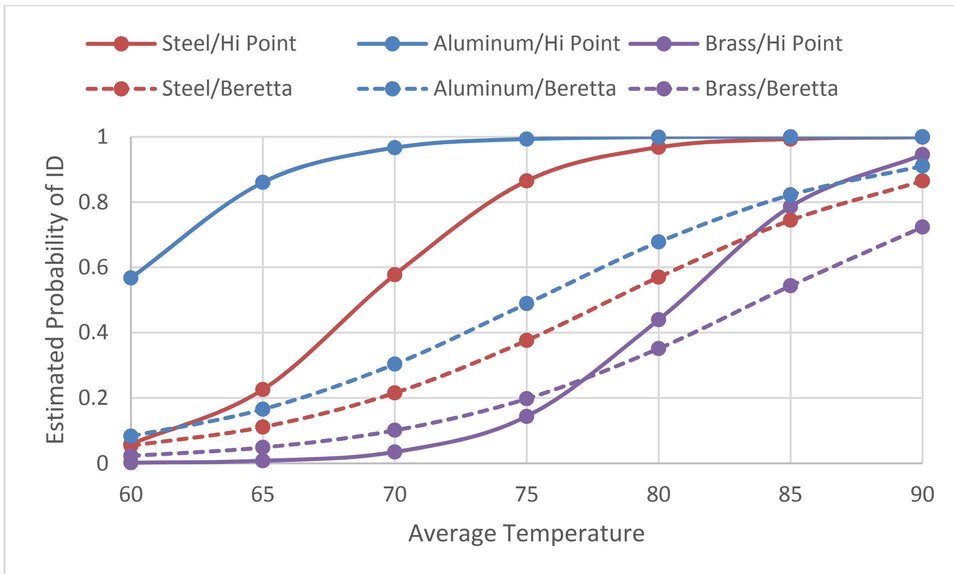
$$\widehat{\text{logit}}(p_i) = 1.5735 - 11.1277 \text{ steel} + 1.2083 \text{ gun} + 0.0184 \text{ temperature} + 0.1064 \text{ steel} * \text{temperature}$$

Water

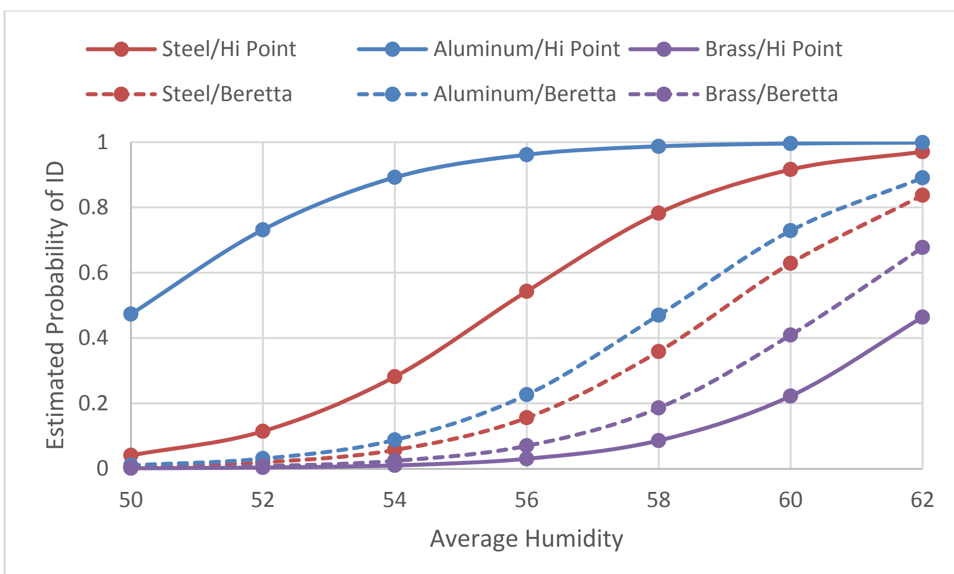


$$\widehat{\text{logit}}(p_i) = 0.2481 - 1.4275 \text{ aluminum} + 2.3499 \text{ brass} - 0.1555 \text{ rainfall} + 0.1195 \text{ aluminum} * \text{rainfall} - 0.00438 \text{ brass} * \text{rainfall}$$

Pig Buried
With humidity fixed at 57.2%



With temperature fixed at 71.7°F



$$\widehat{\text{logit}}(p_i) = -132.6 + 0.4611\ \text{aluminum} - 0.8946\ \text{brass} - 8.9870\ \text{gun} + 1.3929\ \text{temperature} \\ + 2.1030\ \text{humidity} + 2.5864\ \text{aluminum} * \text{gun} - 2.7472\ \text{brass} * \text{gun} \\ + 0.1513\ \text{gun} * \text{temperature} - 0.0216\ \text{temperature} * \text{humidity}$$

Table 1 contains the odds ratios (with 95% confidence intervals) for composition and gun. Consider the first odds ratio in Table 1b. This odds ratio can be interpreted as follows. The estimated odds of correctly identifying an aluminum or brass cartridge case are 17.86 times higher than the estimated odds of correctly identifying a steel cartridge case, when the total rainfall is 10 inches. Also given in Table 1 are the 95% confidence intervals for each odds ratio. If a confidence interval does not contain 1 then the odds ratio is significant at the 0.05 level.

Table 1. Odds ratios for composition and gun at each location.

Shaded Buried

Comparison	OR	95% CI
Aluminum or Brass vs. Steel (month=3)	2.45	(0.13, 45.45)
Aluminum or Brass vs. Steel (month=6)	14.49	(1.44, 142.86)
Aluminum or Brass vs. Steel (month=9)	83.33	(3.52, >1000)
Aluminum or Brass vs. Steel (month=12)	500.00	(4.18, >1000)

Open Exposed

Comparison	OR	95% CI
Aluminum or Brass vs. Steel (rainfall=10)	17.86	(4.83, 66.67)
Aluminum or Brass vs. Steel (rainfall=20)	55.56	(11.11, 333.33)
Aluminum or Brass vs. Steel (rainfall=30)	200.00	(12.66, >1000)
Aluminum or Brass vs. Steel (rainfall=40)	500.00	(12.05, >1000)

Open Buried

Comparison	OR	95% CI
Hi Point vs. Beretta	3.35	(1.19, 9.41)
Aluminum or Brass vs. Steel (temperature=60)	111.11	(21.74, 500.00)
Aluminum or Brass vs. Steel (temperature=70)	40.00	(13.16, 125.00)
Aluminum or Brass vs. Steel (temperature=80)	13.70	(3.13, 58.82)
Aluminum or Brass vs. Steel (temperature=90)	4.74	(0.46, 50.00)

Water

Comparison	OR	95% CI
Brass vs. Aluminum (rainfall=5)	23.26	(7.19, 76.92)
Aluminum vs. Steel (rainfall=5)	1.95	(0.55, 6.940
Brass vs. Steel (rainfall=5)	45.88	(11.48, 183.30)
Brass vs. Aluminum (rainfall=15)	6.80	(2.02, 23.26)
Aluminum vs. Steel (rainfall=15)	20.38	(0.94, 441.75)
Brass vs. Steel (rainfall=15)	138.86	(6.83, >1000)
Brass vs. Aluminum (rainfall=25)	1.97	(0.16, 23.81)
Aluminum vs. Steel (rainfall=25)	212.90	(0.87, >1000)
Brass vs. Steel (rainfall=25)	420.27	(1.87, >1000)

Pig Buried

Comparison	OR	95% CI
Aluminum vs. Brass (Beretta)	3.88	(1.27, 11.90)
Aluminum vs. Steel (Beretta)	1.03	(0.37, 2.86)
Steel vs. Brass (Beretta)	3.77	(1.25, 11.36)
Aluminum vs. Brass (Hi Point)	803.82	(50.46, >1000)
Aluminum vs. Steel (Hi Point)	11.63	(1.24, 109.27)
Steel vs. Brass (Hi Point)	71.43	(9.80, 500.00)
Hi Point vs. Beretta (Aluminum temperature=60)	14.49	(1.53, 142.86)
Beretta vs. Hi Point (Brass temperature=60)	14.26	(1.30, 156.86)
Hi Point vs. Beretta (Steel temperature=60)	1.29	(0.32, 5.08)
Hi Point vs. Beretta (Aluminum temperature=75)	142.86	(12.50, >1000)
Beretta vs. Hi Point (Brass temperature=75)	1.47	(0.34, 6.39)
Hi Point vs. Beretta (Steel temperature=75)	12.50	(2.87, 52.63)
Hi Point vs. Beretta (Aluminum temperature=90)	>1000	(45.45, >1000)
Hi Point vs. Beretta (Brass temperature=90)	6.58	(0.99, 43.48)
Hi Point vs. Beretta (Steel temperature=90)	125.00	(7.87, >1000)

Analysis of Scanning Electron Microscope (SEM) Data

Six casings of each composition were collected at each location at 3, 6, 9, and 12 months. In some instances (open buried steel 12 mos., water all 12 mos., pig buried aluminum and steel 3 mos.), some of the casings were missing at the time of collection resulting in a sample size less than six. The researcher failed to collect cartridge cases from the water environment due to the failure of the fishing line – when the PVC frame was removed from the water, the fishing lines for two sample groups were no longer intact, and the cartridge cases remained in the water. In all, 410 casings were analyzed to determine the percentage of elements present on the casings.

The percentages of elements varied greatly for each composition and location. Consequently, it was necessary to perform the analysis for each combination of composition and location separately. This resulted in very small sample sizes. Additionally, the compositional structure of the data (meaning the percentages were dependent upon each other and summed to 100%) prevented the use of many statistical analyses. Because of these issues, this part of the experiment was treated as a pilot study. Summary statistics were computed and plots constructed to identify which elements should potentially be considered for future study. The mean percentages by month, location, and composition are presented in Table 2.

The top two elements (by percentage) for each combination of location and composition were identified. The remaining elements were added together and called Other. The top two elements and Other were then used to construct ternary diagrams using Excel. These diagrams are displayed in Figure 3.

In Table 2, elements that are either strictly increasing or decreasing (or very close to it) are highlighted. It is interesting to note that oxygen is highlighted six times in Table 2. No other element is highlighted more than three times. Ternary diagrams for each combination of location and composition are displayed in Figure 3. In a ternary diagram, the closer the point is to a vertex of the triangle, the higher the percentage of that element. Consider the diagram for open exposed aluminum. At 3 and 6 months, the casings are highest in nickel, but at 9 and 12 months, oxygen and other are more predominant. Several other diagrams display a similar pattern.

Table 2. Mean percentage of elements present on the cartridge cases at each location.

Shaded Exposed

	n	C	O	Mg	Al	Si	Ca	Ni	Cu	Zn	Ta	Re
Aluminum												
3 mos.	6	11.5	3.0		0.17			75.2	10.1			
6 mos.	6	12.1	3.3		0.12			72.6	11.8			
9 mos.	6	11.9	5.4		0.57	0.97		66.4	14.8			
12 mos.	6	11.5	2.0		0.47			76.7	8.3	1.1		
Brass												
3 mos.	6	10.4	0.76					64.5	23.6	0.70		
6 mos.	6	11.9	5.0					74.0	8.8	0.36		
9 mos.	6	11.7	5.1					66.3	16.1		0.74	
12 mos.	6	13.1	5.2			0.75		64.8	16.2			
Steel												
3 mos.	6	12.5	8.6	0.25		0.30	1.2		55.4	21.6		
6 mos.	6	16.8	22.3			0.23			52.3	2.0		6.4
9 mos.	6	12.6	8.5		0.24	0.49		7.8	53.5	16.9		
12 mos.	6	18.1	11.8			0.88	0.19		55.0	14.0		

Shaded Buried

	n	C	O	Na	Mg	Al	Si	K	Ca	Fe	Ni	Cu	Zn	Re
Aluminum														
3 mos.	6	14.5	7.1				0.81		4.7		60.3	12.6		
6 mos.	6	12.6	7.7	0.17		1.7	2.3		0.56		70.9	4.1		
9 mos.	6	12.5	6.6			0.77	0.63		2.5		54.9	20.1	2.0	
12 mos.	6	29.5	7.1			0.44	0.40		0.35		46.6	15.7		
Brass														
3 mos.	6	21.9	1.1								52.6	24.4		
6 mos.	6	11.1	6.0	0.40		1.3	2.3			0.08	52.4	23.2		3.3
9 mos.	6	11.2	3.1			0.64	0.88				58.3	23.2	2.6	
12 mos.	6	14.5	3.8			0.67	1.1				60.8	17.9	2.1	
Steel														
3 mos.	6	18.0	21.7		0.36	0.36	4.4		12.3			34.2	8.5	
6 mos.	6	11.4	23.2		0.56	1.1	10.2	0.12	6.5	0.23		35.1	11.7	
9 mos.	6	14.7	42.0		0.33	2.3	13.6	0.20	14.5	0.89		8.4	3.1	
12 mos.	6	13.9	40.9		0.58	1.5	11.0		16.7	2.7		9.5	3.2	

Open Exposed

	n	C	O	Mg	Al	Si	K	Ca	Fe	Ni	Cu	Zn	Ta	Re
Aluminum														
3 mos.	6	15.5	11.9		1.2	2.6		4.5		64.3				
6 mos.	6	8.6	6.6		1.7	1.3				72.5	9.4			
9 mos.	6	13.1	20.6	0.61	2.3	2.9		14.0	0.36	41.5	4.7			
12 mos.	6	21.0	26.6	0.66	2.5	3.8	0.15	10.9	0.66	28.9	4.8			
Brass														
3 mos.	6	9.6	3.5		0.74	1.6				70.5	14.0			
6 mos.	6	11.8	3.7		0.61	1.2				57.8	17.2			7.7
9 mos.	6	7.3	6.0		1.6	2.1			0.44	72.5	8.0	2.0		
12 mos.	6	8.7	8.6	0.22	3.1	4.5	0.14	0.16	0.42	56.5	17.6			
Steel														
3 mos.	6	14.9	23.7	0.33	2.3	6.6	0.23	9.4	0.80		31.3	10.4		
6 mos.	6	11.8	27.2	0.78	2.5	5.7	0.18	12.5	0.87		27.9	10.6		
9 mos.	6	13.0	42.3	0.66	3.3	9.5	0.44	14.8	1.3		11.0	3.6		
12 mos.	6	12.1	46.8	0.35	2.2	6.7	0.12	28.5	1.3		0.13		1.4	0.56

Open Buried

	n	C	O	Na	Mg	Al	Si	K	Ca	Mn	Fe	Ni	Cu	Zn	Ta	Re
Aluminum																
3 mos.	6	14.1	17.5		0.60	3.2	4.8	0.26	7.0		0.88	50.2	1.9			
6 mos.	6	9.3	10.5		0.32	1.7	2.0		8.1		0.56	53.3	14.3			
9 mos.	6	11.1	11.6		0.24	1.7	1.6		7.7		0.10	60.6	4.0			1.4
12 mos.	6	12.3	12.6	0.33	0.25	1.9	2.9	0.26	9.2		0.60	47.4	11.8	0.48		
Brass																
3 mos.	6	8.5	4.2			1.3	1.7				0.22	63.3	18.8	2.1		
6 mos.	6	8.7	5.7	0.13		1.6	2.4				0.42	54.0	25.2	1.8		
9 mos.	6	7.0	3.0			0.47	0.95				0.22	71.4	17.0			
12 mos.	6	13.0	6.3	0.66		0.95	1.8	0.15			0.46	55.2	18.4	3.1		
Steel																
3 mos.	6	12.5	27.6		1.6	2.2	6.2	0.29	8.0		3.4		27.1	11.3		
6 mos.	6	9.5	45.1		5.2	2.6	5.4	0.34	14.6	0.12	3.9		9.3	3.4	0.43	
9 mos.	6	8.9	38.7		1.0	2.4	5.4	0.17	7.9		20.3		10.1	2.4		
12 mos.	5	8.0	44.0		1.2	3.2	9.4	0.46	16.6		15.3		1.9			

Water

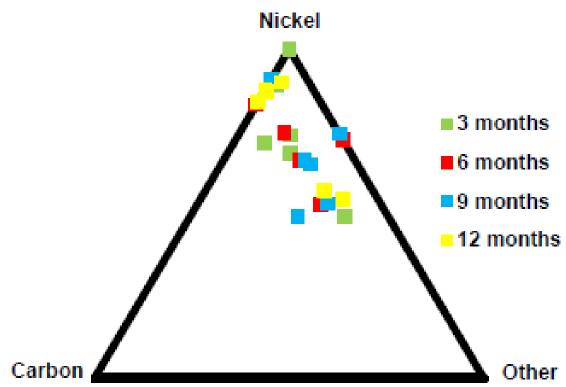
	n	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	Mn	Fe	Ni	Cu	Zn	Tl
Aluminum																	
3 mos.	6	11.7	28.8		0.84	0.45	0.58		0.47		27.7	0.93	0.18	15.1	9.9	3.1	0.16
6 mos.	6	11.4	33.4		0.56	0.82	0.95		0.92		26.2		0.19		20.6	5.0	
9 mos.	6	13.7	43.3		0.82	1.1	2.9		0.44		29.7		0.17	0.96	7.0		
Brass																	
3 mos.	6	11.4	4.5			0.19	0.38		0.47	0.17			0.16	31.0	41.7	10.0	
6 mos.	6	12.8	14.8			0.20	0.53	0.43	0.54		0.39		6.7	10.3	49.2	1.5	
9 mos.	6	13.9	15.1	0.52		0.28	1.4	0.10	0.84	2.7	0.14		10.9	1.3	47.1	5.8	
Steel																	
3 mos.	6	10.6	40.6		0.42		0.15		0.12		26.4	0.18	5.4		4.4	1.5	
6 mos.	6	13.1	43.4		0.81	0.85	2.0	0.18			29.5		10.0				
9 mos.	6	9.9	45.5		0.13	0.55	1.5		0.24		34.0	0.51	6.7		0.92		

Pig Buried

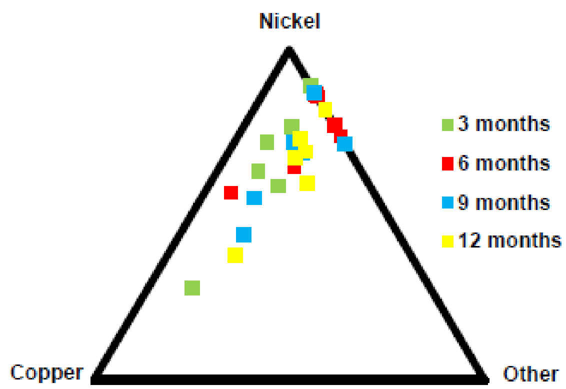
	n	C	N	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Mn	Fe	Ni	Cu	Zn	Ta
Aluminum																			
3 mos.	5	34.5		7.0	0.57	0.10	0.55			4.0			0.28			32.2	18.9	1.9	
6 mos.	6	48.9		8.1		0.21	0.58	0.12		2.1			0.42			4.4	25.9	9.4	
9 mos.	6	19.7		6.9		0.31	0.34	0.13		2.7			0.44			6.6	49.5	13.4	
12 mos.	6	26.3		23.1	0.74	0.16	3.6	6.7		1.9		0.19	0.71		1.9	8.1	24.4	2.0	
Brass																			
3 mos.	6	49.8		8.9			0.39	0.54	0.10	1.3	1.0		0.09			6.0	23.3	8.5	
6 mos.	6	57.1	0.77	8.7			0.02		0.14	1.2	0.79		0.46			1.1	20.1	8.4	1.2
9 mos.	6	57.8	0.79	14.5			0.49	1.6		0.86	0.55		0.15		0.21		15.2	7.6	
12 mos.	6	31.2		10.6			0.10	0.31		0.60	4.2		0.28			4.7	34.3	13.7	
Steel																			
3 mos.	4	32.2		13.5	1.3	1.6		0.14		3.1			0.76				32.8	14.6	
6 mos.	6	41.3		12.7	0.48	0.98	0.69	1.1		4.3			0.94		1.5		29.4	6.6	
9 mos.	6	42.6		16.3	0.40	0.10	0.98	2.1		2.2	0.15		0.63		0.82		26.1	7.7	
12 mos.	6	38.6		24.3	0.12	0.43	1.0	4.0		0.77	0.42		1.2	0.37	13.3		11.2	4.3	

Figure 3. Ternary diagrams of the top two elements and other for each location and composition
Shaded Exposed

Aluminum



Brass



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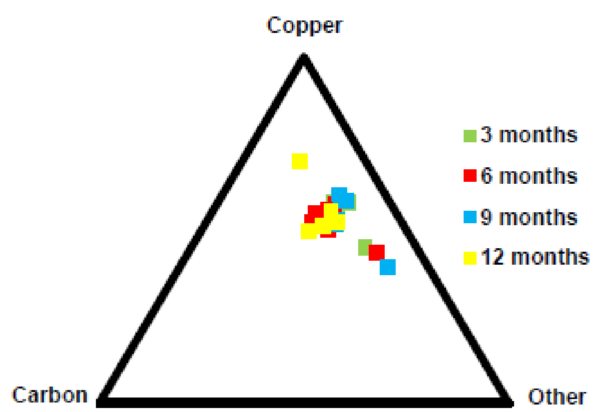
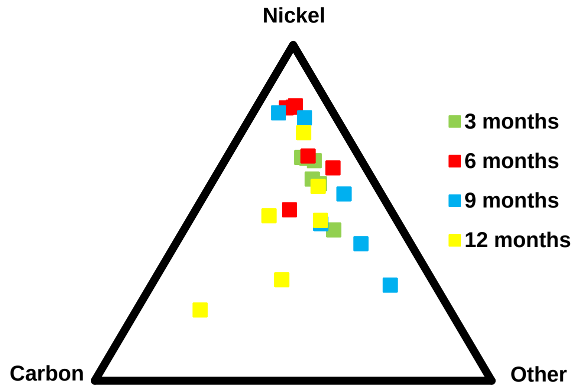
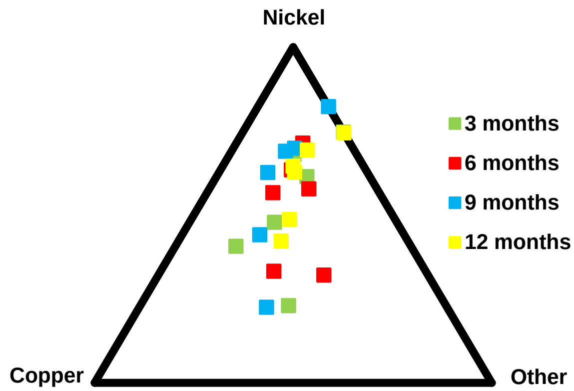


Shaded Buried

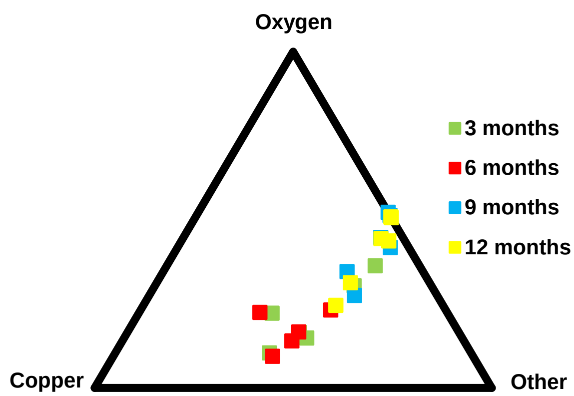
Aluminum



Brass

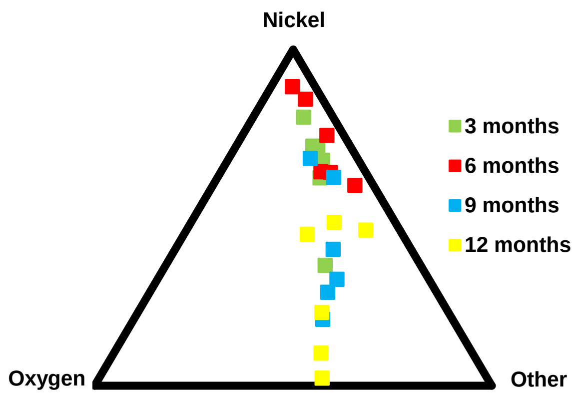


Steel

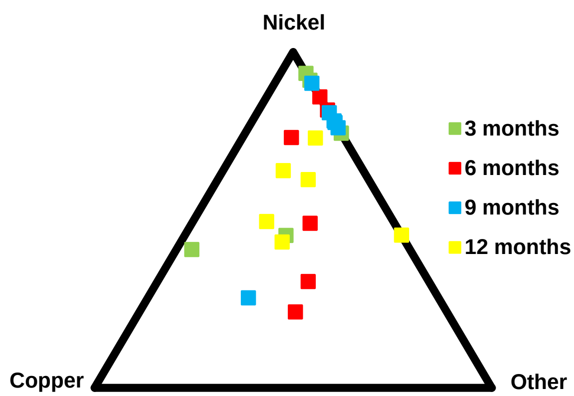


Open Exposed

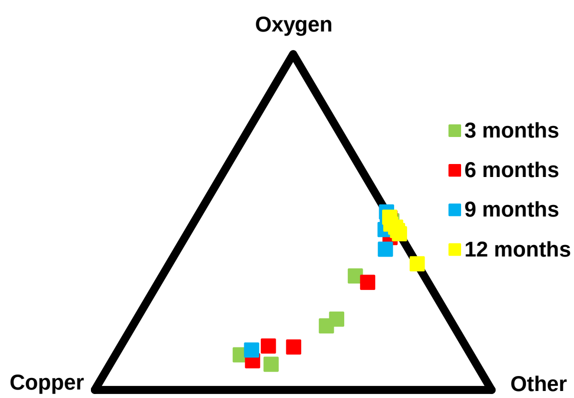
Aluminum



Brass

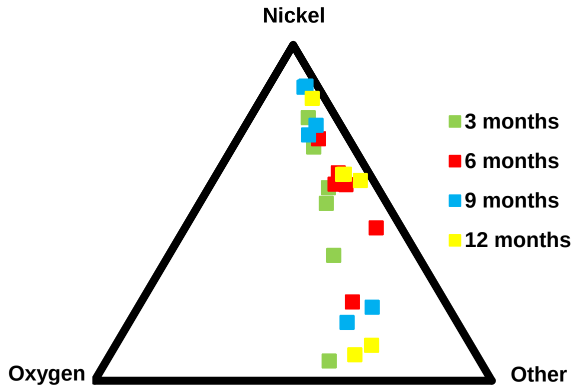


Steel

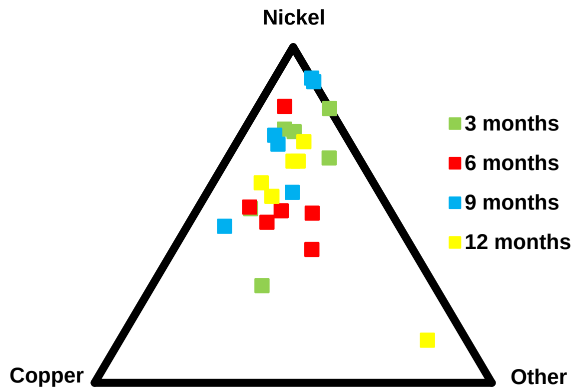


Open Buried

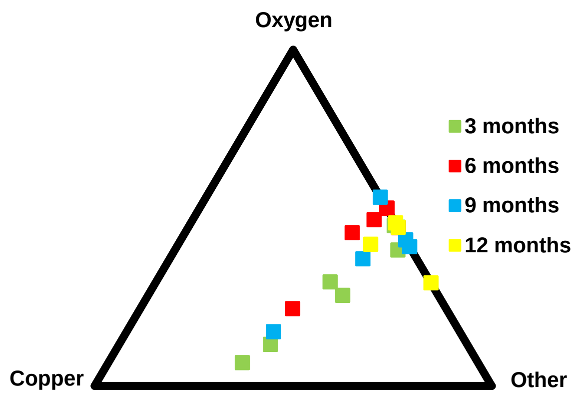
Aluminum



Brass

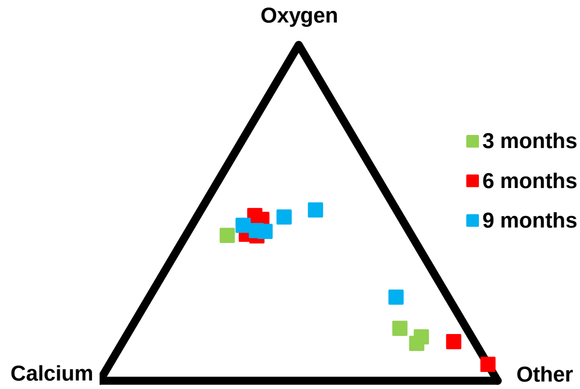


Steel

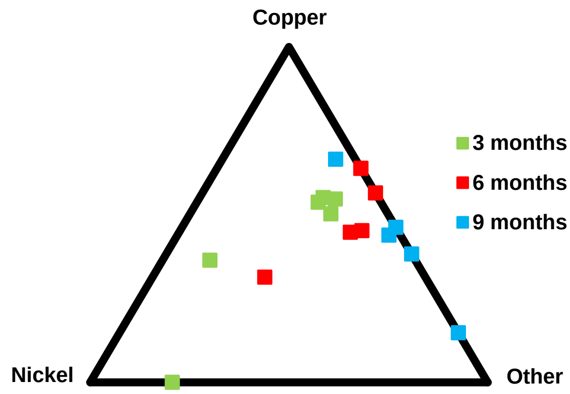


Water

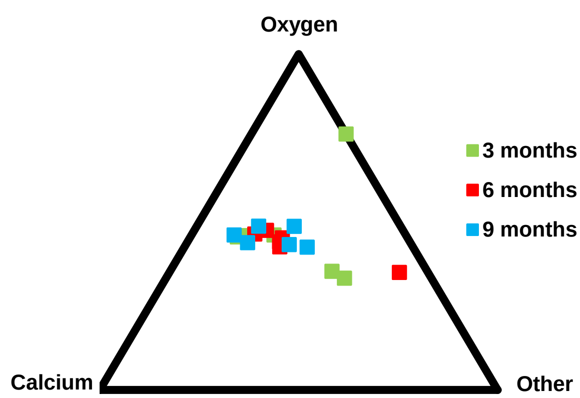
Aluminum



Brass

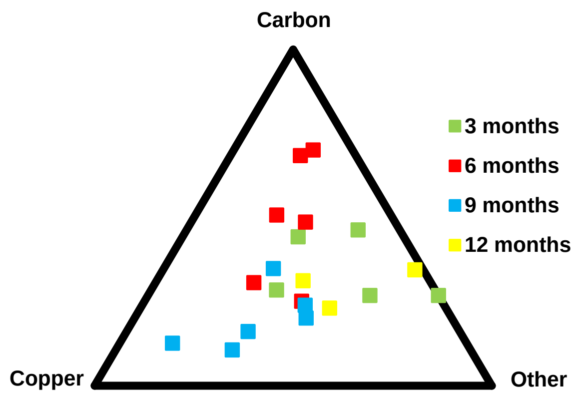


Steel

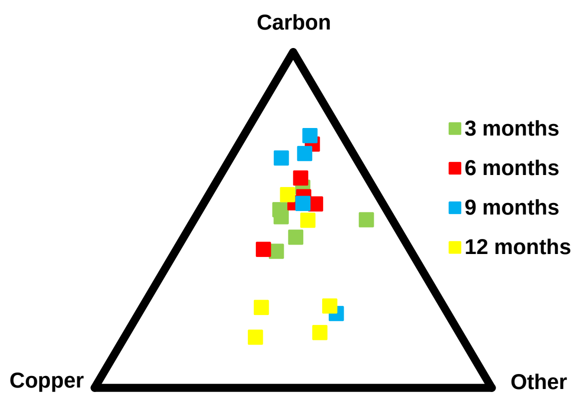


Pig Buried

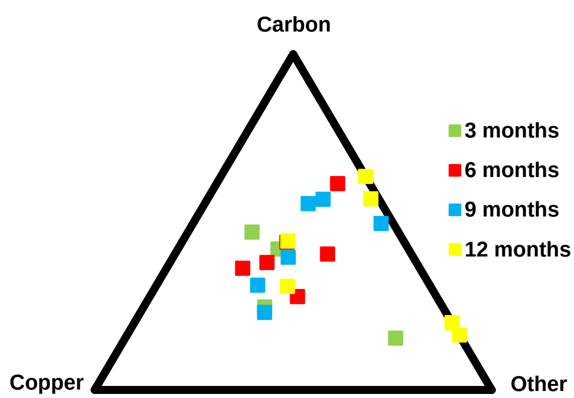
Aluminum



Brass



Steel



Analysis of Restorative Techniques

All casings that could not be identified after collection were randomly assigned to one of three cleaning techniques: Aqua Regia, jewelry cleaner, or the method created by Randich and colleagues, which was dubbed the Randich method for simplicity. The casings were then cleaned using the assigned technique and reexamined. Chi-square tests were performed to determine whether there were any differences in the proportions of casings that could be identified after cleaning. In some cases, the sample size was too small to perform a traditional chi-square test, in which case Fisher's exact test was performed instead. If the chi-square test (or Fisher's exact test) resulted in a significant p-value, pairwise chi-square tests (or Fisher's exact tests) were performed to identify exactly which method was significantly different. *p*-values less than 0.05 were considered to be significant. All randomizations and analyses for this question were performed in SAS v. 9.3.

The percentage of casings identified after cleaning are displayed in Table 3. Only the combinations of location and composition for which some of the casings could not initially be identified, are displayed in the table. A significant difference in the proportions was found for open exposed steel, open buried steel, water aluminum, and water steel. In general, for these cases, Aqua Regia was identified as the best cleaning technique, and jewelry cleaner the worst. It should be noted, however, that the Randich method was not significantly different from Aqua Regia or jewelry cleaner in some cases. These differences are indicated by letters in the table. Specifically, values in the same row, marked with the same letter, are not significantly different.

Table 3. Percentage of cartridge cases identified after cleaning

Location Composition		Technique: Aqua Regia	Technique: Jewelry Cleaner	Technique: Randich Method	p-value
Shaded Buried Steel	*n*	4	4	3	
	%	100	75.0	100	1.000*
Open Exposed Steel	*n*	8	8	8	
	%	100[a]	50.0[b]	100[a]	0.020*
Open Buried Steel	*n*	11	11	11	
	%	100[a]	45.5[b]	90.9[a]	0.007*
Water Aluminum	*n*	16	16	16	
	%	100[a]	56.3[b]	87.5[ab]	0.006*
Water Brass	*n*	3	3	3	
	%	33.3	66.7	33.3	1.000*
Water Steel	*n*	17	18	18	
	%	100[a]	5.6[c]	72.2[b]	<0.001
Pig Buried Aluminum	*n*	3	3	3	
	%	66.7	100	100	1.000*
Pig Buried Brass	*n*	20	17	19	
	%	45.0	58.8	63.2	0.492
Pig Buried Steel	*n*	5	5	7	
	%	80.0	40.0	71.4	0.548

* Fisher's Exact Test was used in this case due to small sample sizes.
[a,b,c] Values in the same row marked with the same letter are not significantly different.

Conclusion and Discussion

All of the samples left on the ground in the wooded, or shaded, environment, were identified to one of the two firearms used in this study, meaning that a qualified examiner should be able to reach a conclusion of “identification” if the cartridge case had been submitted in actual casework. In addition, the aluminum cartridge cases buried in the shaded environment, and those in the open field scenarios (exposed and buried) were also all identified.

Likelihood of Identification

The likelihood that the brass or aluminum cartridge cases would be identified was greater than that of steel cartridge cases in the following environments: buried in wooded area, buried in open field, and left exposed in open field. See Appendix 2 for documentation of comparisons (not all samples are represented in the photographs). For those buried in the shaded environment, the factor that had the greatest effect on the likelihood of identification was time. The difference was first noticeable during the third month of this study, and became more apparent with subsequent sample analyses. The amount of rainfall was identified as the factor that affected the likelihood of identification for cartridge cases exposed in the open field environment. Due to the type of soil, it is possible that more moisture allowed the soil to affect the metal more, or to become bonded with the metal more strongly.

The likelihood of identification over time for each environment was calculated and are represented in Figure 1. As the probability of identifying the samples of to a particular firearm increases, the line representing the metal composition approaches 1. Overall, the likelihood decreased over time, with different factors affecting the likelihood of identification. In some environments, the brass and aluminum cartridge cases were combined due to similarities in the proportion of cartridge cases correctly identified to a particular firearm.

The main factors that affected the decrease in each environment are represented in Figure 2. Note that the graph for samples buried in the shaded environment are the same. The factor that influenced the likelihood of identification significantly was time spent in the environment. These samples were the only group that was affected by time in a significant way. According to the data collected in this study, different factors appear to alter the likelihood of identification in the other environments.

Temperature was a main factor identified as affecting the likelihood of identification in a significant manner on samples buried in the open field - the warmer the temperature was, the greater the likelihood is that the cartridge cases will be identified. The type of firearm was also a main factor that affected the likelihood of identification in a significant way. In this scenario, there is a marked difference between the two firearms that were used in this study. The cartridge cases fired in the Hi Point pistol were more likely to be identified than those fired in the Beretta pistol; this could be due to the fact that the Hi Point creates more individual characteristics, which gives the examiner a better chance at being able to see at least a small portion when using the microscope. The steel cartridge cases fired in the Beretta pistol were the least likely to be identified from this environment.

The researcher was unable to determine any factors that affected the likelihood of identification in the water environment; humidity was removed from the statistical tests because the cartridge cases were fully submerged in water, and the researcher was unable to record the temperature of the water over time. However, the amount of precipitation seemed to have an effect on the likelihood of identification. Overall, the brass cartridge cases were more likely to be identified, with the steel cartridge cases being the least likely, sometimes by a large margin.

The greatest number of differences in data were seen in the environment where the cartridge cases were buried beneath a pig carcass. Both humidity and temperature significantly affected the likelihood of identification, so one was held constant to determine the magnitude of the effect of the other. Surprisingly, the more humid the environment was, the greater the chance that the cartridge cases of all three compositions would be identified. Aluminum cartridge cases fired in the Hi Point firearm were the most likely to be identified at the lowest temperature and lowest humidity, and the likelihood increased as both factors increased. This increase in likelihood was seen for all of the cartridge cases regardless of the firearm used, but brass cartridge cases fired in the Hi Point pistol were the least likely to be identified as humidity increased. When humidity was held constant, the increase in temperature improved the likelihood of these cartridge cases a great deal – at 90°F, the likelihood was greater than cartridge cases of any composition fired in the Beretta firearm.

For those locations in which the interactions of metal composition or firearm and time were significant, odds ratios were calculated and represented in Table 1. The odds ratios seen in the table are the smallest ratio that is statistically significant, and the month at which the ratio becomes statistically significant is also reported. For example, looking at the shaded buried environment, the odds ratio of identifying an aluminum or brass cartridge case versus a steel cartridge case before month 6 was not statistically significant, and therefore not recorded in the table. In contrast, the odds ratio of identifying a brass cartridge case from the water environment versus identifying a steel cartridge case from the water environment is statistically significant in month 1.

The first research question was aimed at determining the likelihood of identification over time. The researcher based this on factors in the different environments, and the result of this study indicates that the combination of composition and environment, time, humidity, temperature, or precipitation does affect an examiner's ability to reach a conclusion of "identification". However, it is more likely that a cartridge case will be identified to a particular firearm if the cartridge case is made of aluminum or brass. Therefore, based on the chemical analysis performed in this study, it is beneficial to first clean a submitted cartridge case with water and ultrasonic cavitation and then analyze it with the comparison microscope before any other solutions are applied.

Elemental Analysis

Due to the method used to record the data collected by the SEM, the data had to be treated as a pilot study. The mean averages of each element was reported – the percentages of the elements were added together and then divided by six to arrive at an average of the element present on the six cartridge cases. This method restricted the possible statistical tests that could be used. Consequently, the results were reported as summary statistics, and then represented in tables and ternary diagrams. However, the data suggests that there may be some predictability in the accumulation of certain elements in the different environments. In some cases, some elements were found to increase or decrease over time. For example, in the shaded exposed environment, the brass cartridge cases were the only composition on which any element increased in percentage over time when analyzed by the SEM, which was oxygen. The accumulation of elements appears to be location specific, or a combination of location and cartridge case composition – those cartridge cases that were buried under the pig had several different elements present on the area of interest that increased or decreased over time. However, because the data provided by the SEM was only from four different times, and because the samples were only exposed to the selected environments for only a year, it is difficult to generalize the results. More research is needed to determine if the observed behaviors of the elements remain consistent/if the accumulation of the elements is natural/reliable/repeats over time.

Restorative Techniques

One question that may have great benefit to the field of firearm and toolmark analysis and others asks what restorative technique should be used if examiners were to encounter cartridge cases in a case that have deteriorated. The first research question indicates what the likelihood may be that the examiner will be able to analyze the cartridge case and be able to render a conclusion. However, if the area of interest is covered by debris or corrosion, and it cannot be removed by water and ultrasonic cavitation, examiners need to know the method that can be used to safely remove the obstructions without altering the individual characteristics on the surface of the cartridge cases.

The effectiveness of the restorative technique seems to rely on the composition of the cartridge case and the environment from which the cartridge case was collected, and while the sample sizes for some of the combinations were small, statistical tests revealed that the results are still significant. For example, each technique was applied to eight steel cartridge cases from the open exposed environment. While this sample group for each technique seems small, the *p*-value that resulted from the statistical tests was less than 0.05, which is statistically significant. Effectiveness of the three restorative techniques can be viewed in Appendix 3 (not all samples are represented in the photographs). The method developed by Randich and colleagues and the application of Aqua Regia resulted in all eight cartridge cases being identified. However, the application of jewelry cleaner to the eight samples only resulted in identification of four cartridge cases out of the eight. Therefore, an examiner could have a choice of what technique to use if they were to receive a steel cartridge case left in an open field scenario. However, these results can only be generalized to those environments where the soil content is the same or similar to that used in this study.

Limitations and Further Research

As with any research, there are limitations in this study. Unfortunately, the researcher did not have the equipment necessary to record the temperature of the water, so it is unknown at this time if temperature affected the cartridge cases in some way. Future studies can remedy this overlooked data by replicating the study, and use something similar to the Tiny Tag device that can record the temperature of the water hourly. These readings would provide one more piece of data that may have an effect on the results. In addition, the pH levels of the water and soil for all locations were not tested at each sample collection, but only at the beginning of the study. Future research should test and document pH levels at each collection to determine if the pH does change over time. If changes do occur, it may affect the rate of deterioration of the samples.

While several different environments were included, the results can only be generalized to regions that are similar in soil content and pH levels in soil and water to those recorded for this study. For example, the results could not be generalized to areas like Montana because the soil found in that state will be comprised of different materials, and could possibly have a different pH level. In addition, the weather patterns will also be different from the region chosen. Temperature, humidity, and precipitation could affect the rate of deterioration and the accumulation of elements in a different way, and so generate different results. Future research could focus on different geographical regions to determine the effects of environment on the compositions of cartridge cases chosen for this study and others.

This study took place over the span of a year, which resulted in a great deal of data. However, it is possible that the cartridge cases would be affected in different ways if left out in their respective environments for longer periods of time. Patterns may have emerged through the use of the SEM that could provide a better basis for the development of a timeline. It is also possible that the likelihood of identifying certain compositions would decrease with extended exposures to the environments. Future studies should increase the exposure time of the samples in order to collect more data on the effects of long-term exposure of cartridge cases.

Only three different metal compositions were chosen for the present study, but there are several other combinations of cartridge case and primer cup compositions available that could provide different data than those used in this study. Shotshells also offer another avenue of research – the brass heads used in shotshells could be affected differently, as could the battery cup assembly. The combination of the brass head and steel battery cup could cause both to react differently than if they were separated. Other studies have included the exposure of fired bullets to different environments, but this study only focused on cartridge cases. Future studies could examine the effects of the environments used in this research on fired bullets of various designs and materials. Doing so would add to the literature of firearms identification and possibly create a timeline for bullets based on collection of data using the SEM or another instrument.

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Appendix 1
Restorative Technique #1 (Randich et al, 2000)

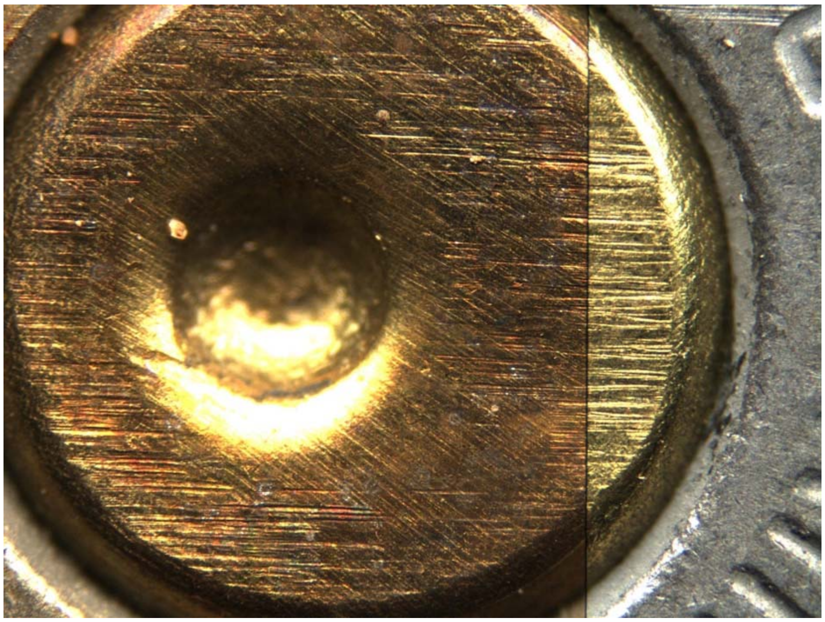
Chemicals (in order of use)	Concentration	Temperature	Time in solution
Deionized water (Millipore milli-Q water)	Ultrapure, 18-MΩ	~ 75ºC in glass beaker (casing will be suspended by stainless steel wire in interior)	Sonicated for 2 minutes
Reagent-grade, light-stabilized trichloroethylene (TCE)		Room temperature ~75ºC for samples with organic debris	Sonicated for 2 minutes Several hours w/o sonication for samples with organic debris
HPLC-grade Acetone		Room temperature	Sonicated for 2 minutes
Sodium metasilicate, ethylene glycol monobutyl ether *	10% for each chemical (by weight) in water, pH ~ 12.5	~50ºC	Sonicated for 2 minutes
Sulfuric acid, thiourea, sodium lauryl sulfate (can repeat if necessary)	3% concentrated sulfuric acide, 5% thiourea, 0.1% sodium lauryl sulfate, pH ~ 1.5	Room/ambient temperature	2-5 seconds w/o sonication for less corroded samples, 1 minute w/sonication for severely corroded
mQ water (same as step 1), two rinses	Ultrapure, 18-MΩ	Room temperature	Sonicated for 2 minutes for each rinse

*Commercial cleaners can be substituted after dilution with water

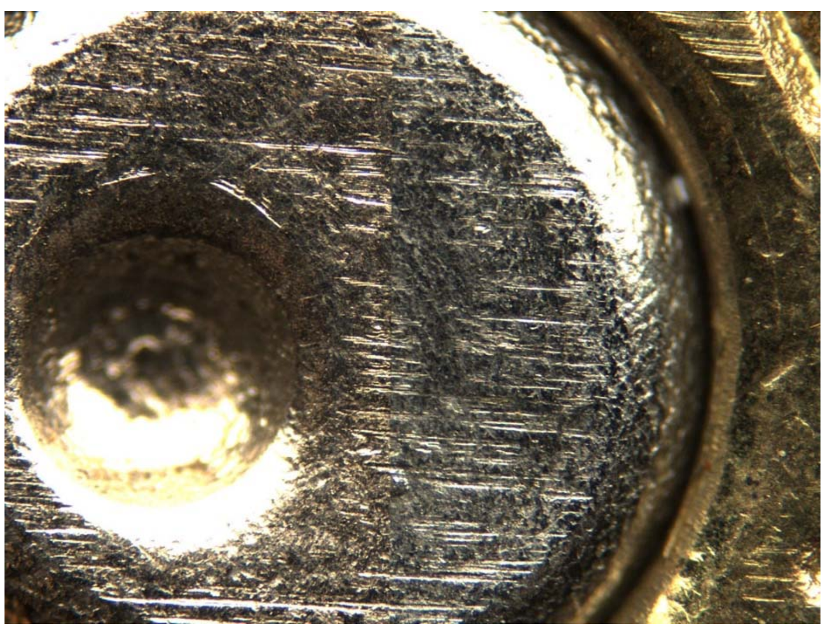
Appendix 2: Representation of samples from environments after various periods of time

(*Note: Examination of cartridge cases not limited to areas seen in photographs)

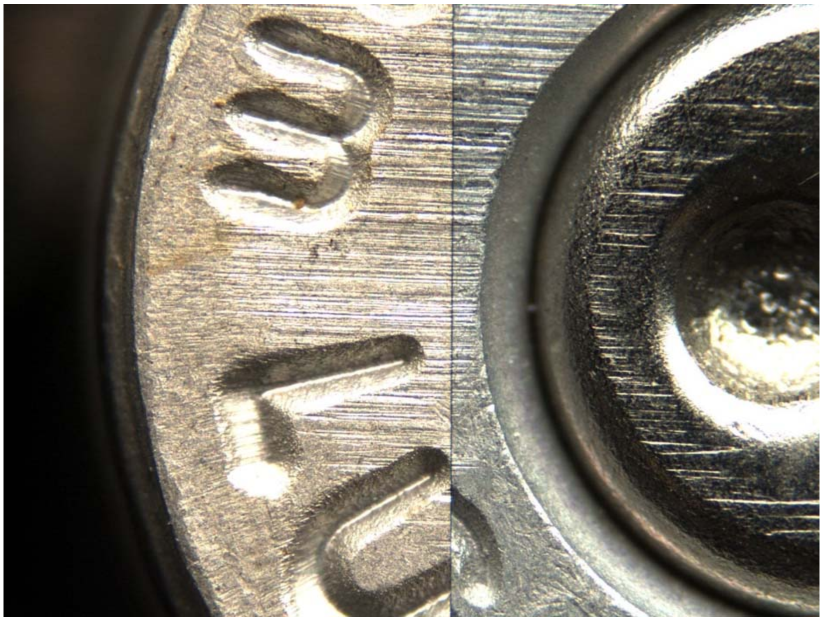
Picture 1: Unknown steel sample #13 from shaded exposed environment after 3 months (left) compared to known steel fired in Hi Point model C9 (right)



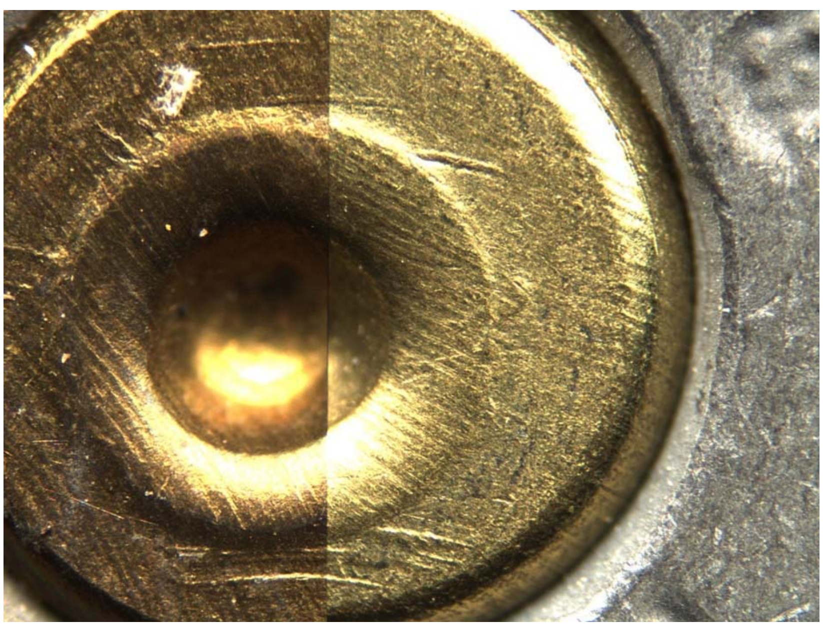
Picture 2: Unknown brass sample #3 from shaded exposed environment after 3 months (left) compared to known brass fired in Hi Point model C9 (right)



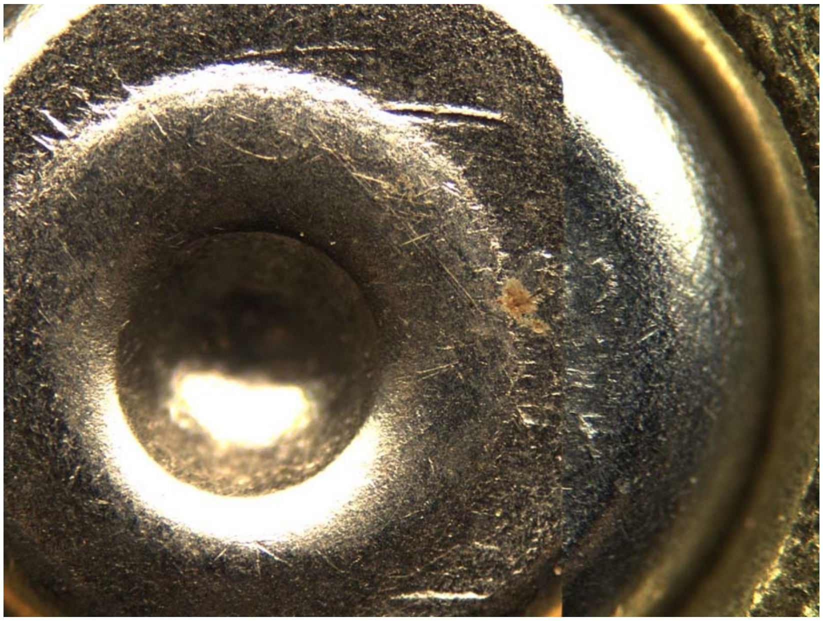
Picture 3: Unknown aluminum sample #14 from shaded exposed environment after 3 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



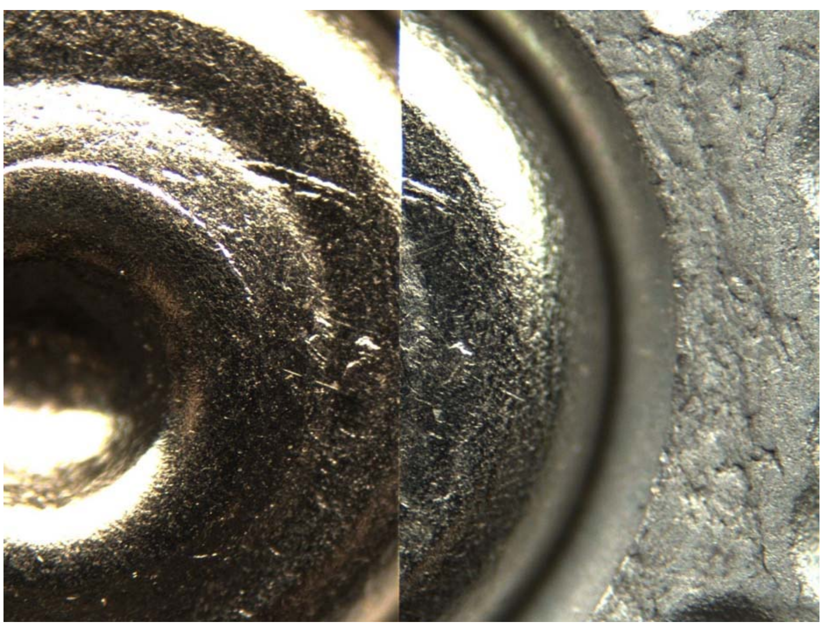
Picture 4: Unknown steel sample #7 from shaded exposed environment after 3 months (left) compared to known steel sample fired in Beretta model 92FS (right)



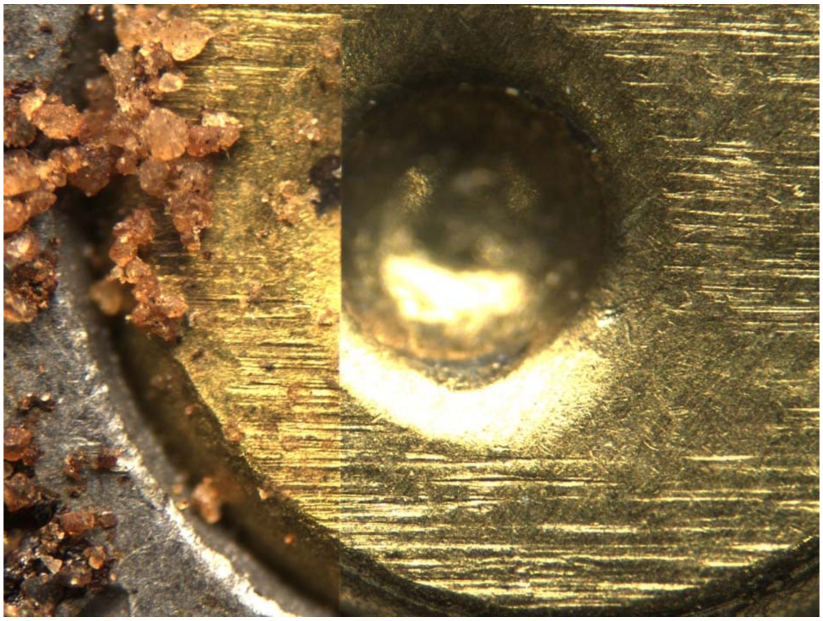
Picture 5: Unknown brass sample #5 from shaded exposed environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)



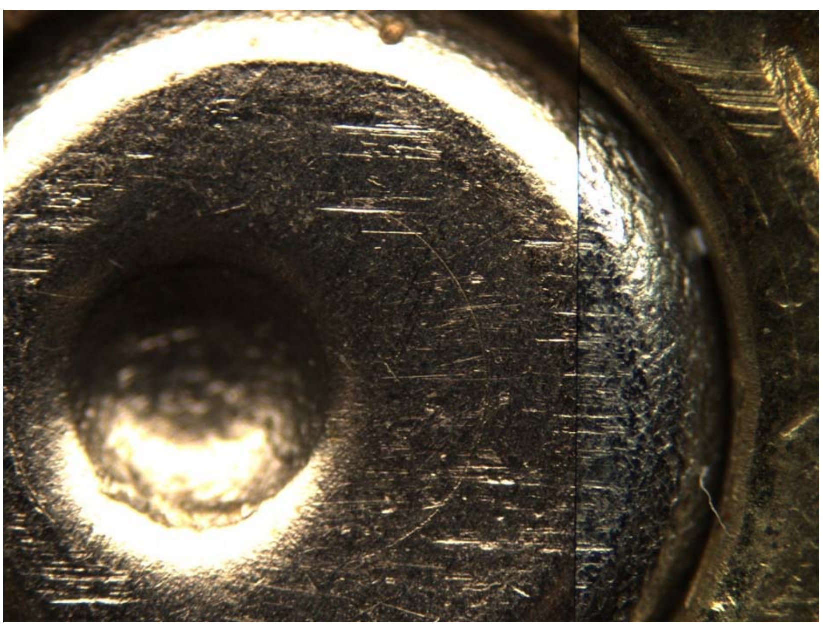
Picture 6: Unknown aluminum sample #1 from shaded exposed environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)



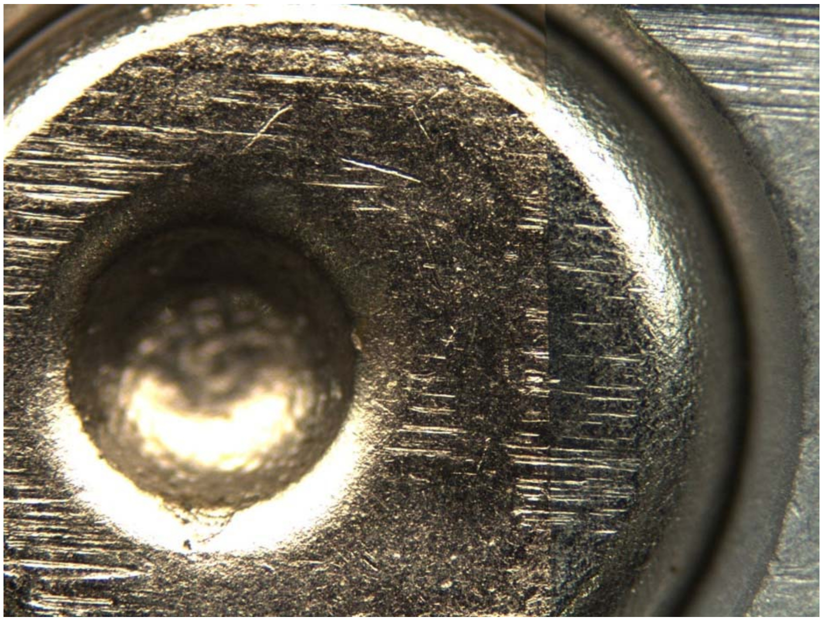
Picture 7: Unknown steel sample #3 from shaded buried environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)



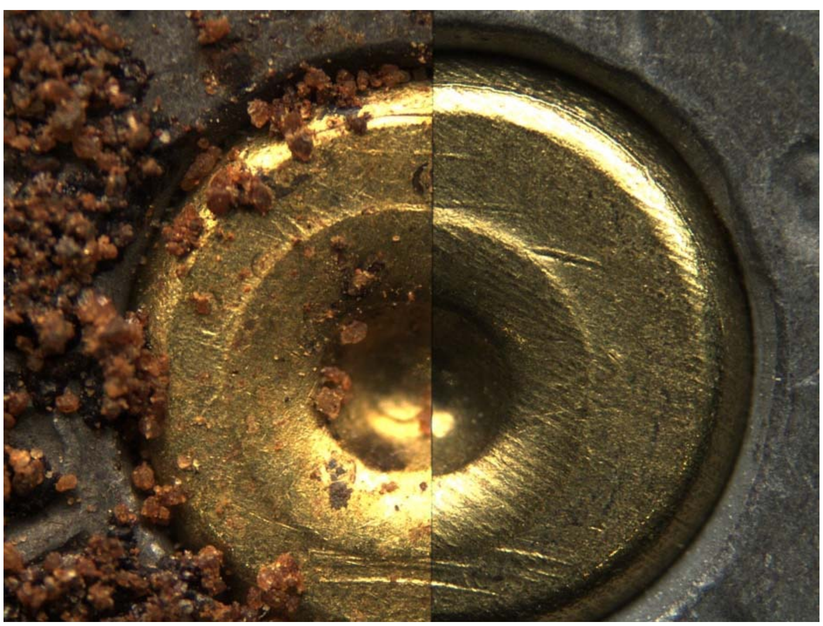
Picture 8: Unknown brass sample #14 from shaded buried environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)



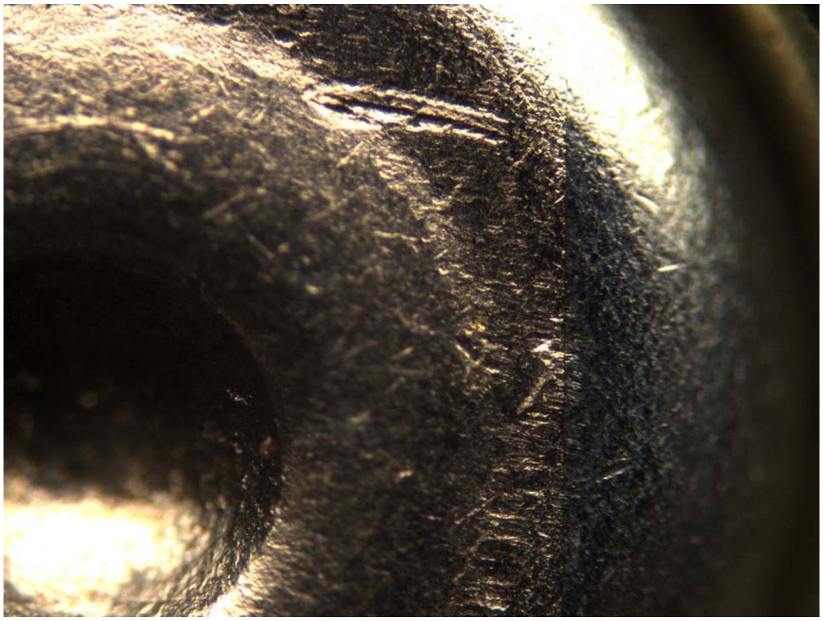
Picture 9: Unknown aluminum sample #16 from shaded buried environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)



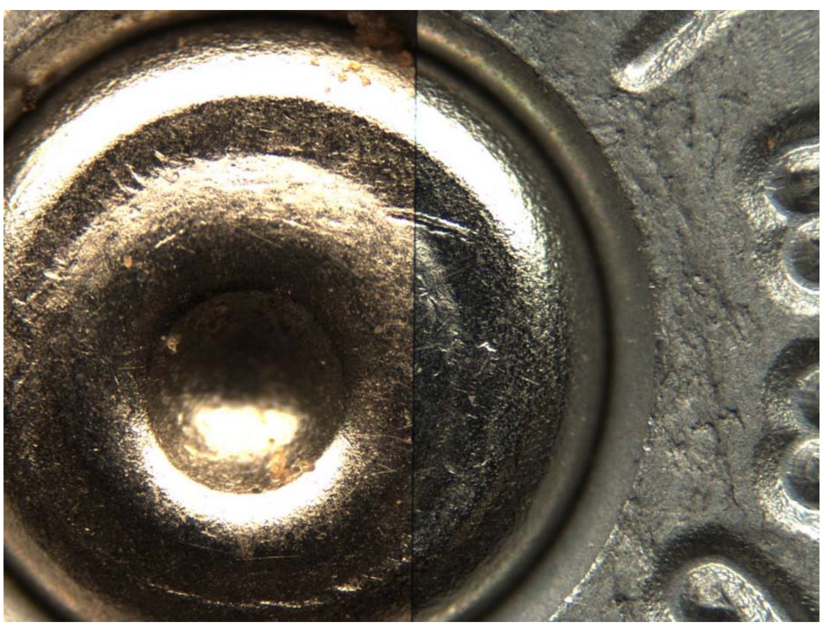
Picture 10: Unknown steel sample #4 from shaded buried environment after 3 months (left) compared to known steel sample fired in Beretta model 92FS (right)



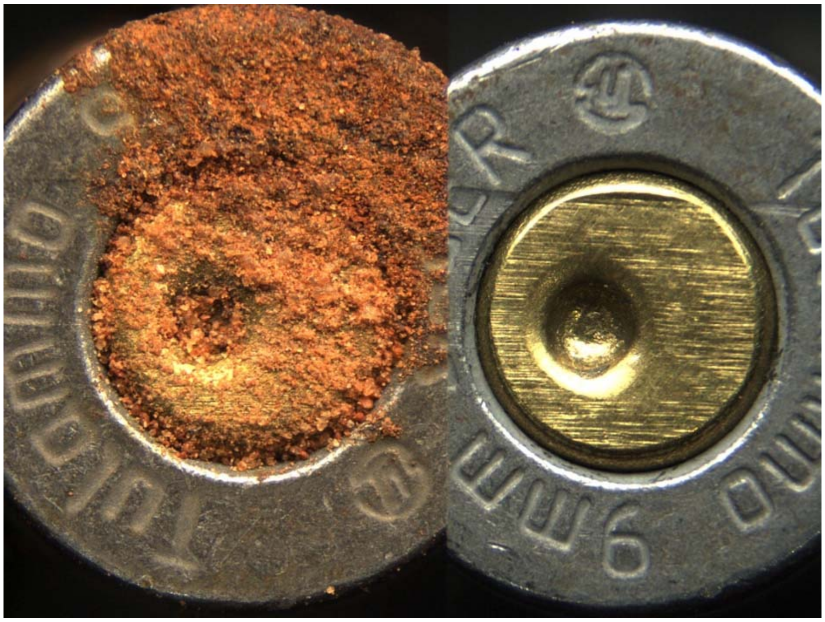
Picture 11: Unknown brass sample #10 from shaded buried environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)



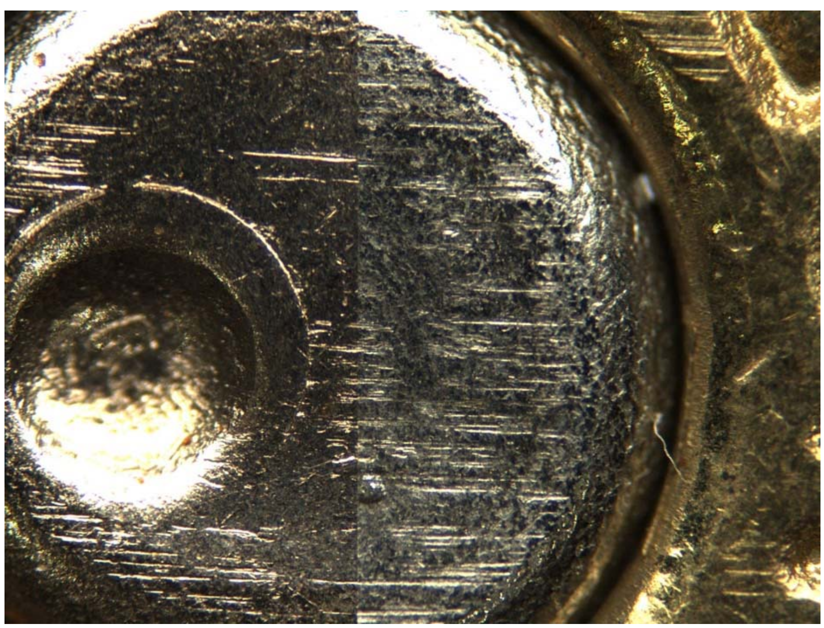
Picture 12: Unknown aluminum sample #13 from shaded buried environment after 3 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



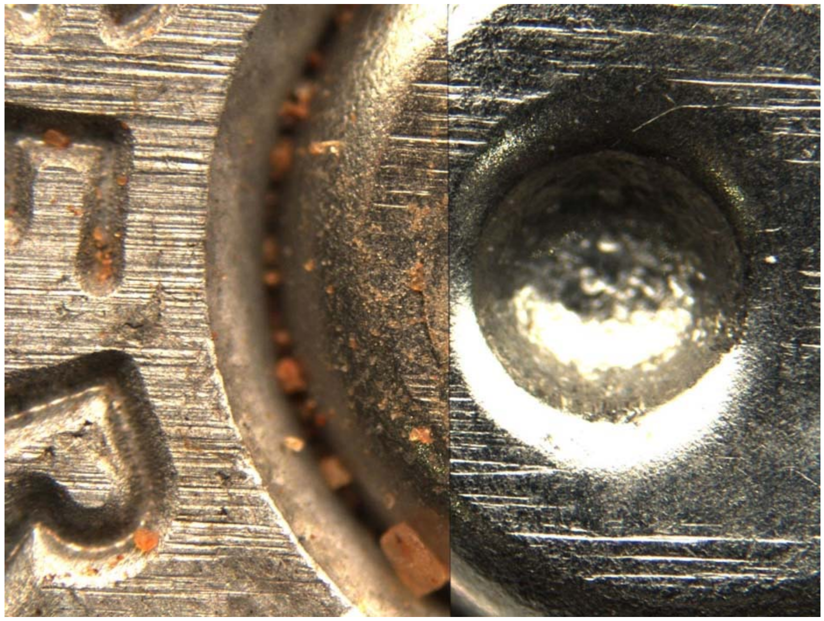
Picture 13: Unknown steel sample #17 from open exposed environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)



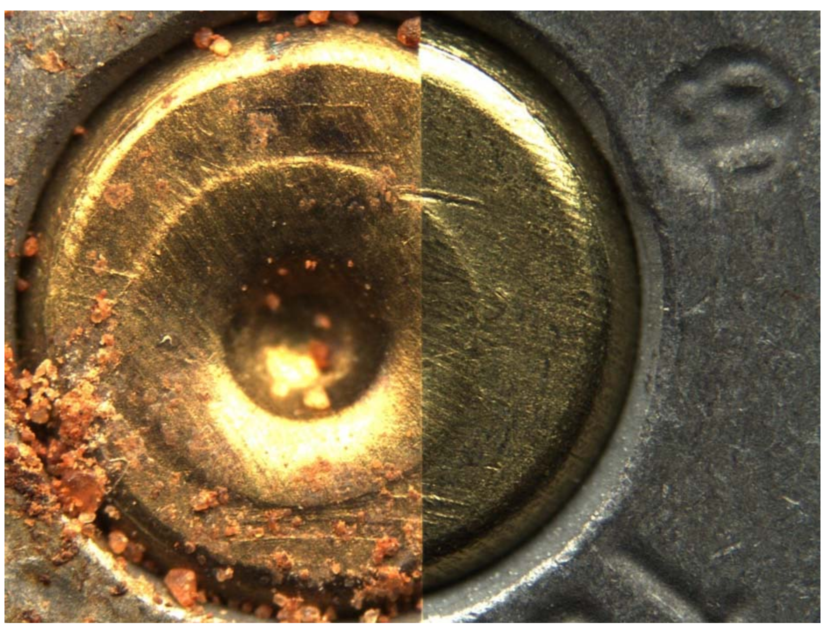
Picture 14: Unknown brass sample #16 from open exposed environment after 3 months (left) compared to known brass sample fired in Hi Point model C9 (right)



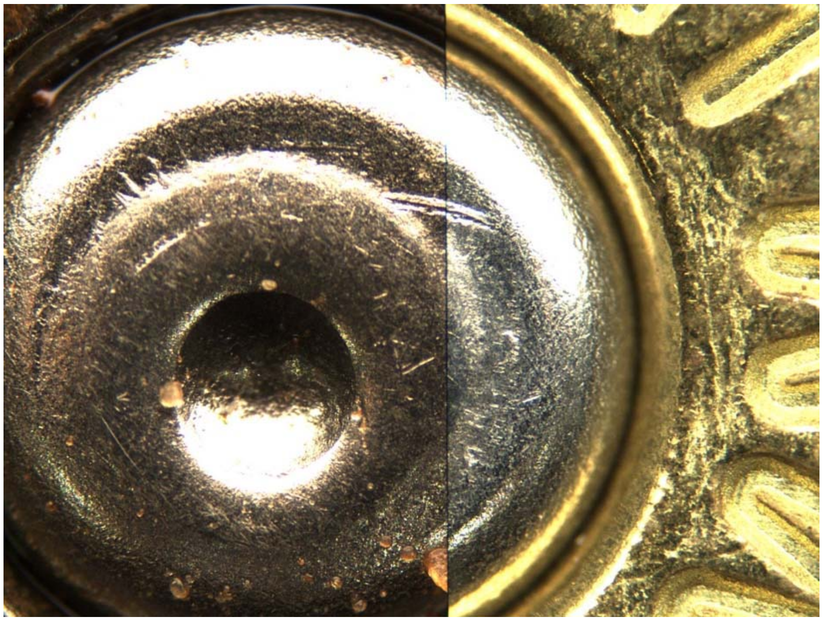
Picture 15: Unknown aluminum sample #3 from open exposed environment after 3 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



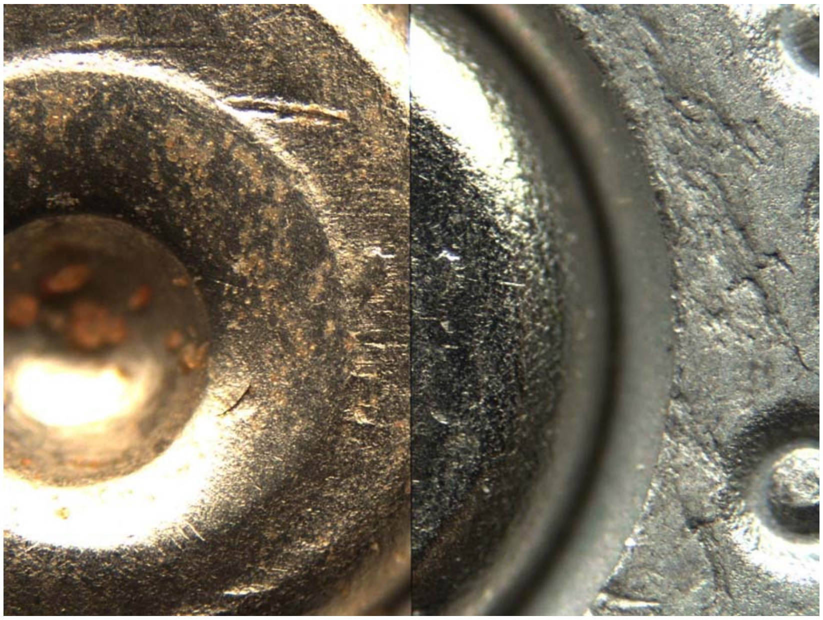
Picture 16: Unknown steel sample #9 from open exposed environment after 3 months (left) compared to known steel sample fired in Beretta model 92FS (right)



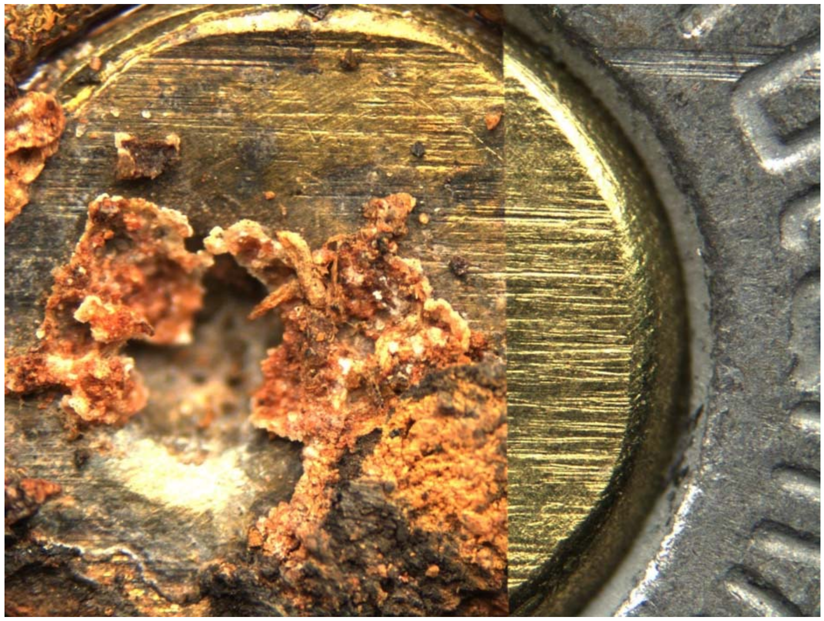
Picture 17: Unknown brass sample #4 from open exposed environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)



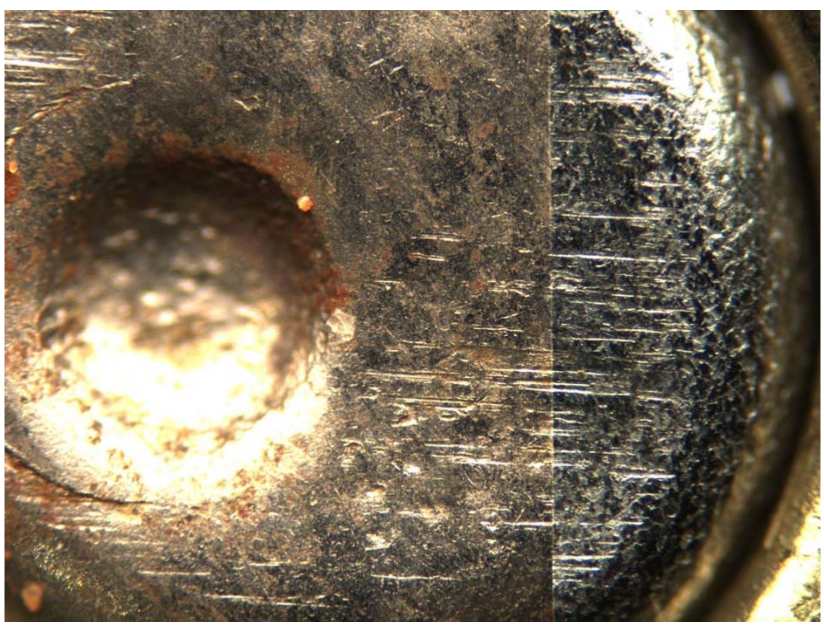
Picture 18: Unknown aluminum sample #10 from open exposed environment after 3 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



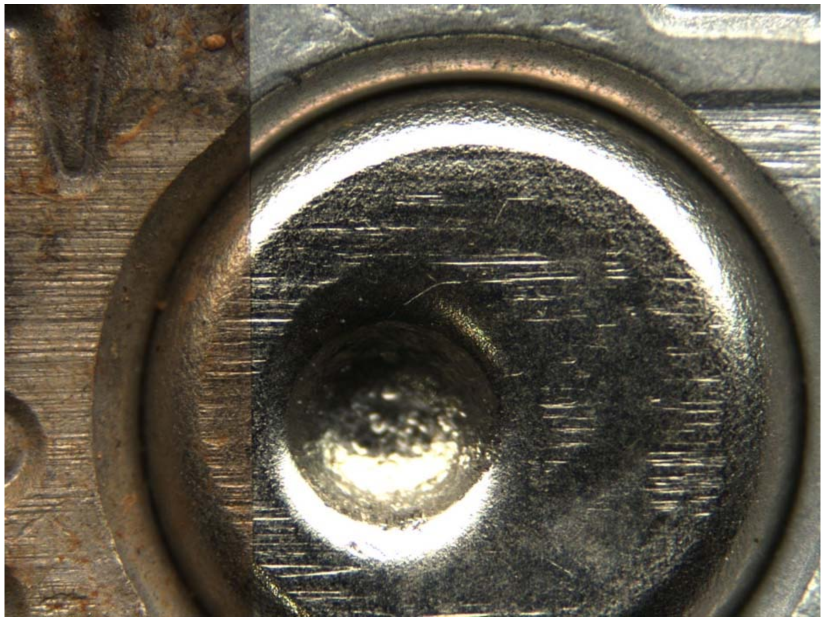
Picture 19: Unknown steel sample #3 from open buried environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)



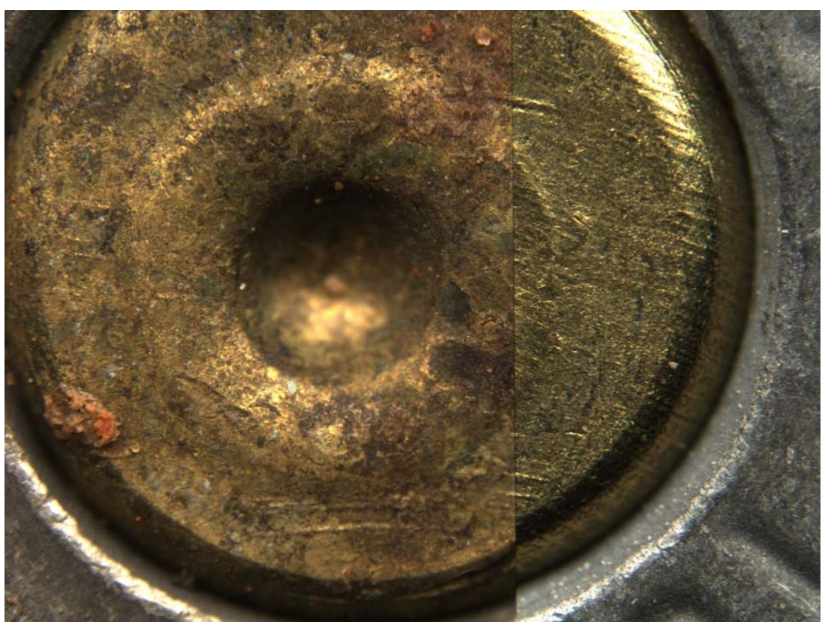
Picture 20: Unknown brass sample #7 from open buried environment after 3 months (left) compared to known brass sample fired in Hi Point model C9 (right)



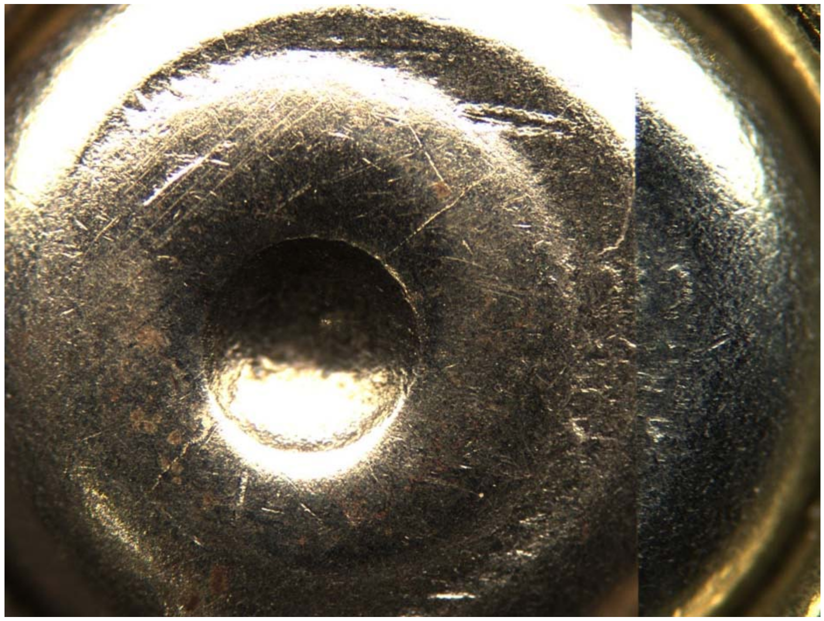
Picture 21: Unknown aluminum sample #10 from open buried environment after 3 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



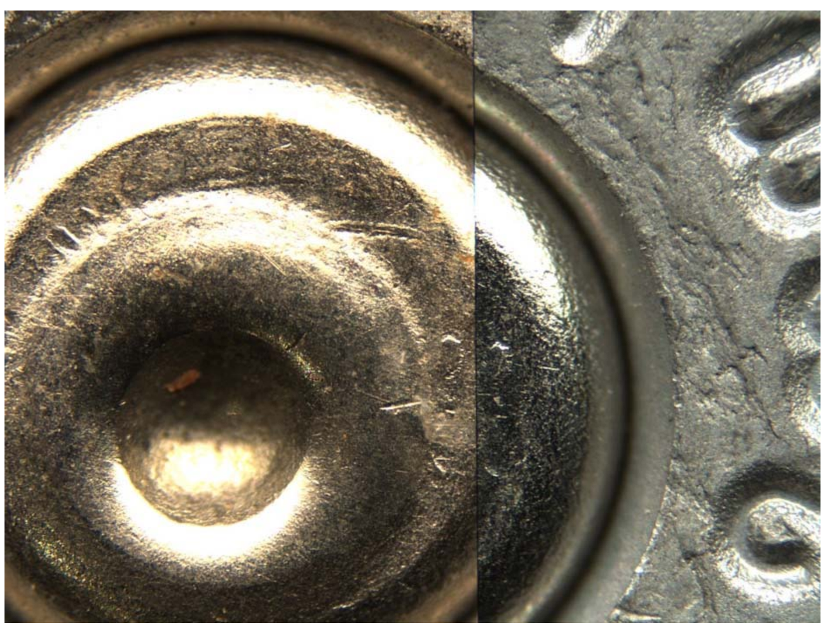
Picture 22: Unknown steel sample #15 from open buried environment after 3 months (left) compared to known steel sample fired in Beretta model 92FS (right)



Picture 23: Unknown brass sample #4 from open buried environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)

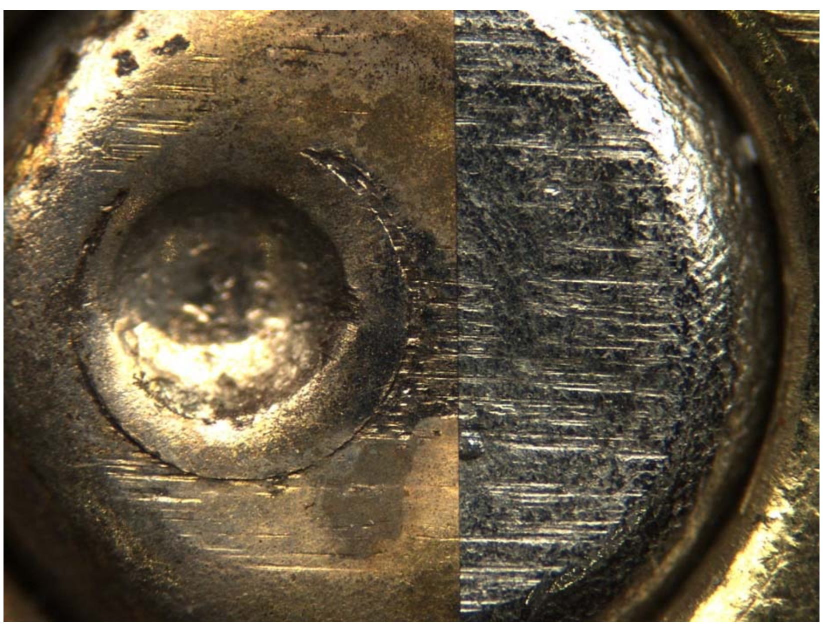


Picture 24: Unknown aluminum sample #11 from open buried environment after 3 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)

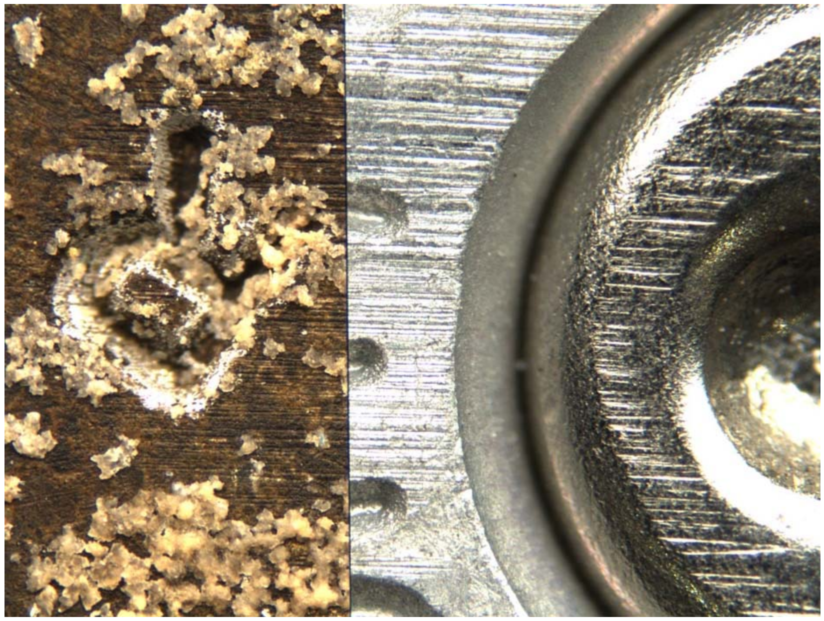


Picture 25: Unknown steel sample #14 from water environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)

Picture 26: Unknown brass sample #5 from water environment after 3 months (left) compared to known brass sample fired in Hi Point model C9 (right)

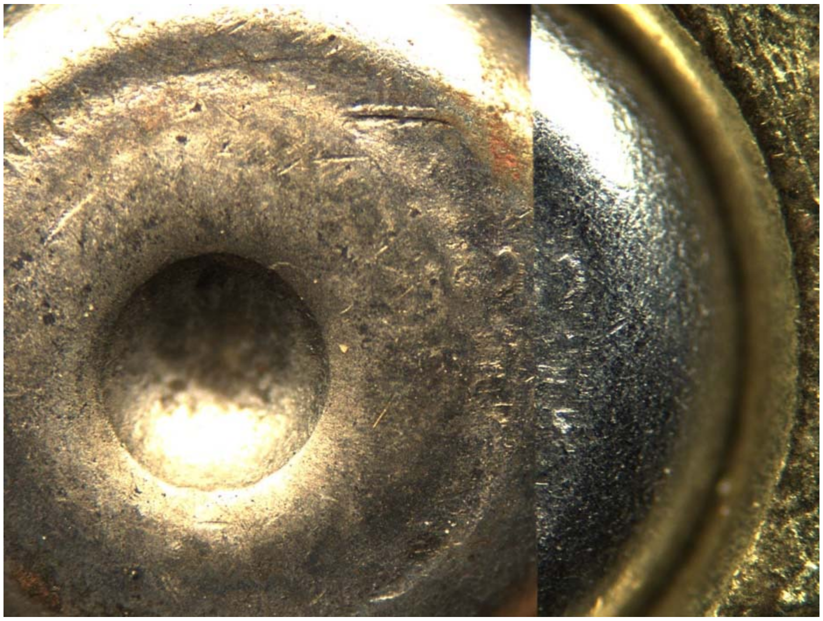


Picture 27: Unknown aluminum sample #7 from water environment after 3 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



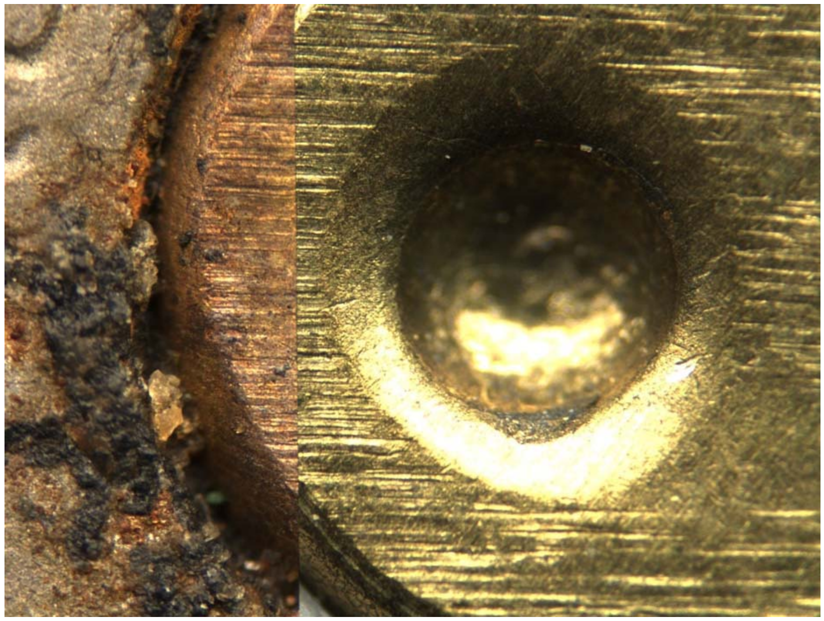
Picture 28: Unknown steel sample #18 from water environment after 3 months (left) compared to known steel sample fired in Beretta model 92FS (right)

Picture 29: Unknown brass sample #11 from water environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)

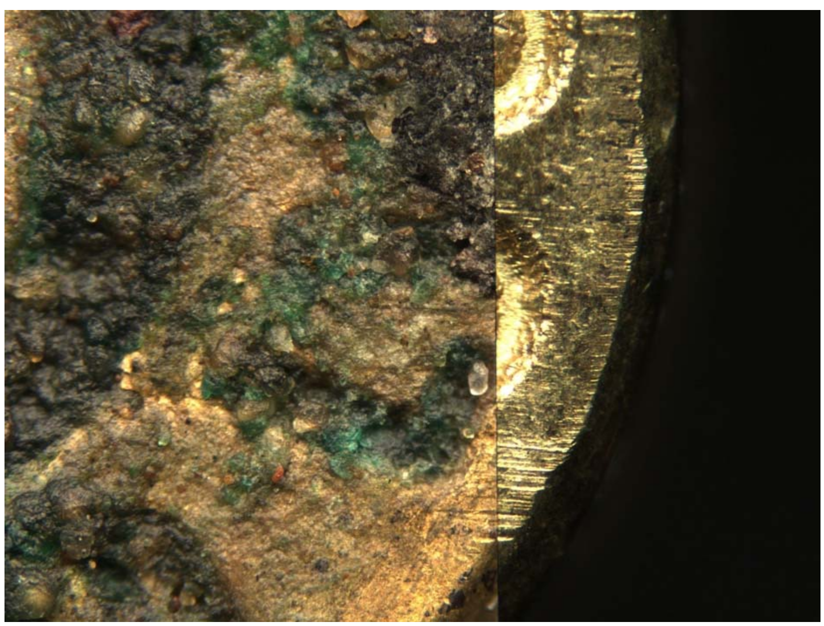


Picture 30: Unknown aluminum sample #2 from water environment after 3 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)

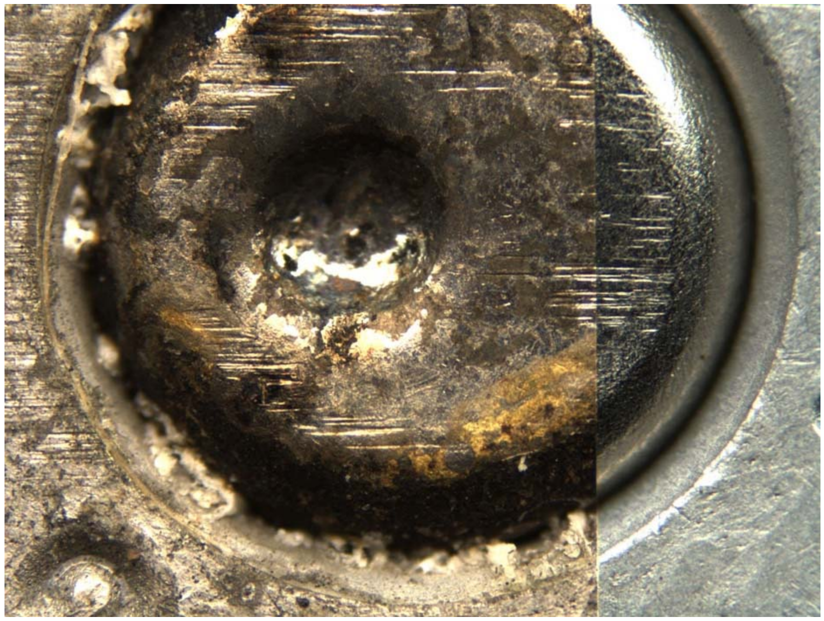
Picture 31: Unknown steel sample #7 from pig buried environment after 3 months (left) compared to known steel sample fired in Hi Point model C9 (right)



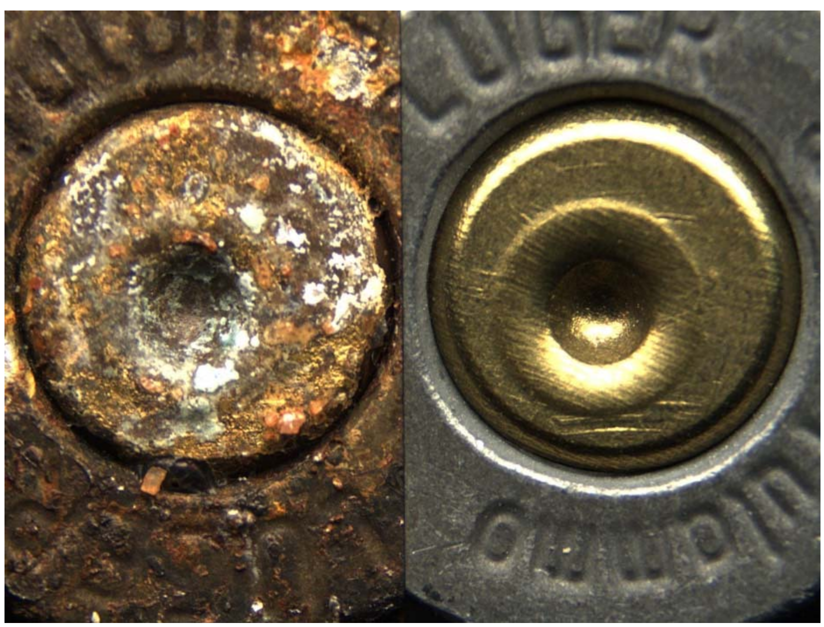
Picture 32: Unknown brass sample #10 from pig buried environment after 3 months (left) compared to known brass sample fired in Hi Point model C9 (right)



Picture 33: Unknown aluminum sample #12 from pig buried environment after 3 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

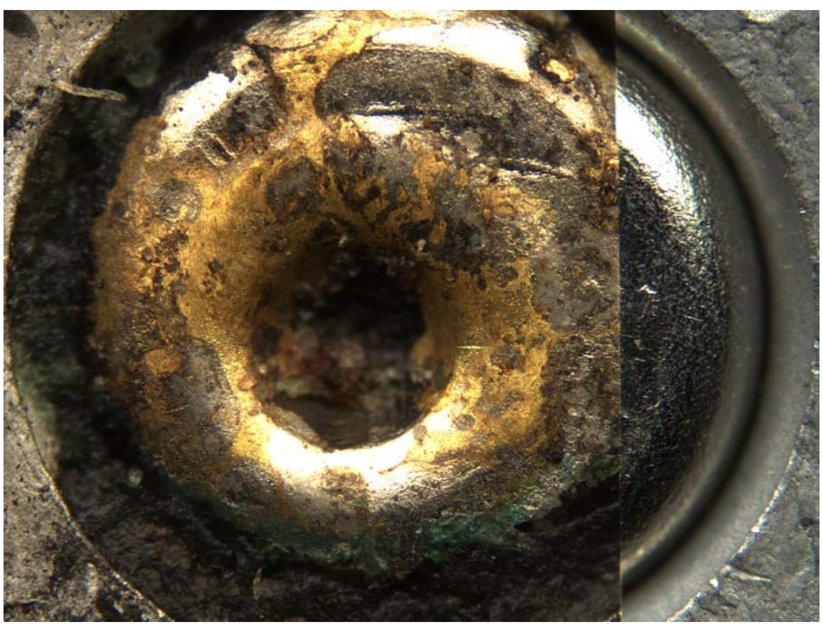


Picture 34: Unknown steel sample #11 from pig buried environment after 3 months (left) compared to known steel sample fired in Beretta model 92FS (right)

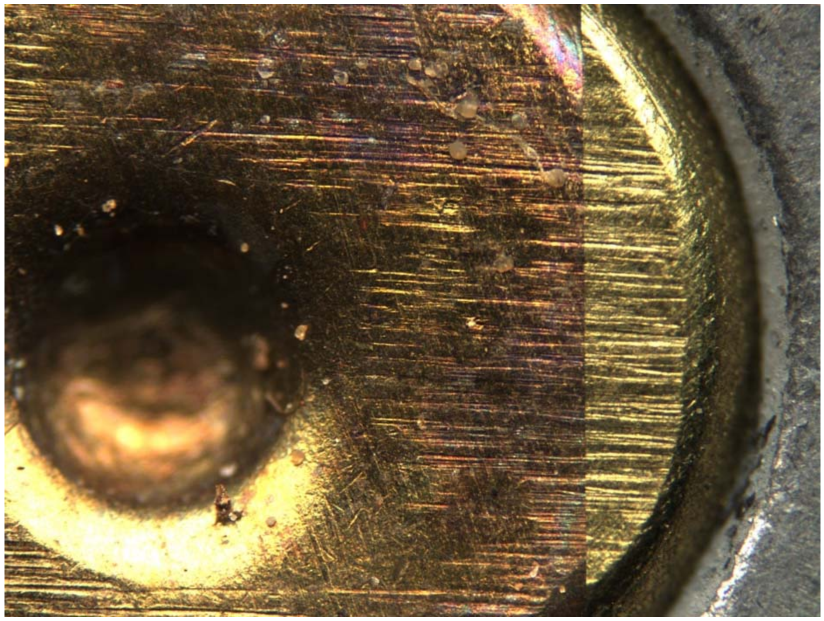


Picture 35: Unknown brass sample #15 from pig buried environment after 3 months (left) compared to known brass sample fired in Beretta model 92FS (right)

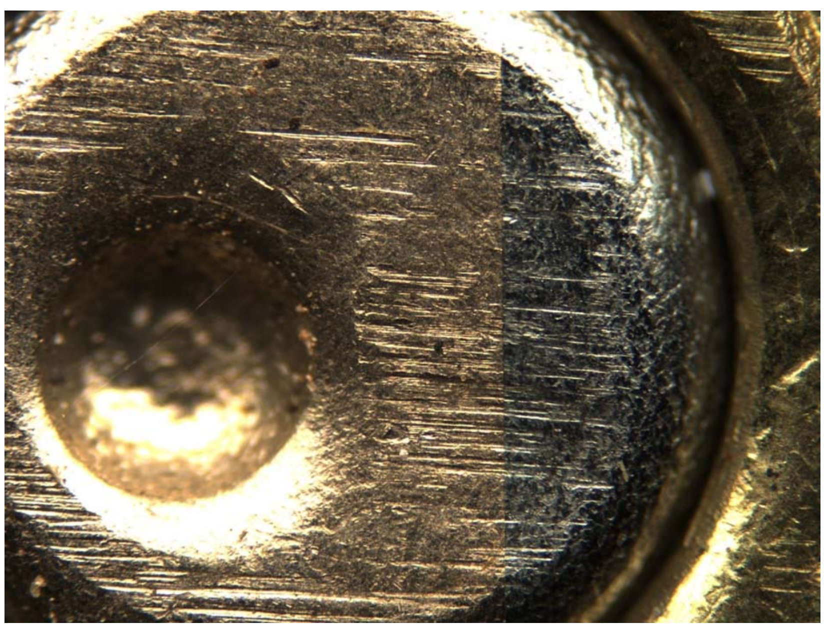
Picture 36: Unknown aluminum sample #3 from pig buried environment after 3 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



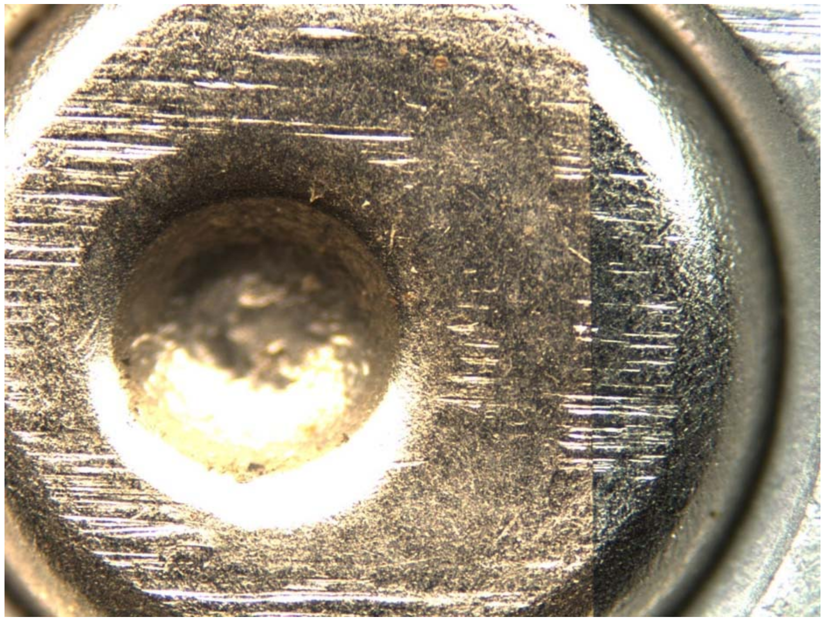
Picture 37: Unknown steel sample #4 from shaded exposed environment after 6 months (left) compared to known steel sample fired in Hi Point model C9 (right)



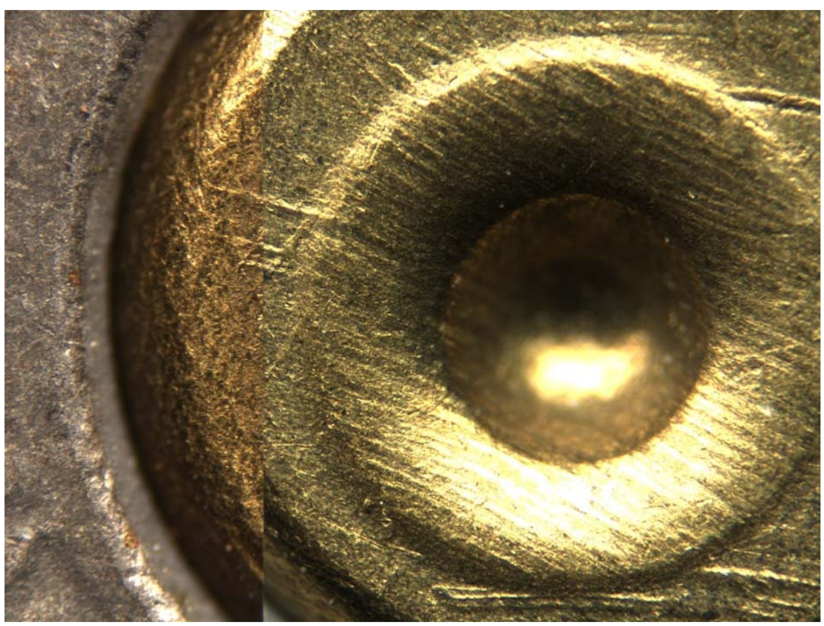
Picture 38: Unknown brass sample #11 from shaded exposed environment after 6 months (left) compared to known brass sample fired in Hi Point model C9 (right)



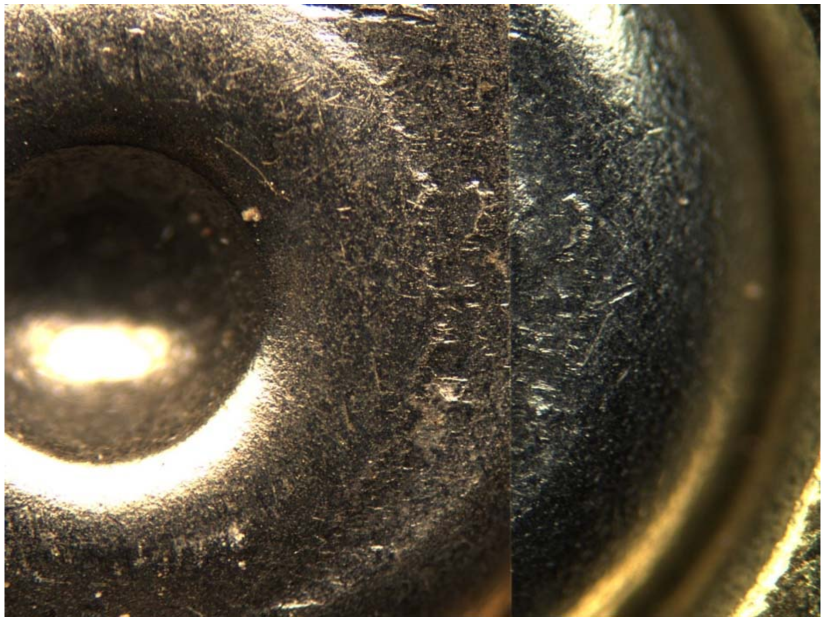
Picture 39: Unknown aluminum sample #2 from shaded exposed environment after 6 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



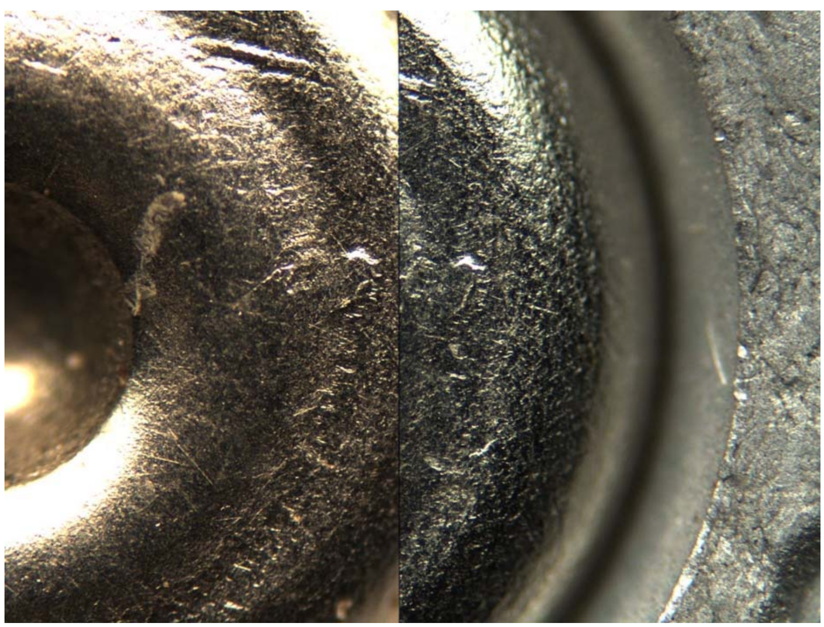
Picture 40: Unknown steel sample #18 from shaded exposed environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)



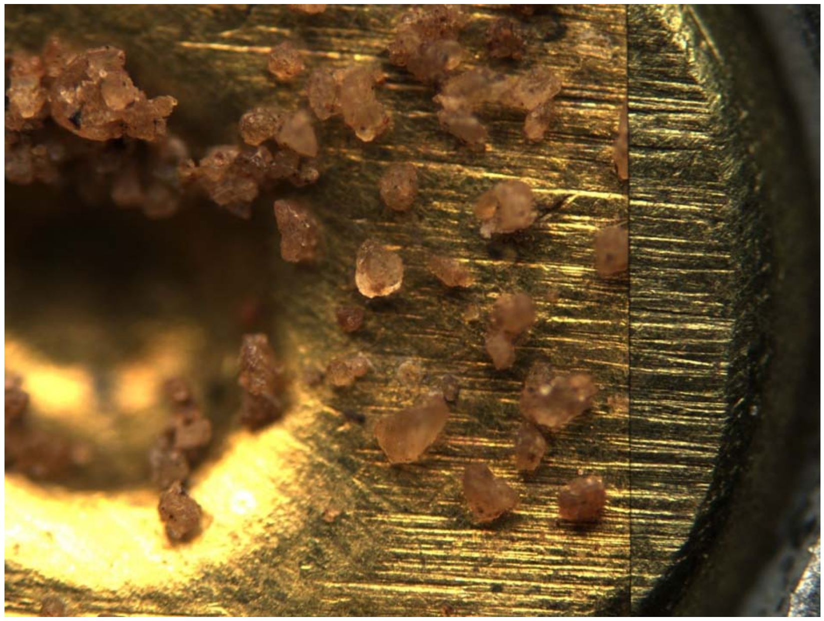
Picture 41: Unknown brass sample #9 from shaded exposed environment after 6 months (left) compared to known brass sample fired in Beretta model 92FS (right)



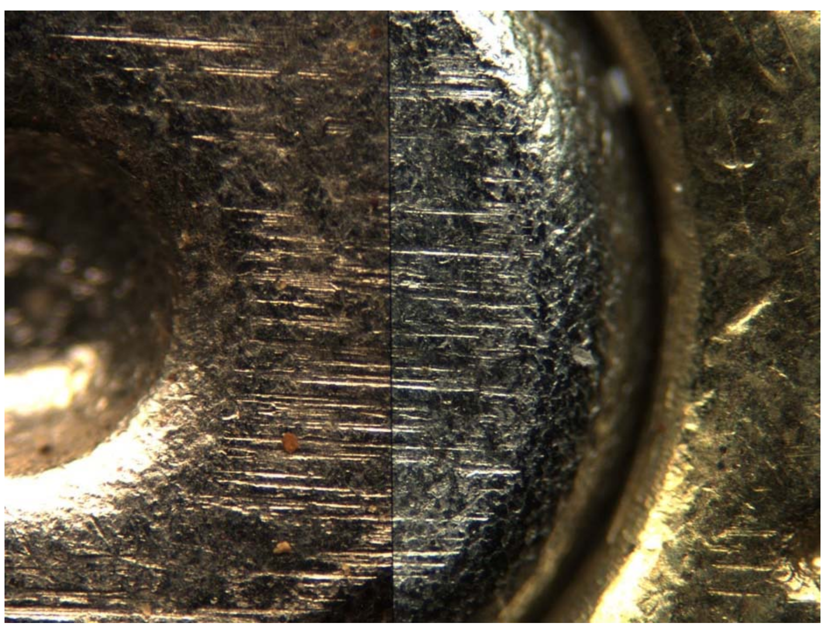
Picture 42: Unknown aluminum sample #17 from shaded exposed environment after 6 months (left) compared to known brass sample fired in Beretta model 92FS (right)



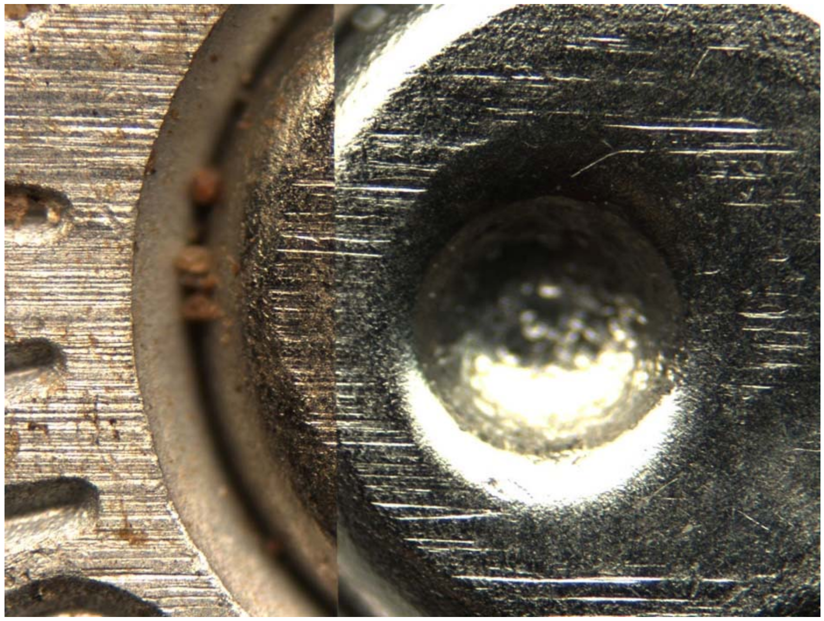
Picture 43: Unknown steel sample #18 from shaded buried environment after 6 months (left) compared to known steel sample fired in Hi Point model C9 (right)



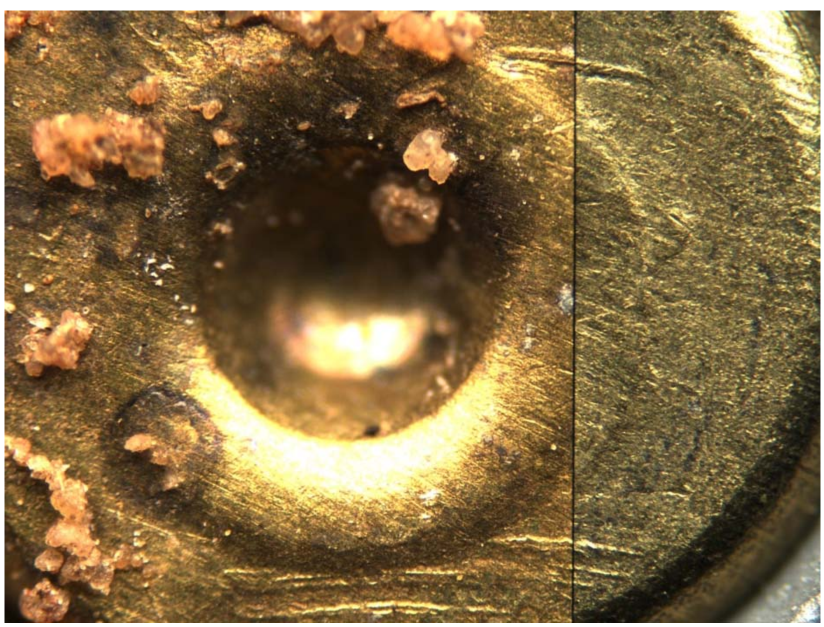
Picture 44: Unknown brass sample #3 from shaded buried environment after 6 months (left) compared to known brass sample fired in Hi Point model C9 (right)



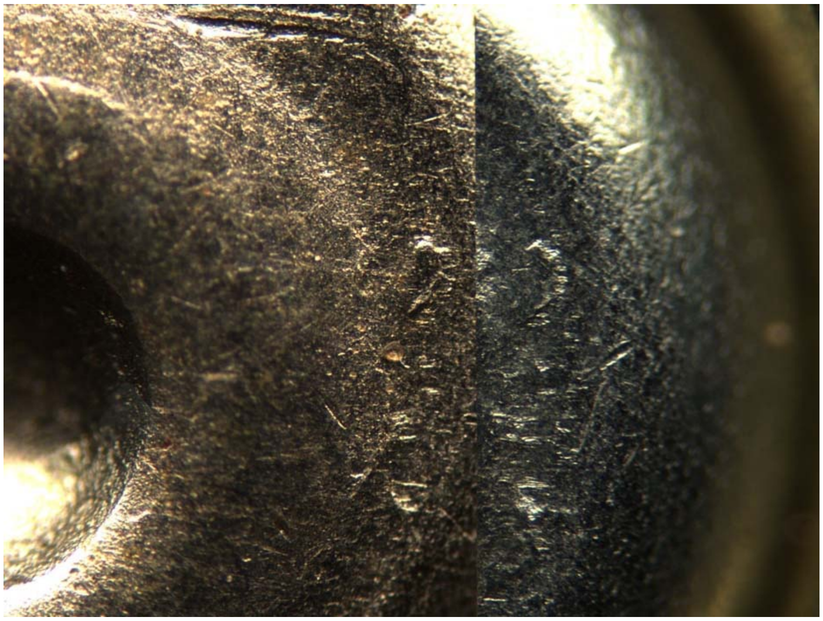
Picture 45: Unknown aluminum sample #2 from shaded buried environment after 6 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



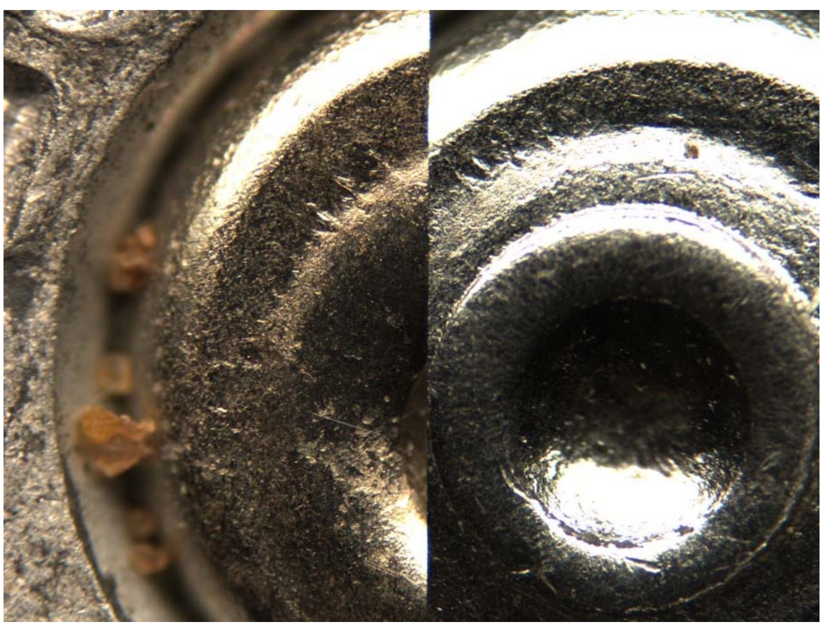
Picture 46: Unknown steel sample #15 from shaded buried environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)



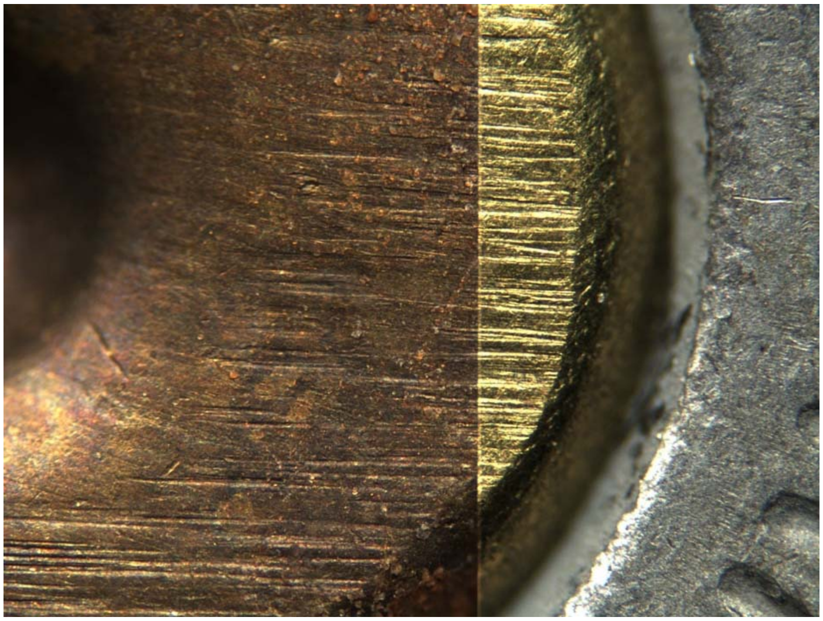
Picture 47: Unknown brass sample #12 from shaded buried environment after 6 months (left) compared to known brass sample fired in Beretta model 92FS (right)



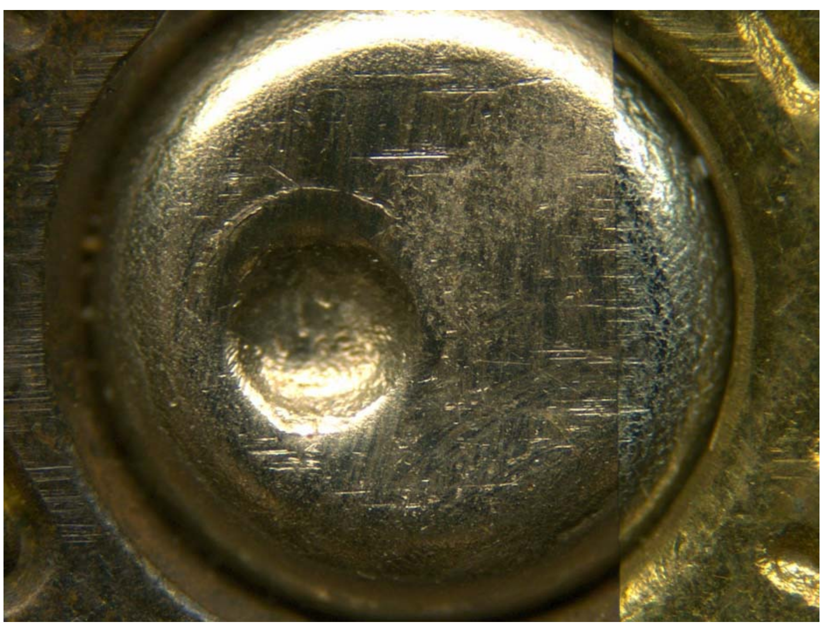
Picture 48: Unknown aluminum sample #9 from shaded buried environment after 6 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



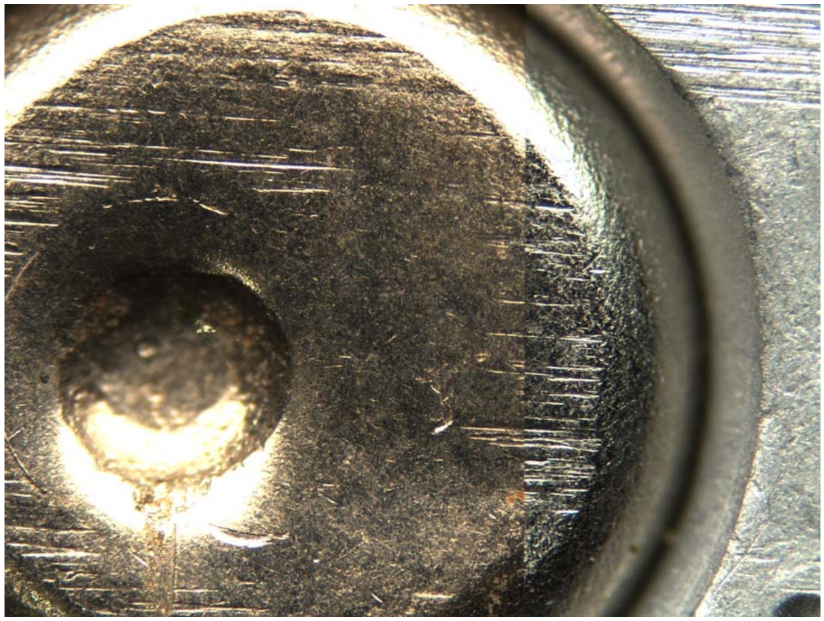
Picture 49: Unknown steel sample #15 from open exposed environment after 6 months (left) compared to known steel sample fired in Hi Point model C9 (right)



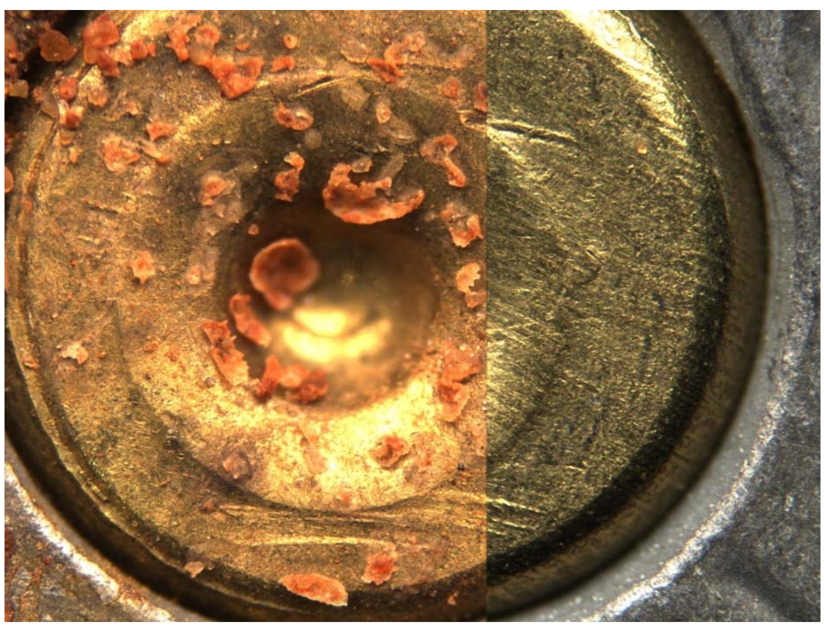
Picture 50: Unknown brass sample #16 from open exposed environment after 6 months (left) compared to known brass sample fired in Hi Point model C9 (right)



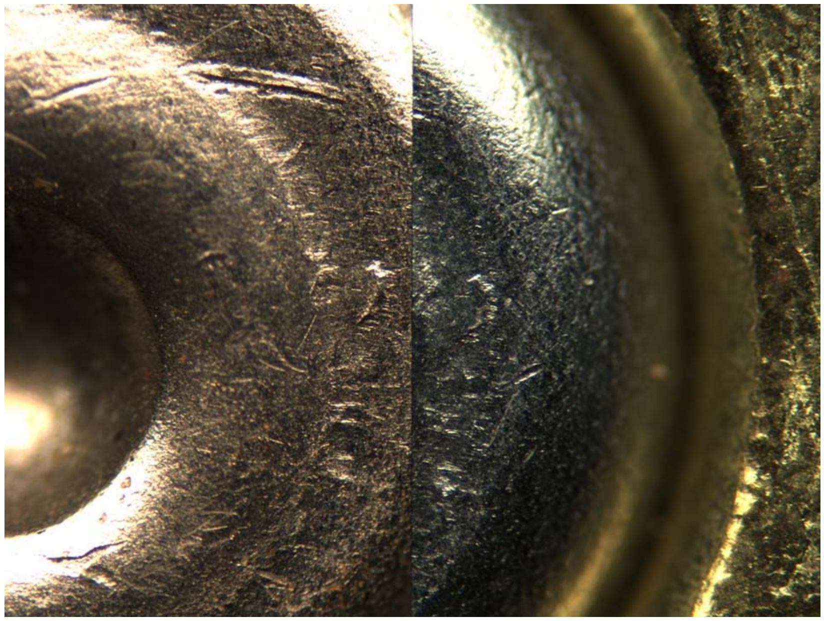
Picture 51: Unknown aluminum sample #10 from open exposed environment after 6 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



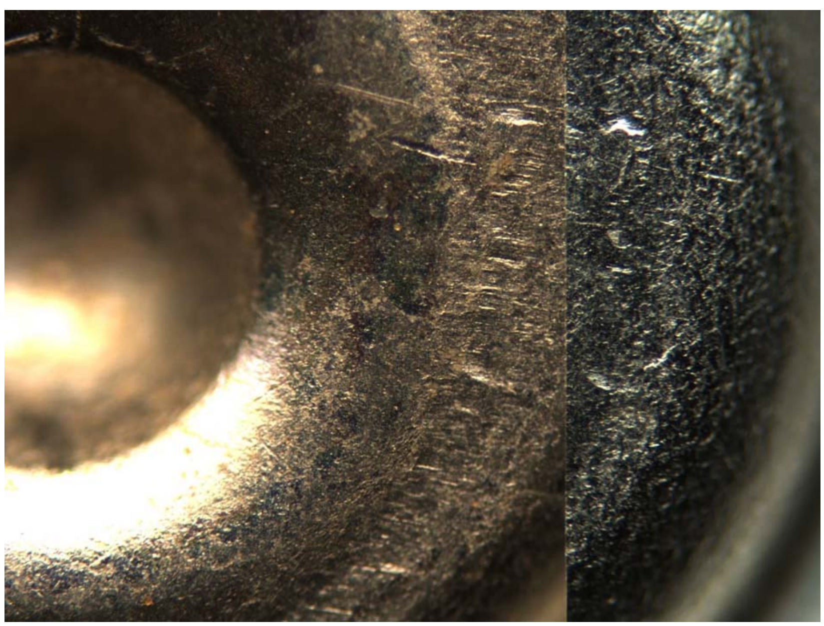
Picture 52: Unknown steel sample #5 from open exposed environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)



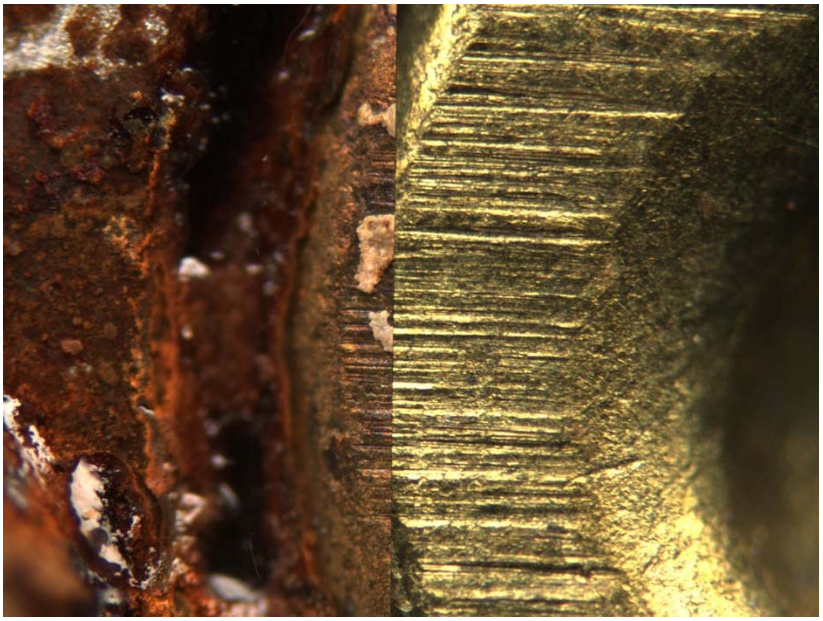
Picture 53: Unknown brass sample #12 from open exposed environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)



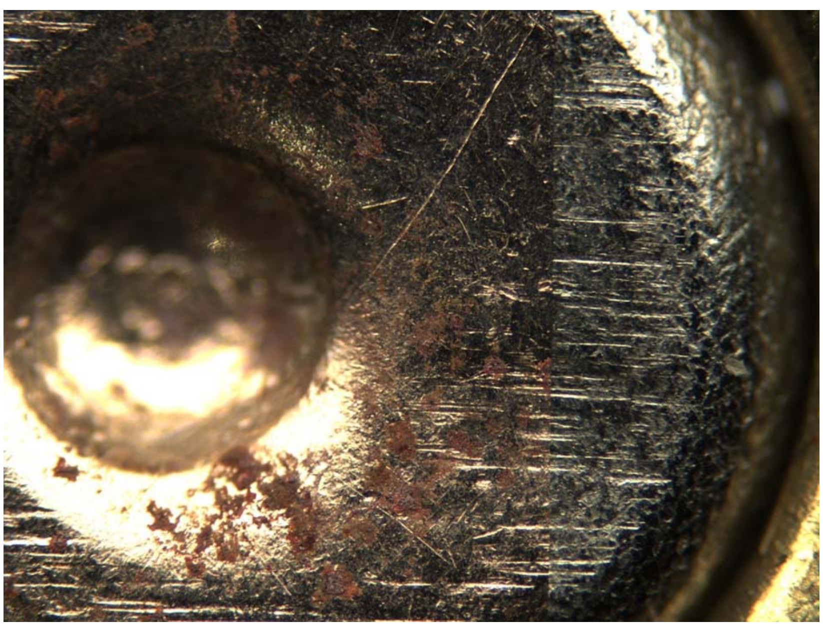
Picture 54: Unknown aluminum sample #4 from open exposed environment after 6 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



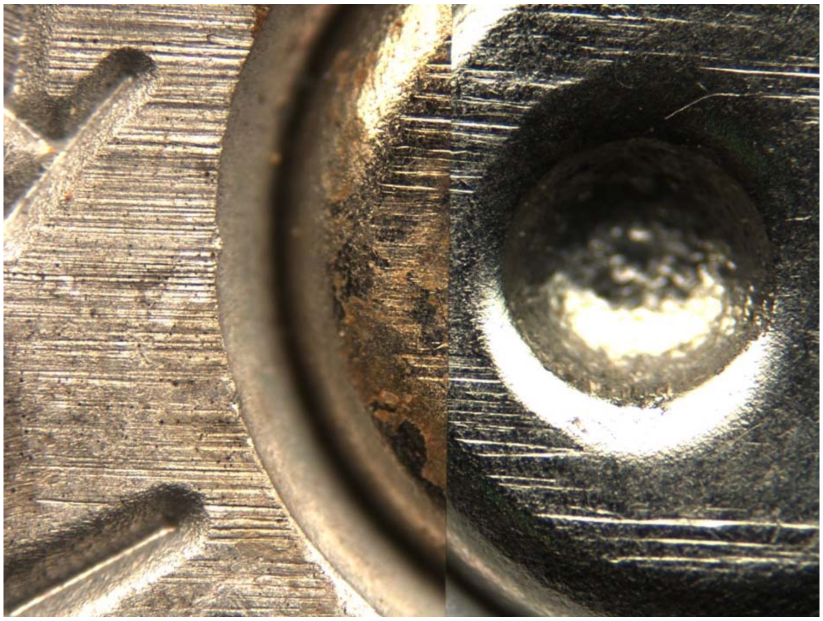
Picture 55: Unknown steel sample #11 from open buried environment after 6 months (left) compared to known steel sample fired in Hi Point model C9 (right)



Picture 56: Unknown brass sample #9 from open buried environment after 6 months (left) compared to known brass sample fired in Hi Point model C9 (right)

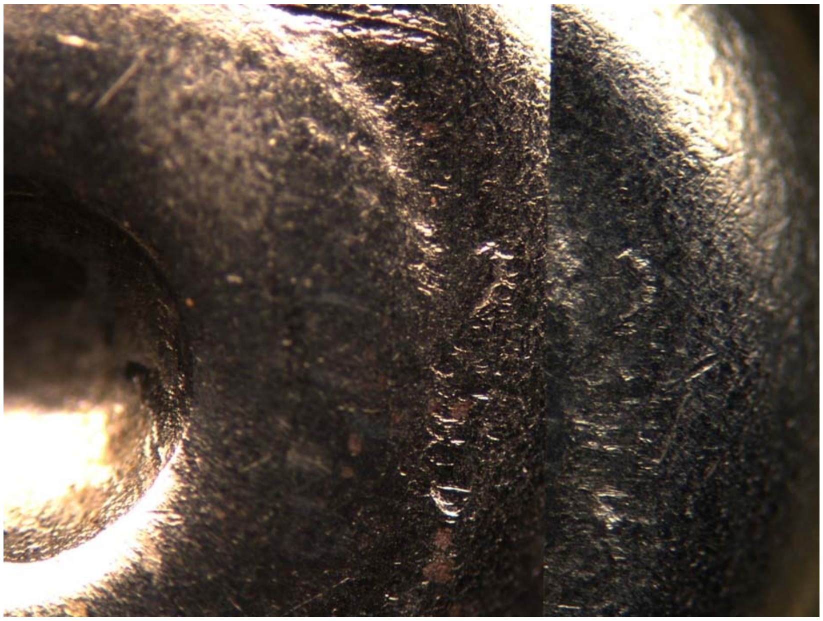


Picture 57: Unknown aluminum sample #13 from open buried environment after 6 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

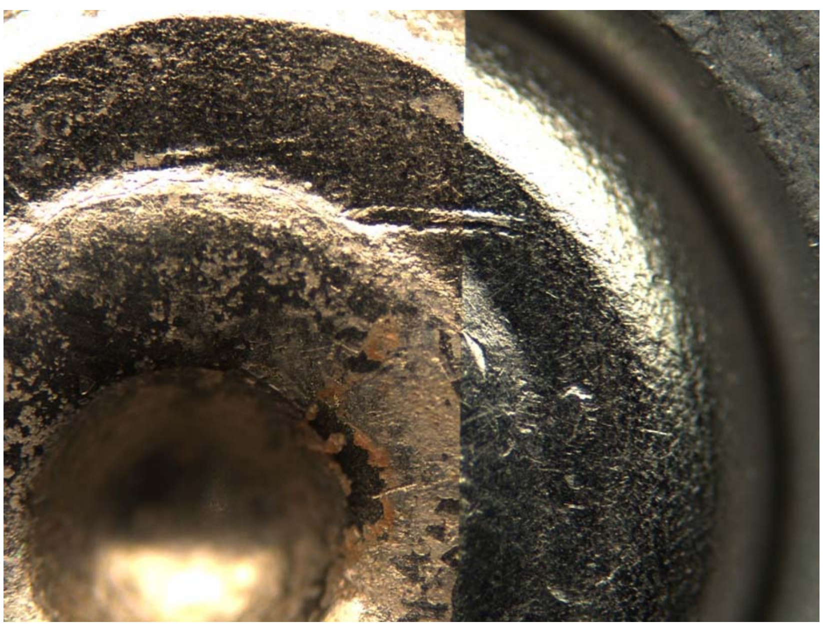


Picture 58: Unknown steel sample #15 from open buried environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)

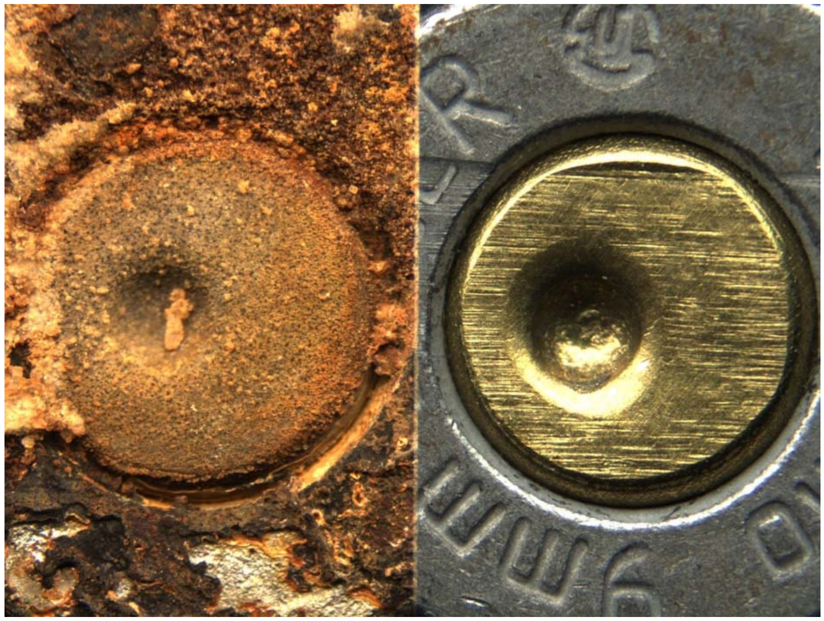
Picture 59: Unknown brass sample #10 from open buried environment after 6 months (left) compared to known brass sample fired in Beretta model 92FS (right)



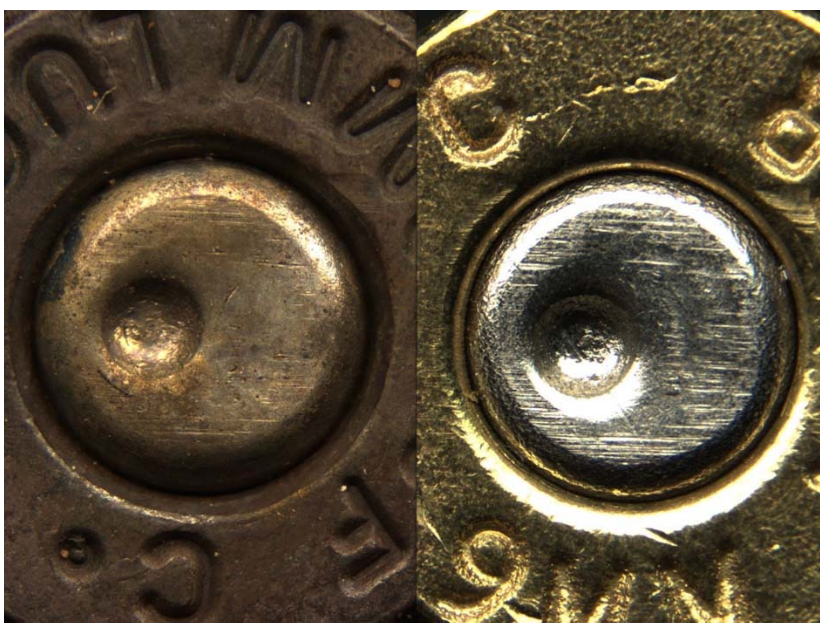
Picture 60: Unknown aluminum sample #17 from open buried environment after 6 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



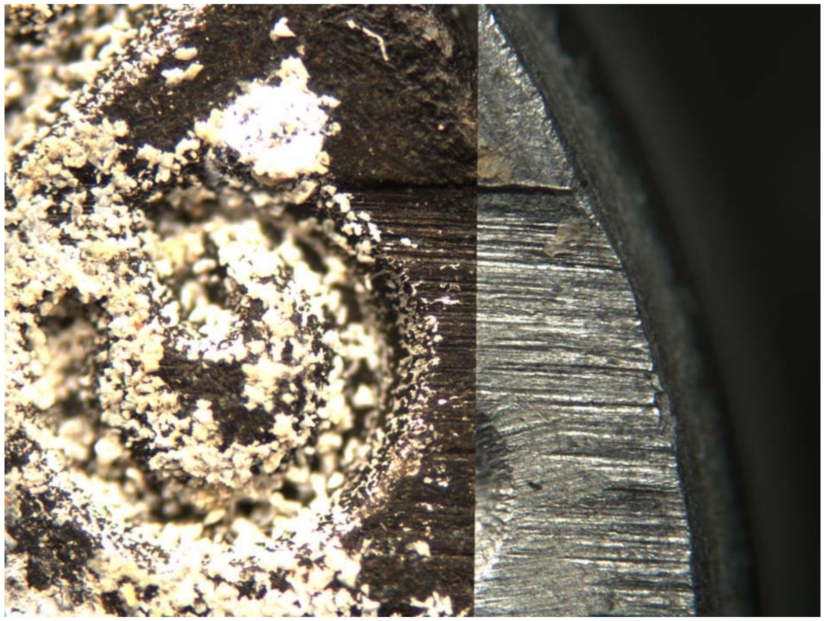
Picture 61: Unknown steel sample #10 from water environment after 6 months (left) compared to known steel sample fired in Hi Point model C9 (right)



Picture 62: Unknown brass sample #9 from water environment after 6 months (left) compared to known brass sample fired in Hi Point model C9 (right)



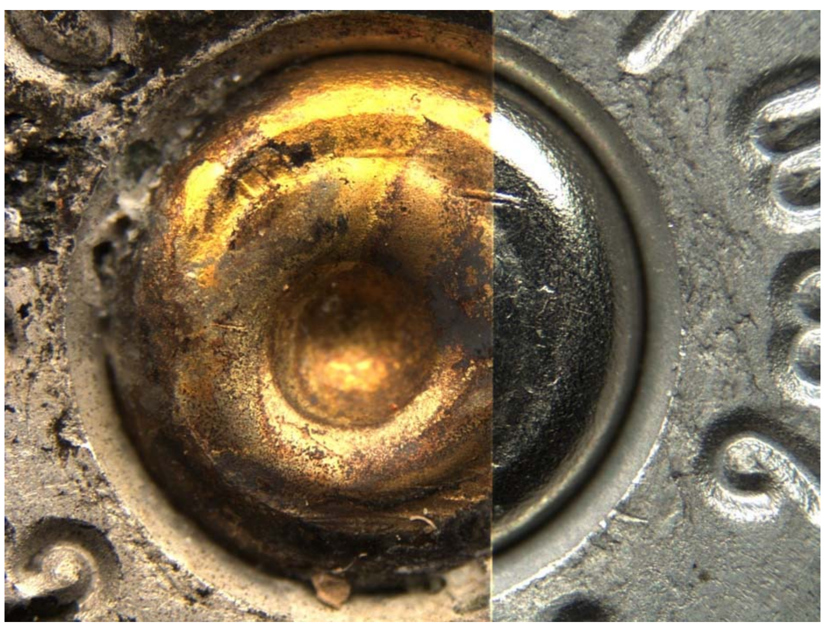
Picture 63: Unknown aluminum sample #15 from water environment after 6 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



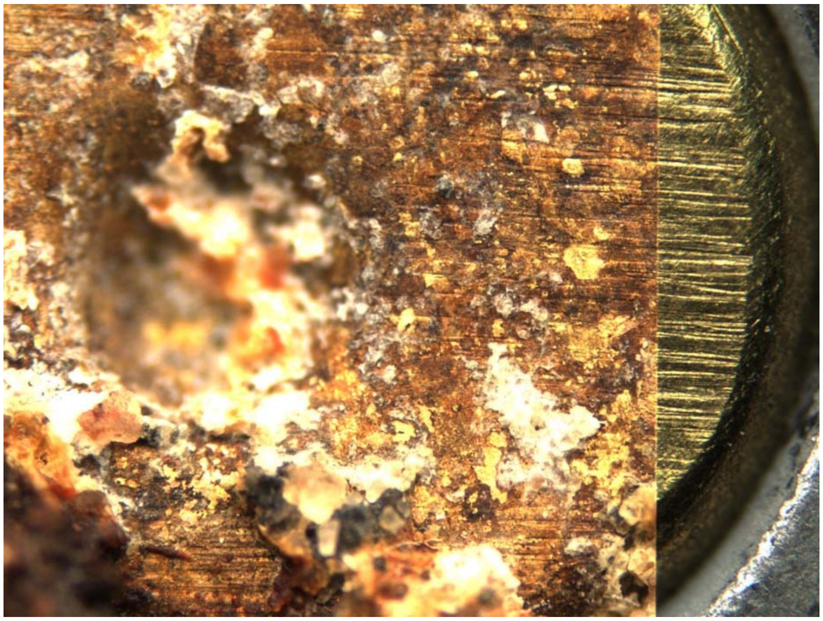
Picture 64: Unknown steel sample #5 from water environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)

Picture 65: Unknown brass sample #4 from water environment after 6 months (left) compared to known brass sample fired in Beretta model 92FS (right)

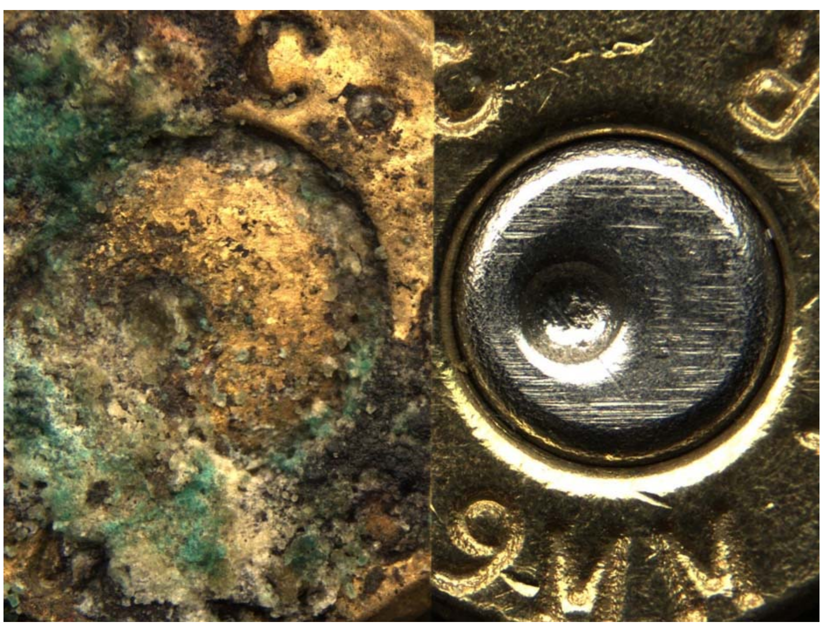
Picture 66: Unknown aluminum sample #2 from water environment after 6 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



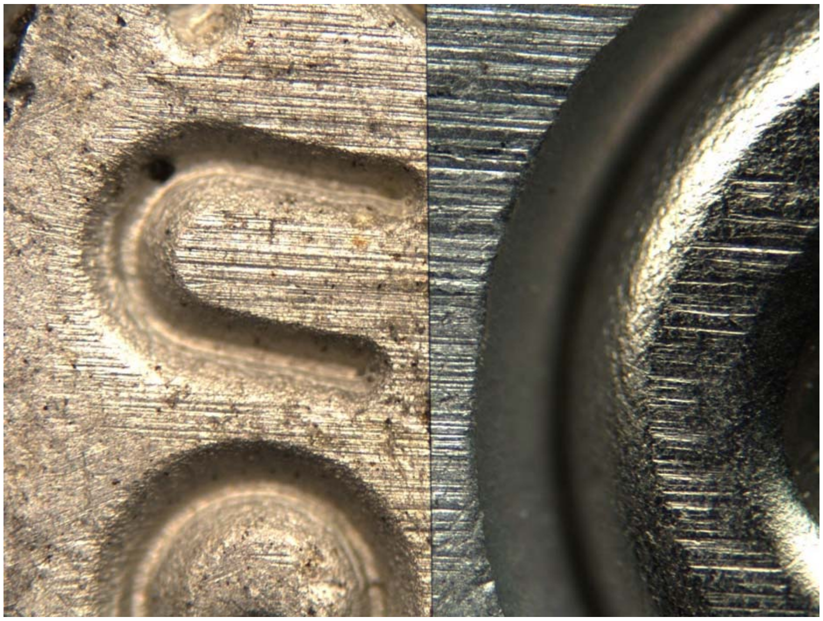
Picture 67: Unknown steel sample #7 from pig buried environment after 6 months (left) compared to known steel sample fired in Hi Point model C9 (right)



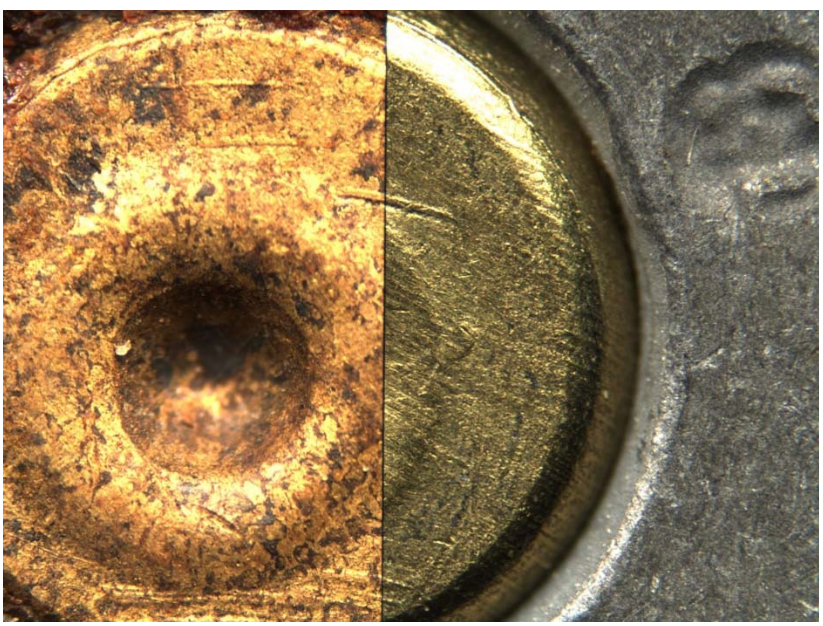
Picture 68: Unknown brass sample #18 from pig buried environment after 6 months (left) compared to known brass sample fired in Hi Point model C9 (right)



Picture 69: Unknown aluminum sample #12 from pig buried environment after 6 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

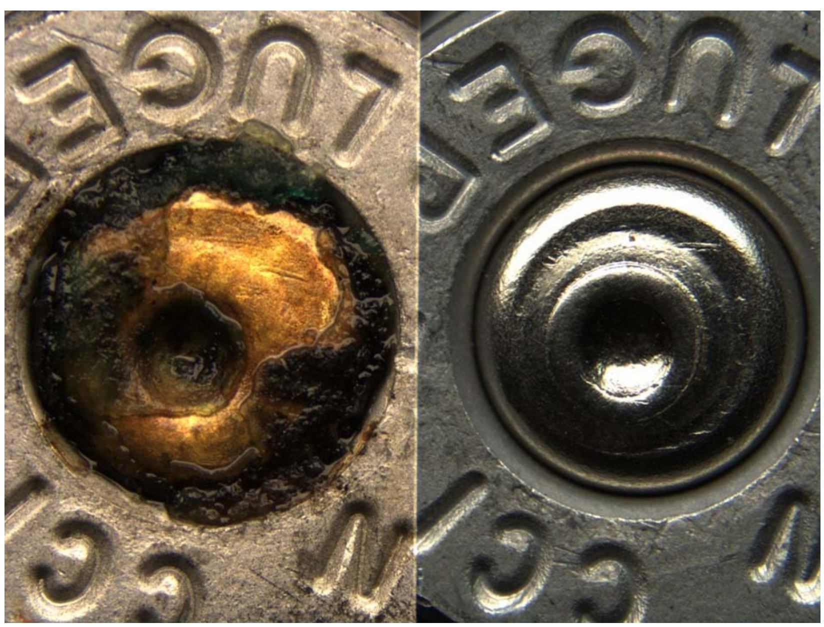


Picture 70: Unknown steel sample #5 from pig buried environment after 6 months (left) compared to known steel sample fired in Beretta model 92FS (right)

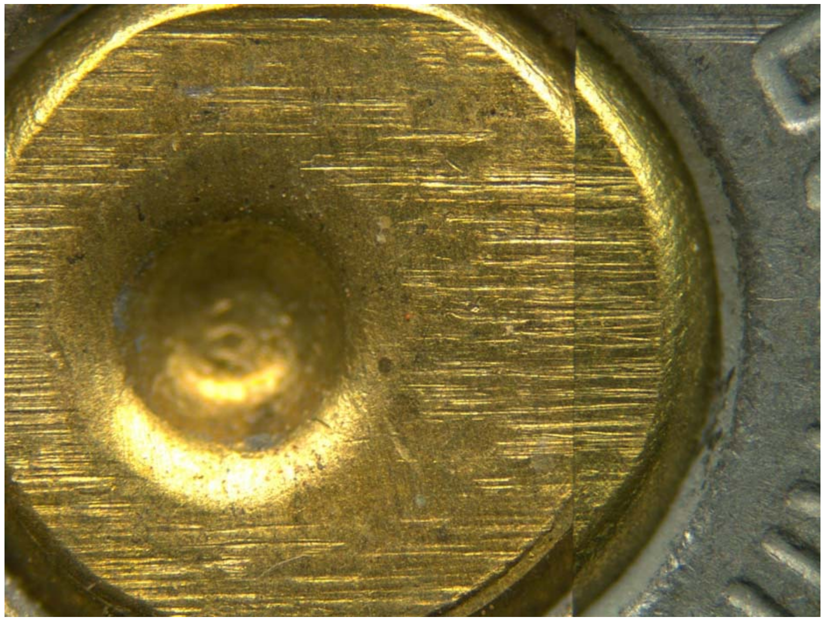


Picture 71: Unknown brass sample #8 from pig buried environment after 6 months (left) compared to known brass sample fired in Beretta model 92FS (right)

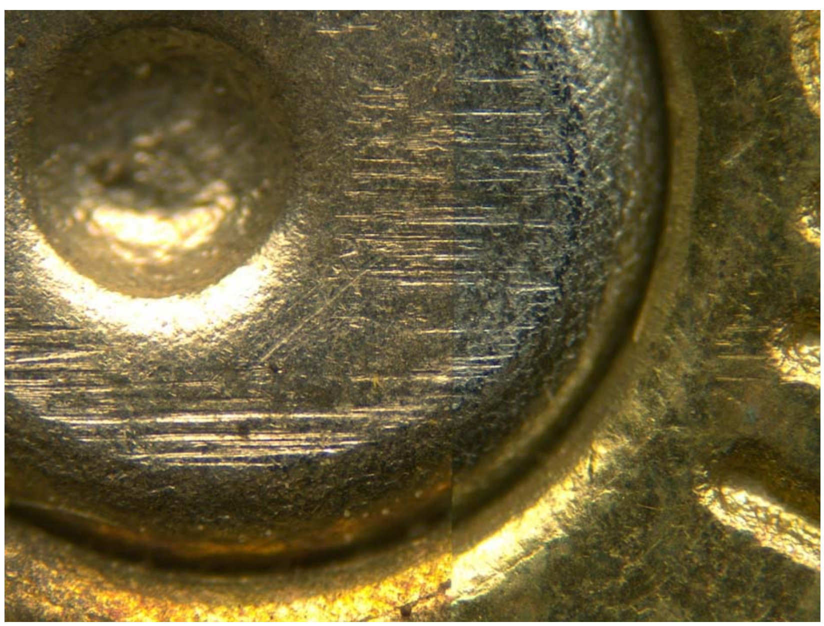
Picture 72: Unknown aluminum sample #1 from pig buried environment after 6 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



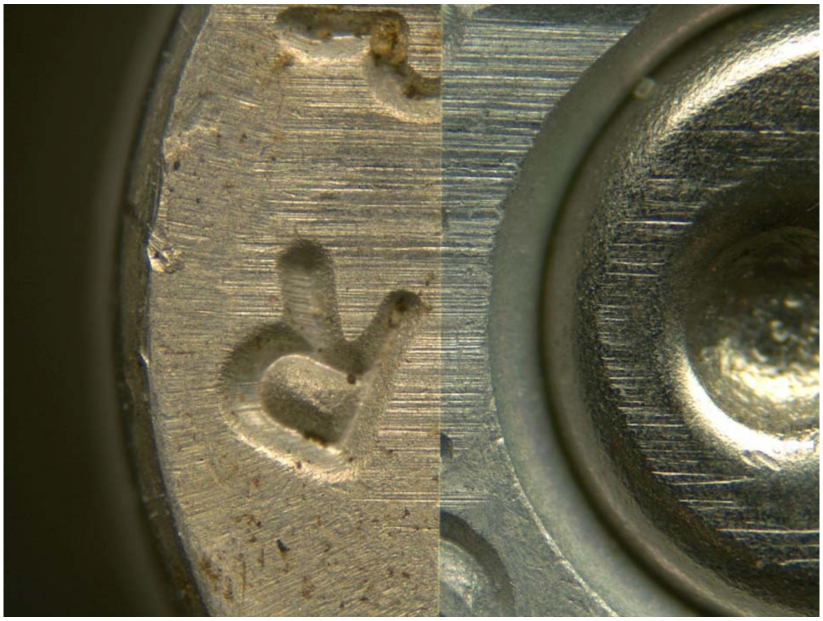
Picture 73: Unknown steel sample #18 from shaded exposed environment after 9 months (left) compared to known steel sample fired in Hi Point model C9 (right)



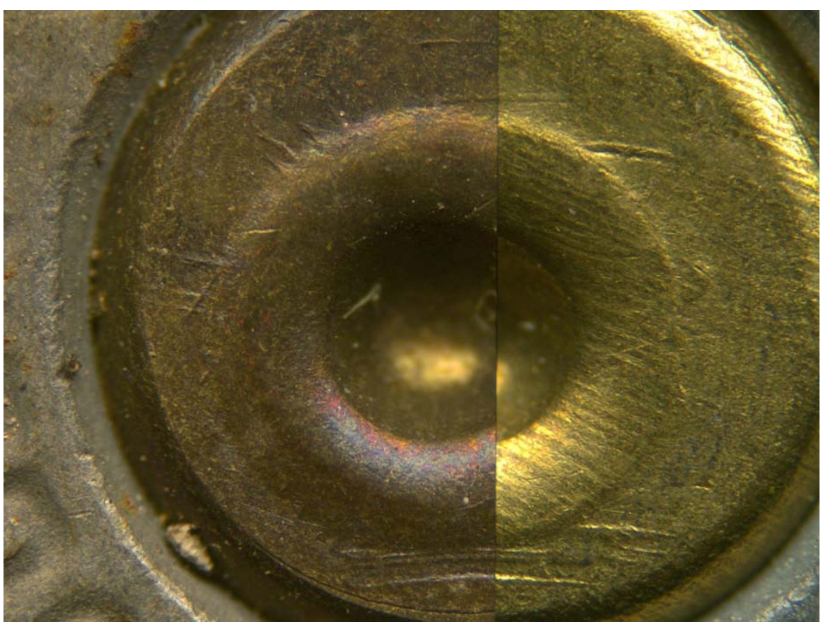
Picture 74: Unknown brass sample #17 from shaded exposed environment after 9 months (left) compare to known brass sample fired in Hi Point model C9 (right)



Picture 75: Unknown aluminum sample #11 from shaded exposed environment after 9 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

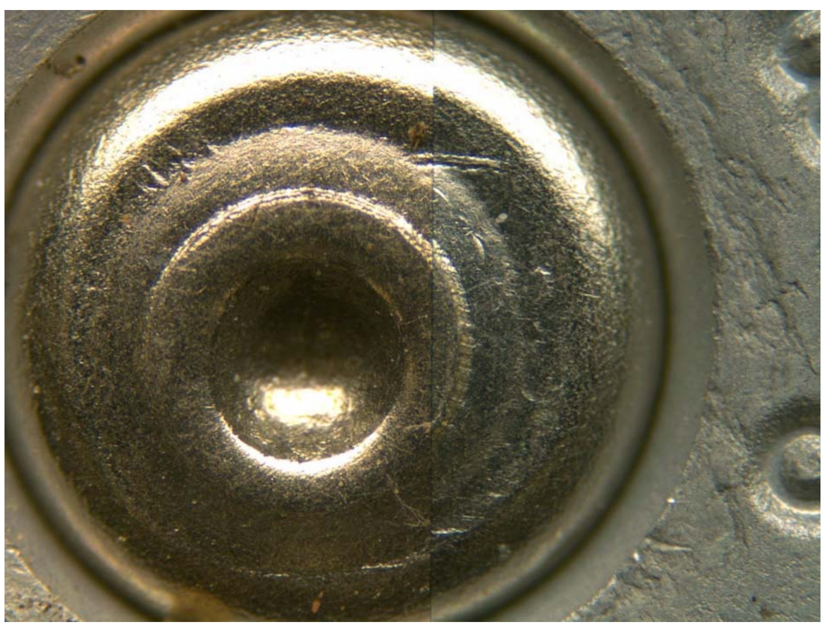


Picture 76: Unknown steel sample #10 from shaded exposed environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)

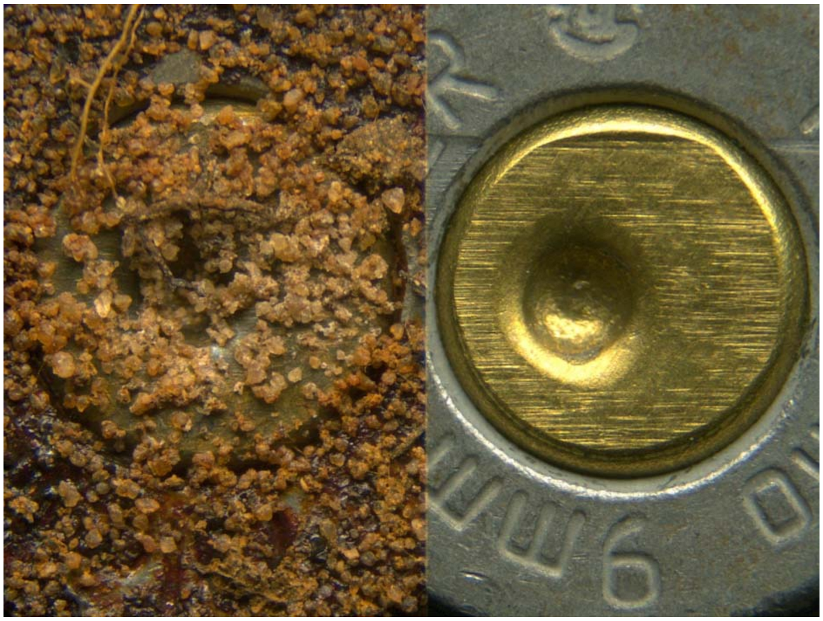


Picture 77: Unknown brass sample #9 from shaded exposed environment after 9 months (left) compared to known brass sample fired in Beretta model 92FS (right)

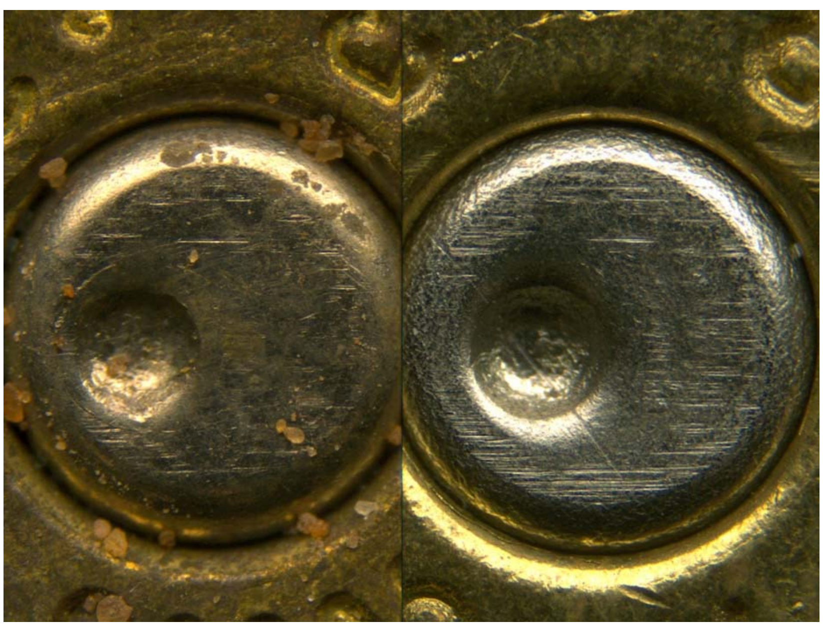
Picture 78: Unknown aluminum sample #7 from shaded exposed environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



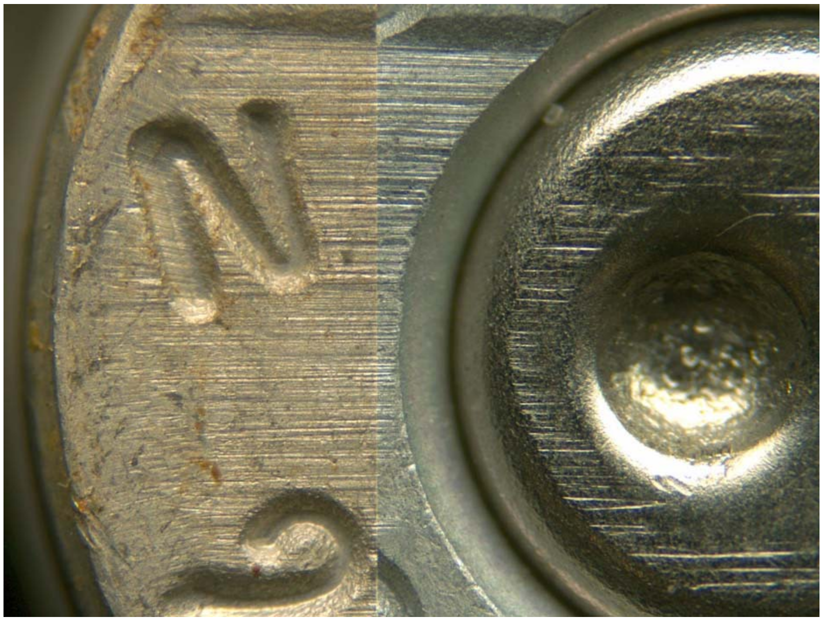
Picture 79: Unknown steel sample #5 from shaded buried environment after 9 months (left) compared to known steel sample fired in Hi Point model C9 (right)



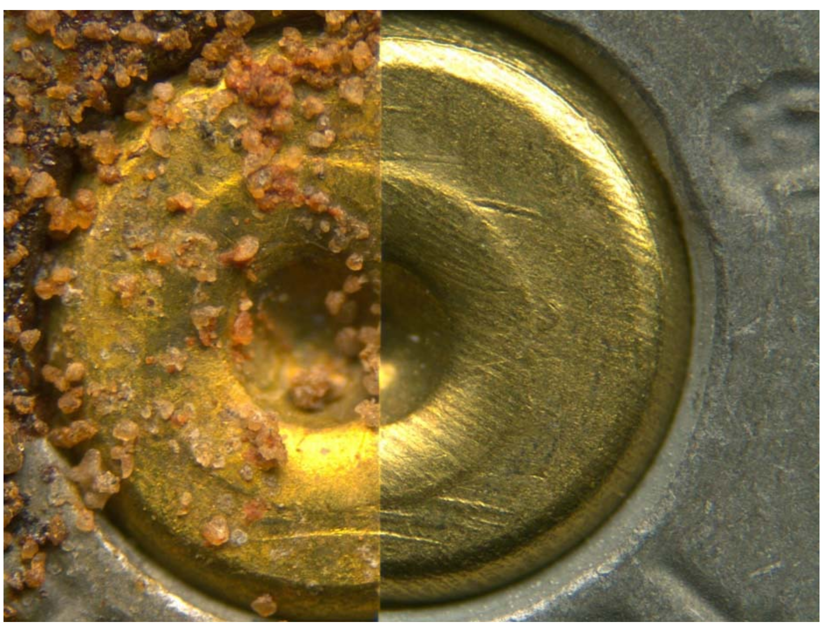
Picture 80: Unknown brass sample #10 from shaded buried environment after 9 months (left) compared to known brass sample fired in Hi Point model C9 (right)



Picture 81: Unknown aluminum sample #9 from shaded buried environment after 9 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

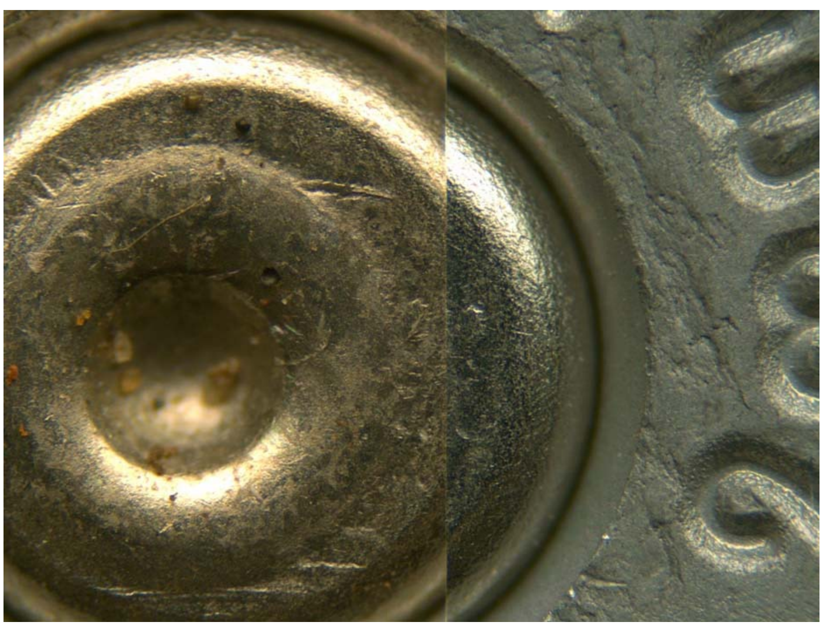


Picture 82: Unknown steel sample #1 from shaded buried environment after 9 months (left) compared to known steel sample fired in Beretta model 92FS (right)

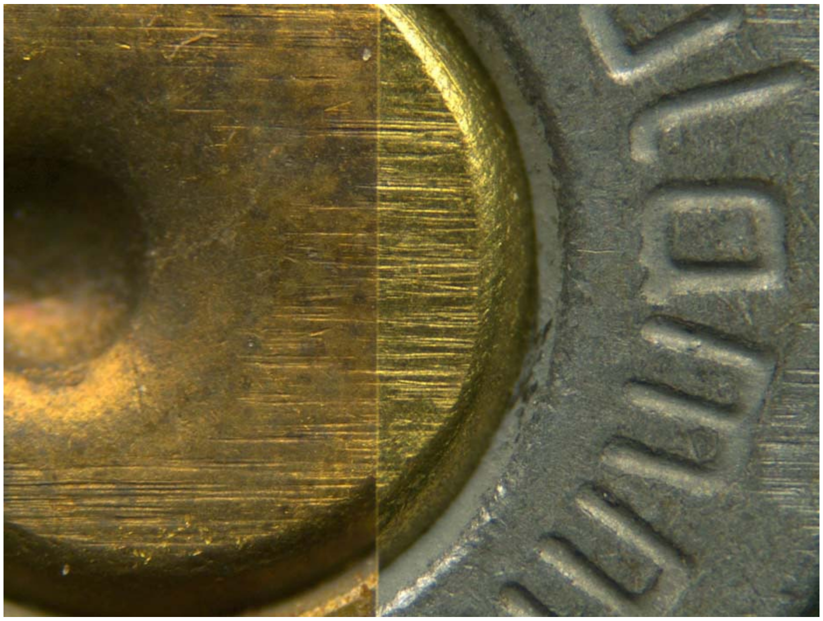


Picture 83: Unknown brass sample #3 from shaded buried environment after 9 months (left) compared to known brass sample fired in Beretta model 92FS (right)

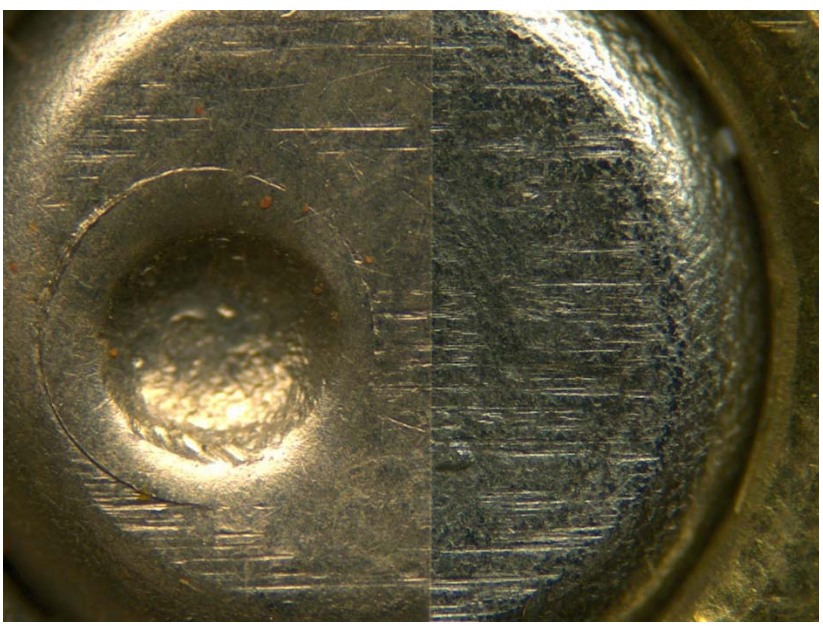
Picture 84: Unknown aluminum sample #15 from shaded buried environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



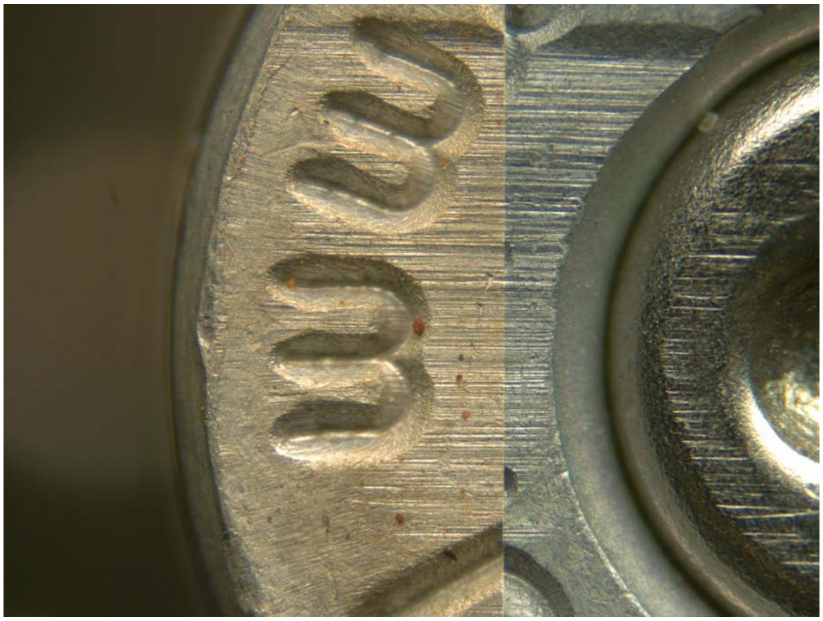
Picture 85: Unknown steel sample #13 from open exposed environment after 9 months (left) compared to known steel sample fired in Hi Point model C9 (right)



Picture 86: Unknown brass sample #6 from open exposed environment after 9 months (left) compared to known brass sample fired in Hi Point model C9 (right)

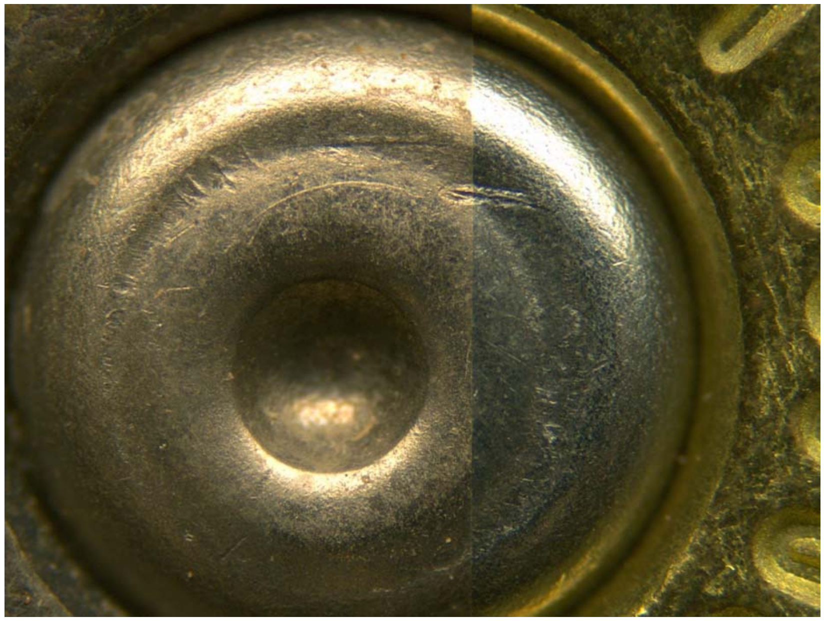


Picture 87: Unknown aluminum sample #12 from open exposed environment after 9 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

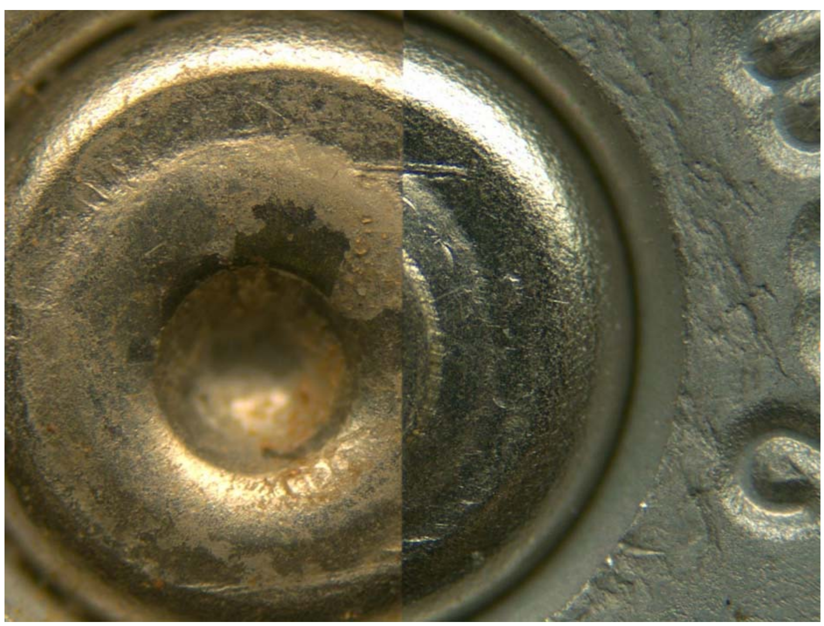


Picture 88: Unknown steel sample #14 from open exposed environment after 9 months (left) compared to known steel sample fired in Beretta model 92FS (right)

Picture 89: Unknown brass sample #7 from open exposed environment after 9 months (left) compared to known brass sample fired in Beretta model 92FS (right)

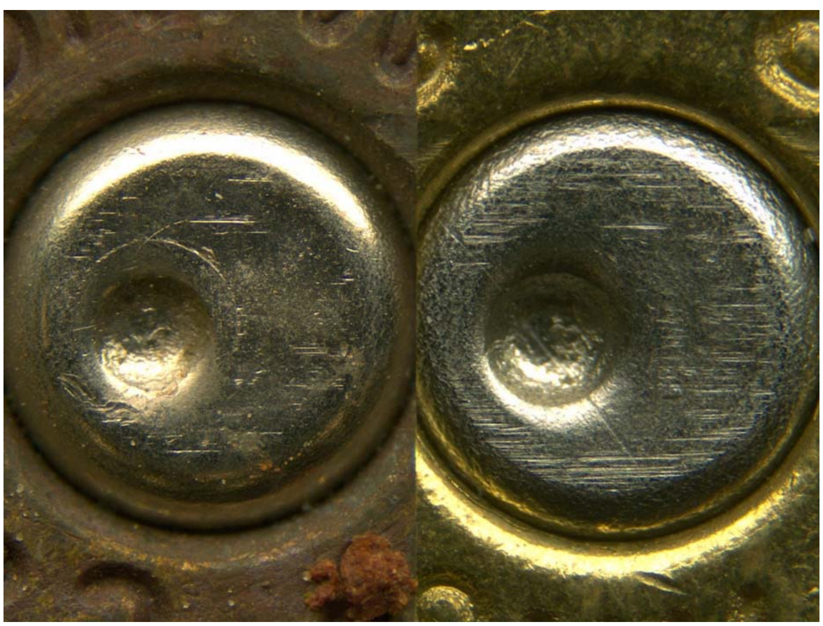


Picture 90: Unknown aluminum sample #5 from open exposed environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)

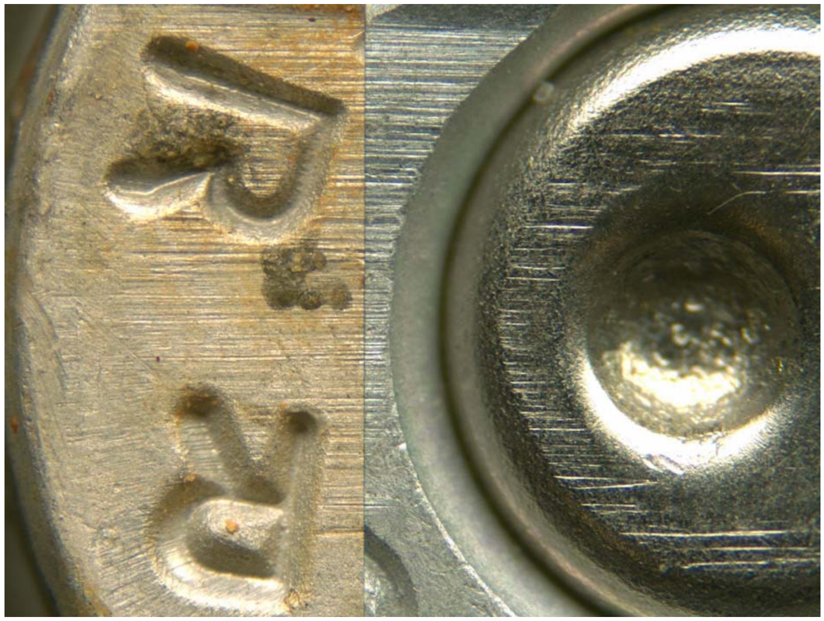


Picture 91: Unknown steel sample #13 from open buried environment after 9 months (left) compared to known steel sample fired in Hi Point model C9 (right)

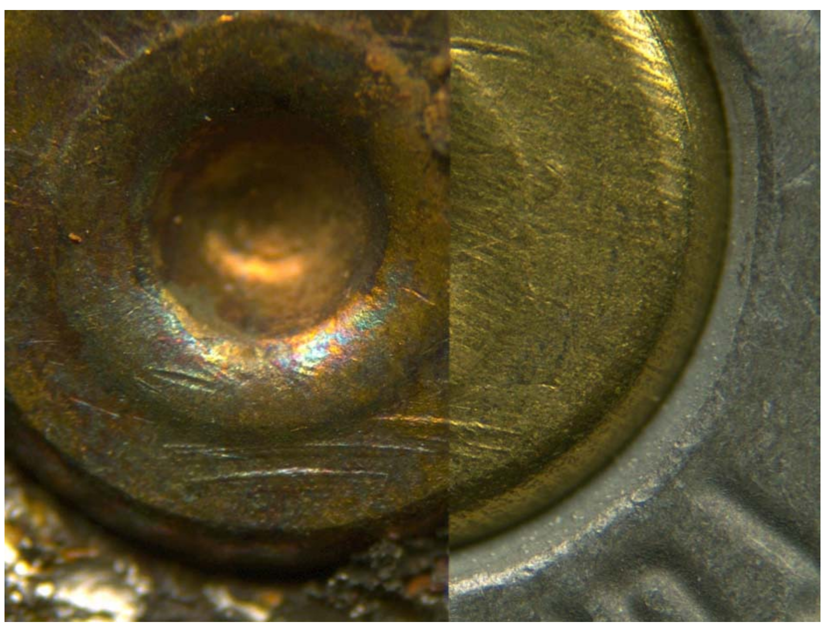
Picture 92: Unknown brass sample #2 from open buried environment after 9 months (left) compared to known brass sample fired in Hi Point model C9 (right)



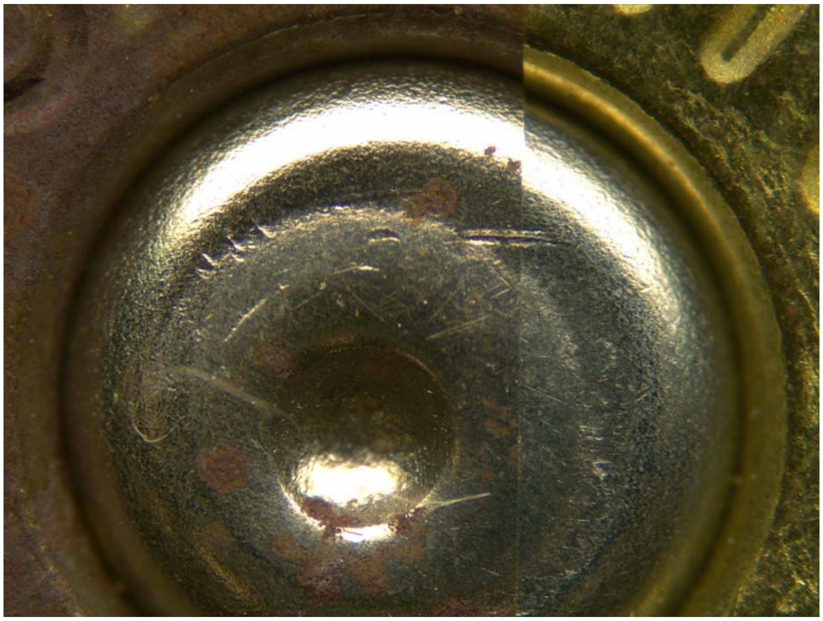
Picture 93: Unknown aluminum sample #1 from open buried environment after 9 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



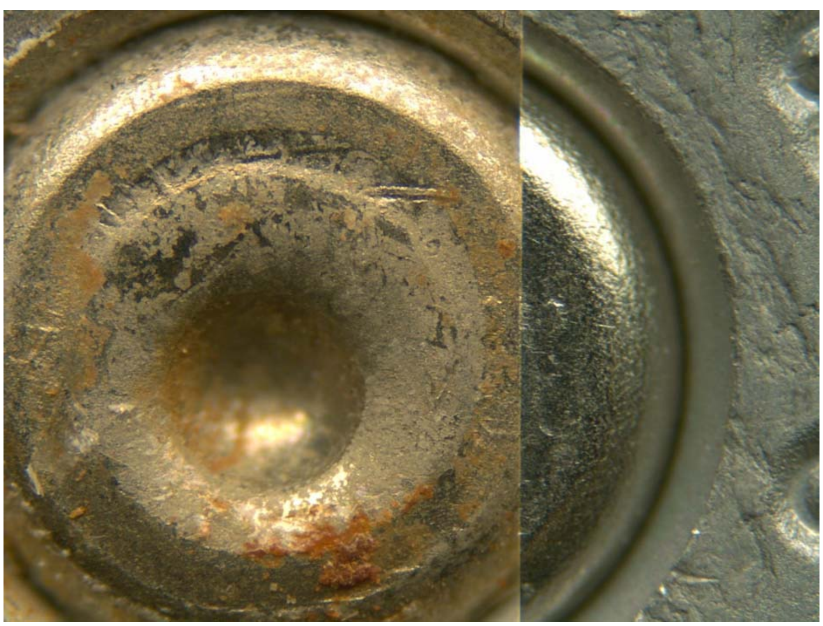
Picture 94: Unknown steel sample #5 from open buried environment after 9 months (left) compared to known steel sample fired in Beretta model 92FS (right)



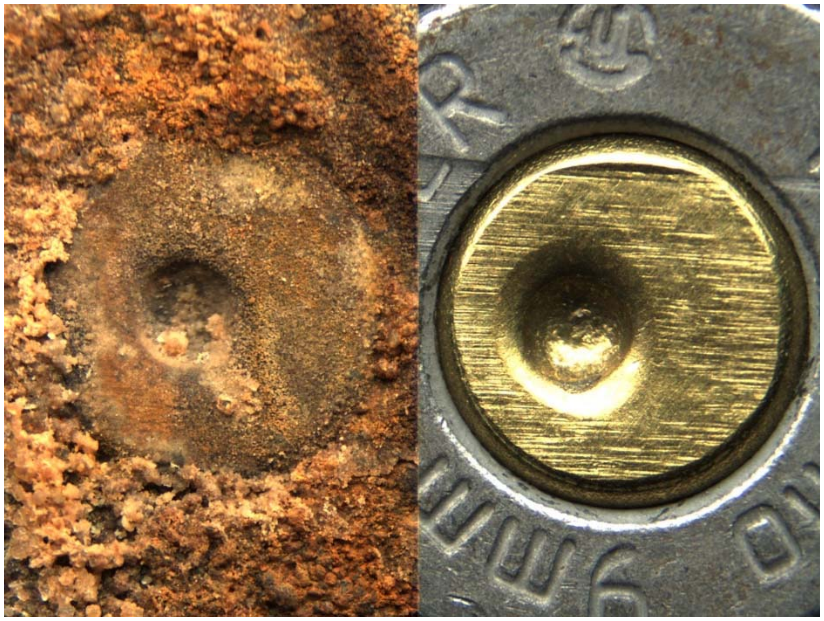
Picture 95: Unknown brass sample #16 from open buried environment after 9 months (left) compared to known brass sample fired in Beretta model 92FS (right)



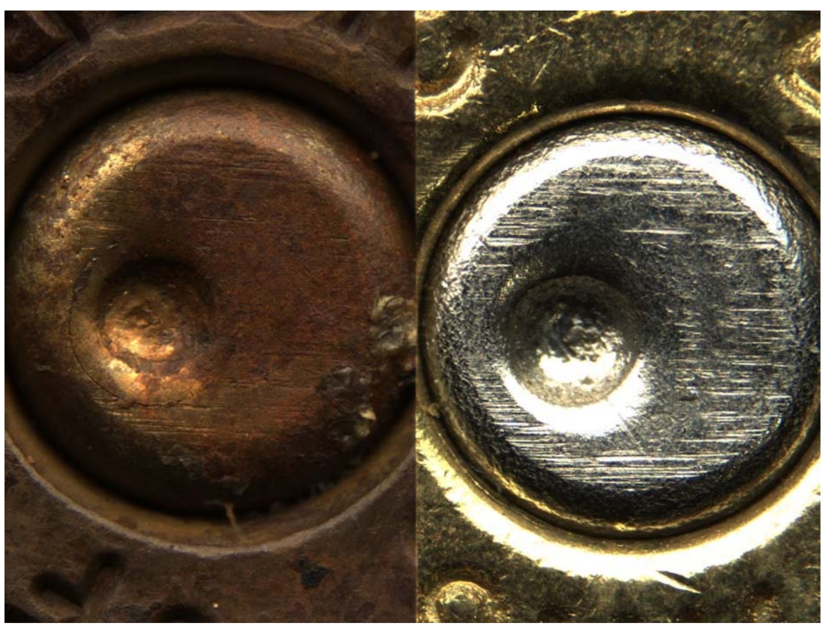
Picture 96: Unknown aluminum sample #14 from open buried environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



Picture 97: Unknown steel sample #10 from water environment after 9 months (left) compared to known steel sample fired in Hi Point model C9 (right)

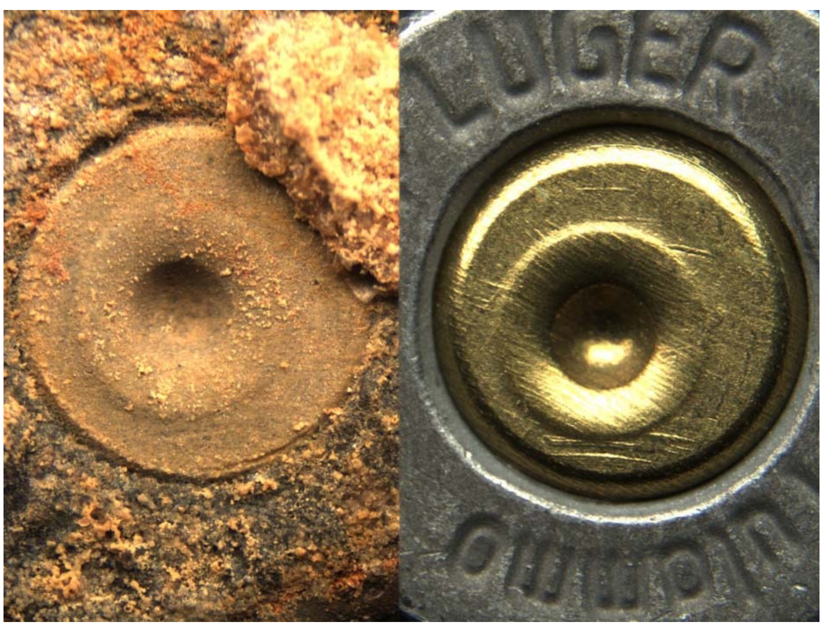


Picture 98: Unknown brass sample #2 from water environment after 9 months (left) compared to known brass sample fired in Hi Point model C9 (right)

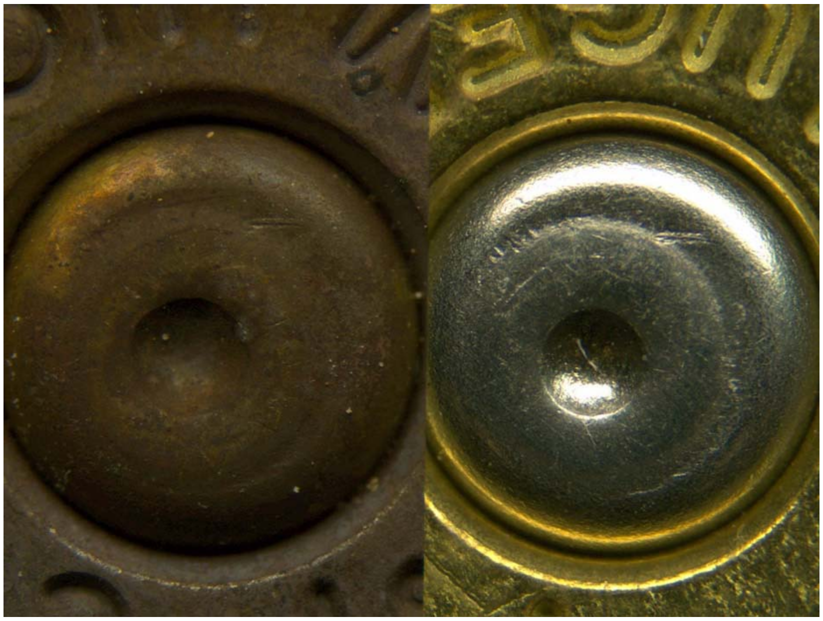


Picture 99: Unknown aluminum sample #13 from water environment after 9 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

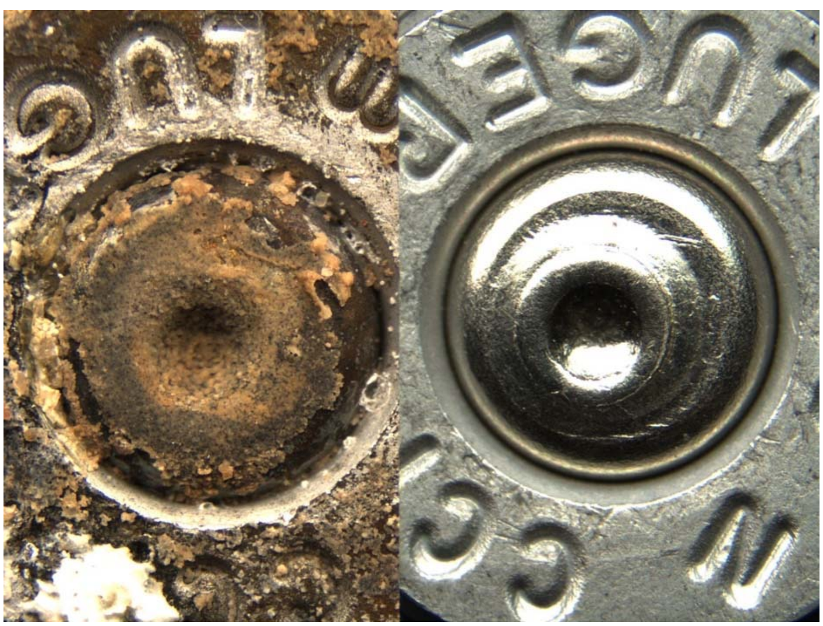
Picture 100: Unknown steel sample #15 from water environment after 9 months (left) compared to known steel sample fired in Beretta model 92FS (right)



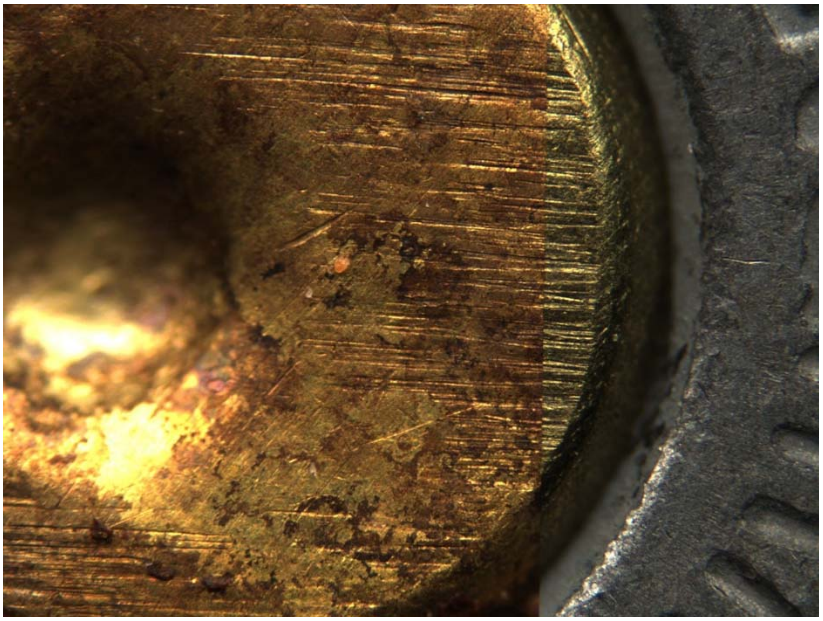
Picture 101: Unknown brass sample #9 from water environment after 9 months (left) compared to known brass sample fired in Beretta model 92FS (right)



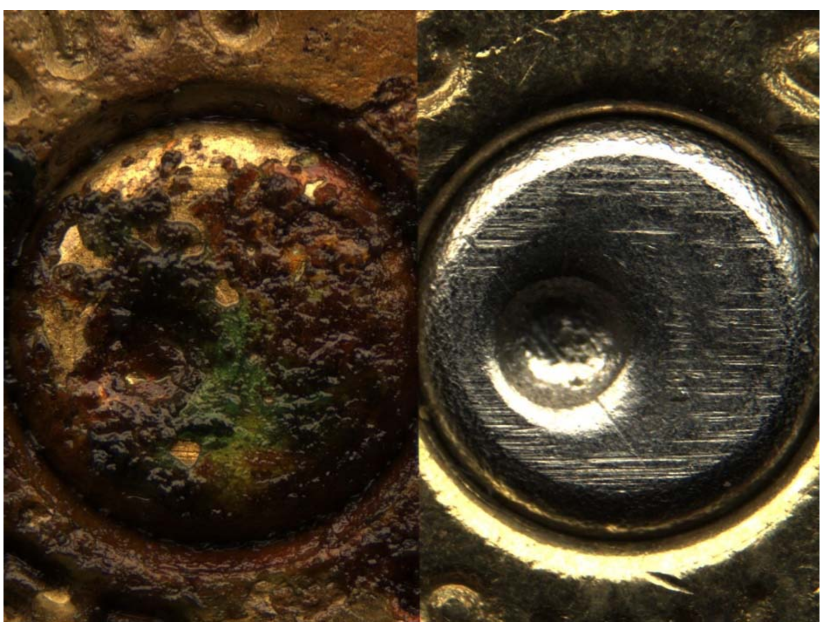
Picture 102: Unknown aluminum sample #16 from water environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



Picture 103: Unknown steel sample #5 from pig buried environment after 9 months (left) compared to known steel sample fired in Hi Point model C9 (right)

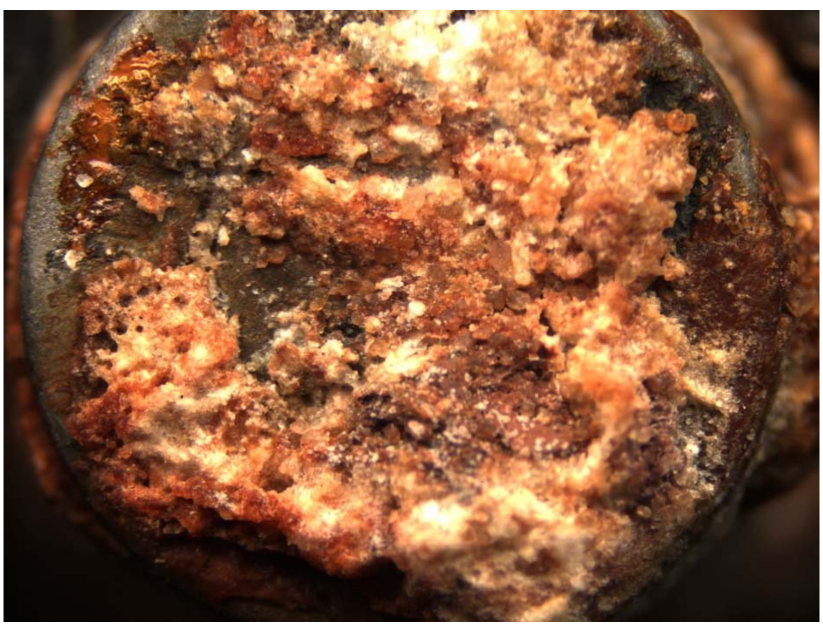


Picture 104: Unknown brass sample #12 from pig buried environment after 9 months (left) compared to known brass sample fired in Hi Point model C9 (right)



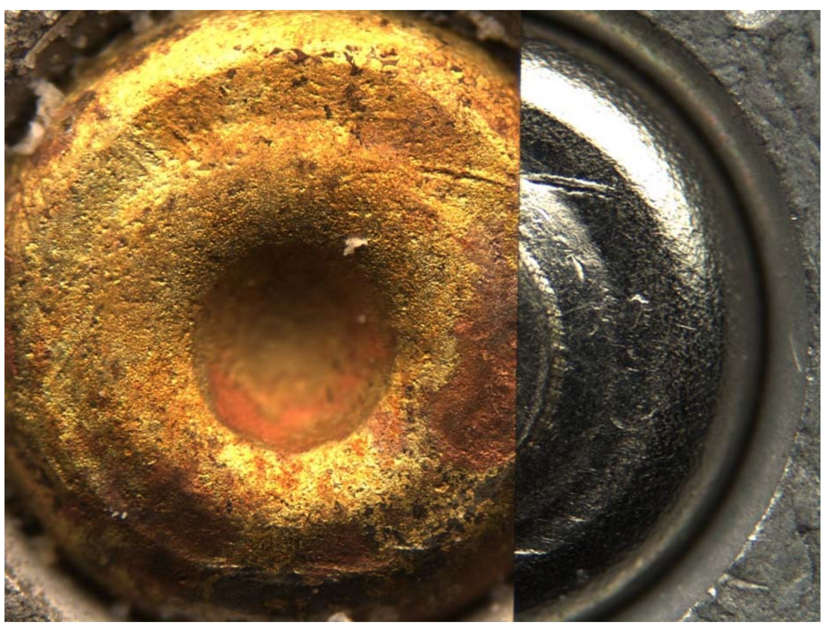
Picture 105: Unknown aluminum sample #9 from pig buried environment after 9 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

Picture 106: Unknown steel sample #18 from pig buried environment after 9 months (left) compared to known steel sample fired in Beretta model 92FS (right)



Picture 107: Unknown brass sample #14 from pig buried environment after 9 months (left) compared to known brass sample fired in Beretta model 92FS (right)

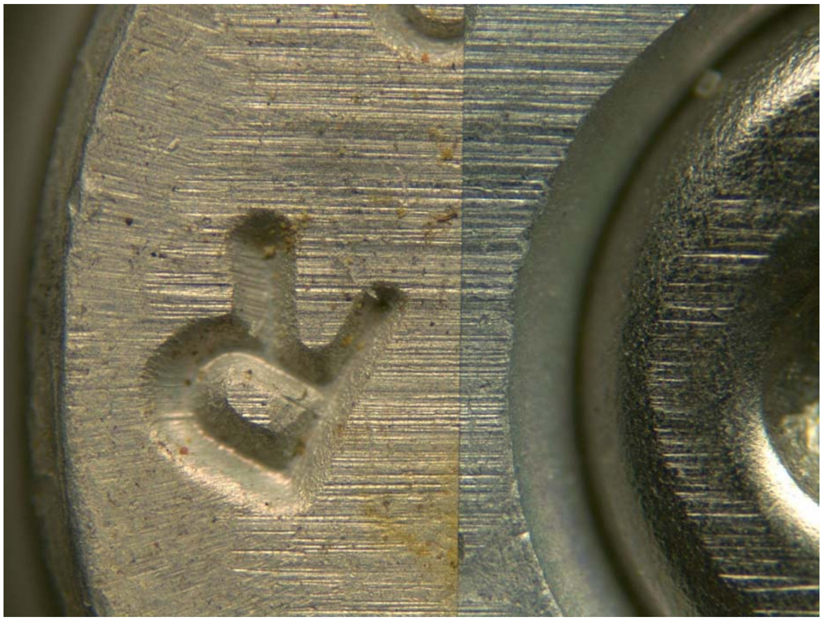
Picture 108: Unknown aluminum sample #2 from pig buried environment after 9 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



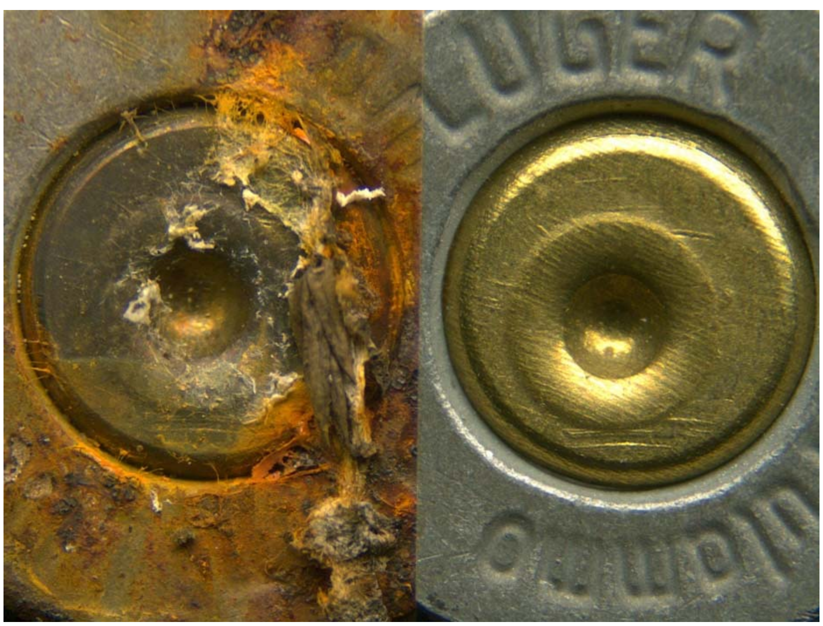
Picture 109: Unknown steel sample #5 from shaded exposed environment after 12 months (left) compared to known steel sample fired in Hi Point model C9 (right)

Picture 110: Unknown brass sample #11 from shaded exposed environment after 12 months (left) compared to known brass sample fired in Hi Point model C9 (right)

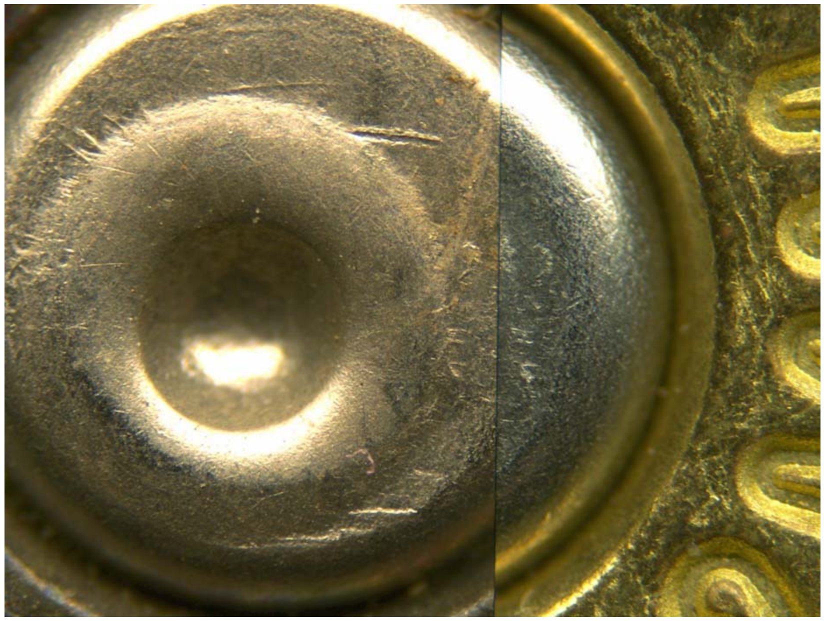
Picture 111: Unknown aluminum sample #1 from shaded exposed environment after 12 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



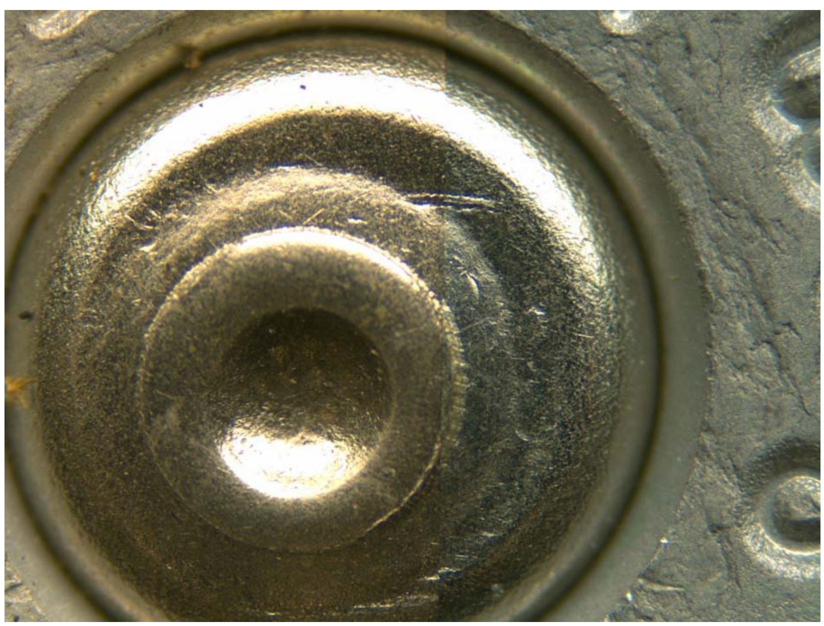
Picture 112: Unknown steel sample #7 from shaded exposed environment after 12 months (left) compared to known steel sample fired in Hi Point model C9 (right)



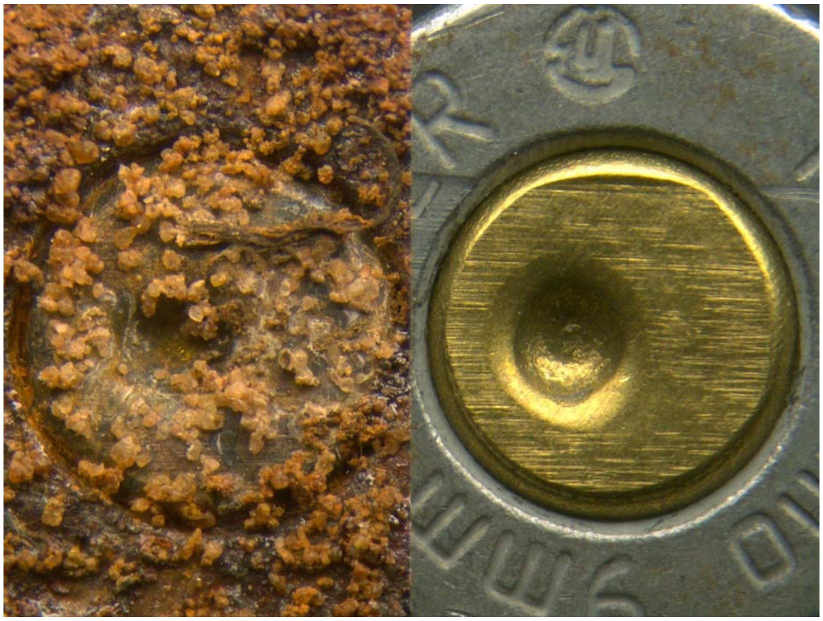
Picture 113: Unknown brass sample #9 from shaded exposed environment after 12 months (left) compared to known brass sample fired in Beretta model 92FS (right)



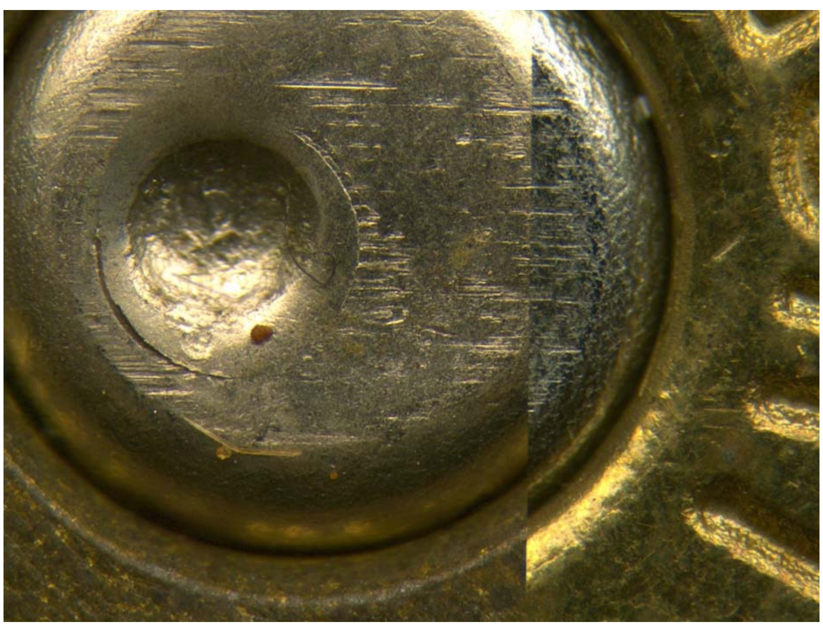
Picture 114: Unknown aluminum sample #13 from shaded exposed environment after 12 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



Picture 115: Unknown steel sample #1 from shaded buried environment after 12 months (left) compared to known steel sample fired in Hi Point model C9 (right)

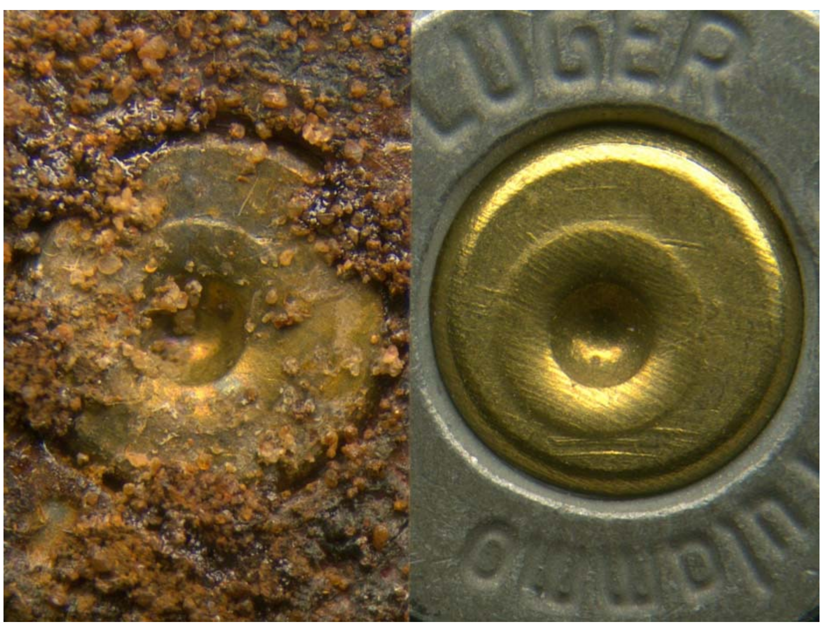


Picture 116: Unknown brass sample #15 from shaded buried environment after 12 months (left) compared to known brass sample fired in Hi Point model C9 (right)

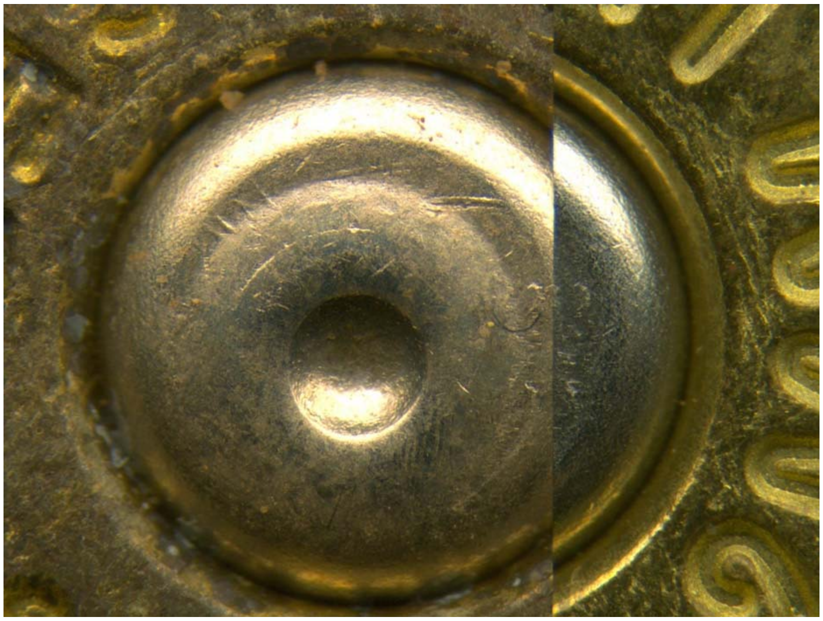


Picture 117: Unknown aluminum sample #7 from shaded buried environment after 12 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)

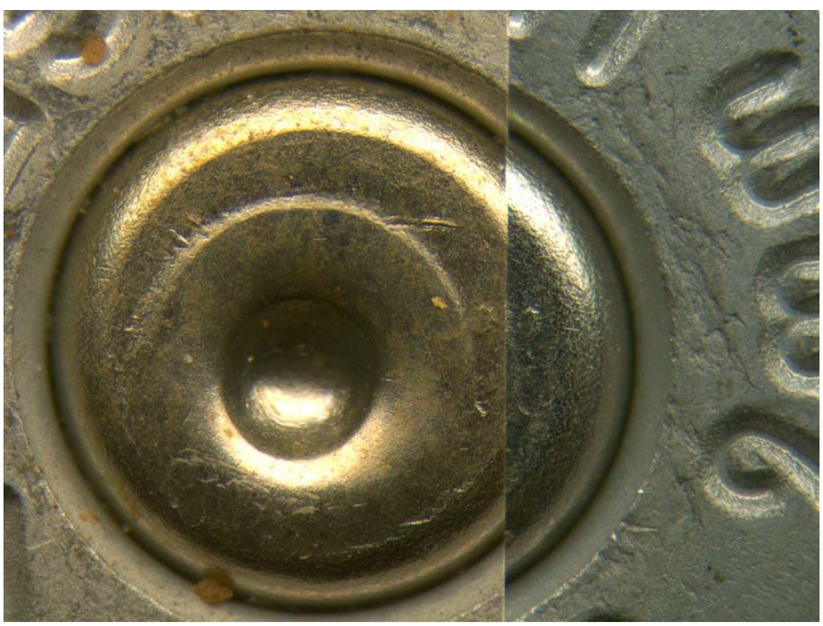
Picture 118: Unknown steel sample #5 from shaded buried environment after 12 months (left) compared to known steel sample fired in Beretta model 92FS (right)



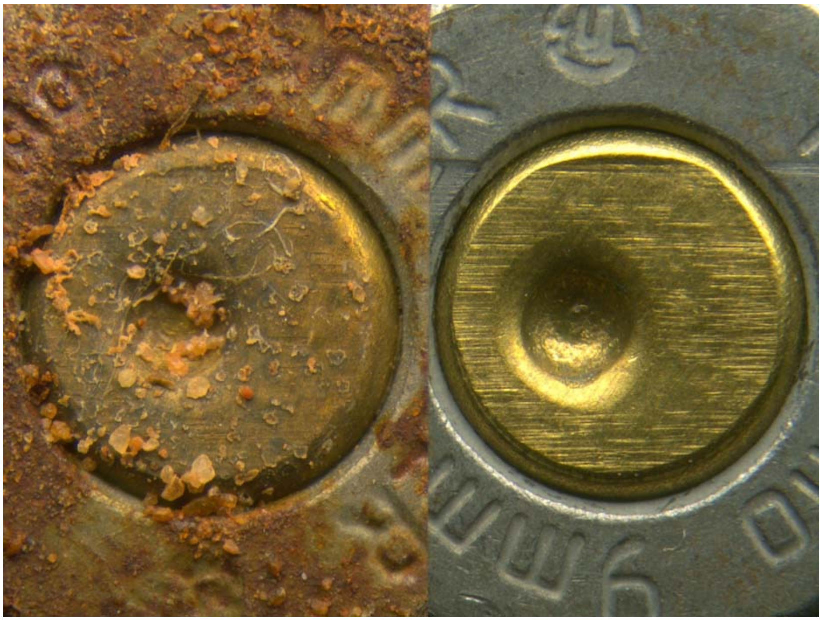
Picture 119: Unknown brass sample #3 from shaded buried environment after 12 months (left) compared to known brass sample fired in Beretta model 92FS (right)



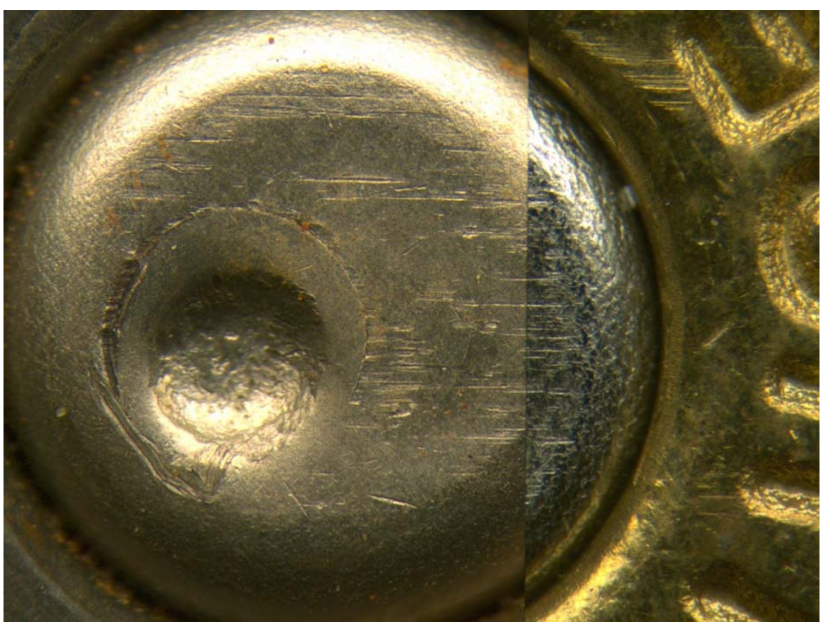
Picture 120: Unknown aluminum sample #12 from shaded buried environment after 12 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



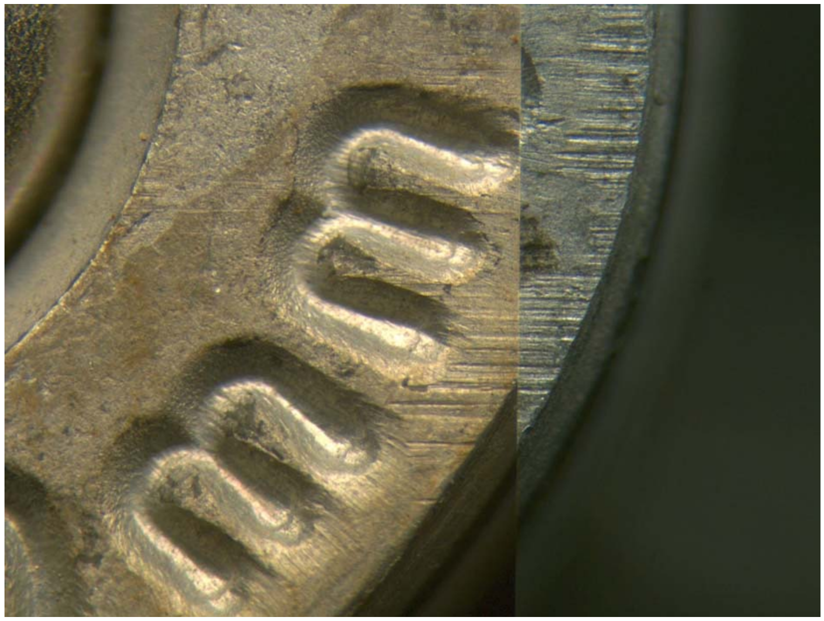
Picture 121: Unknown steel sample #8 from open exposed environment after 12 months (left) compared to known steel sample fired in Hi Point model C9 (right)



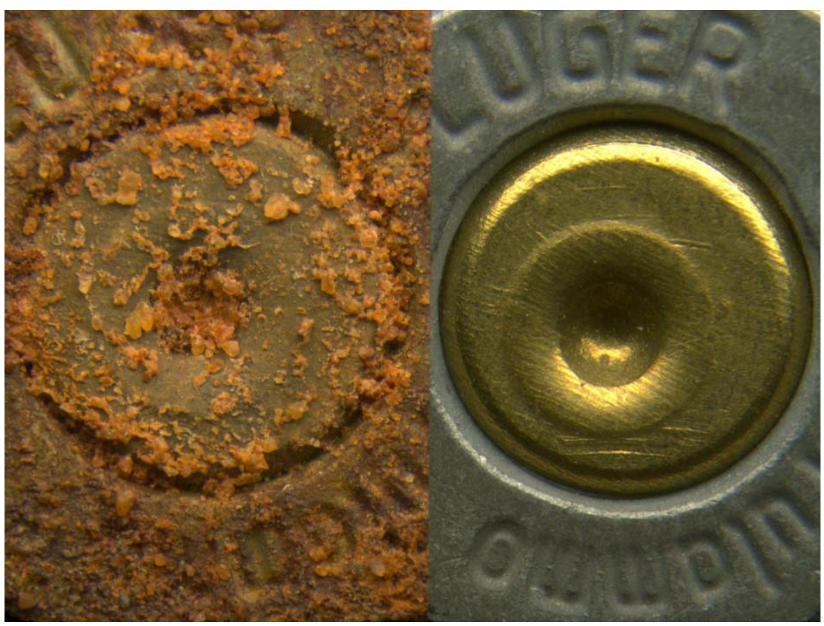
Picture 122: Unknown brass sample #14 from open exposed environment after 12 months (left) compared to known brass sample fired in Hi Point model C9 (right)



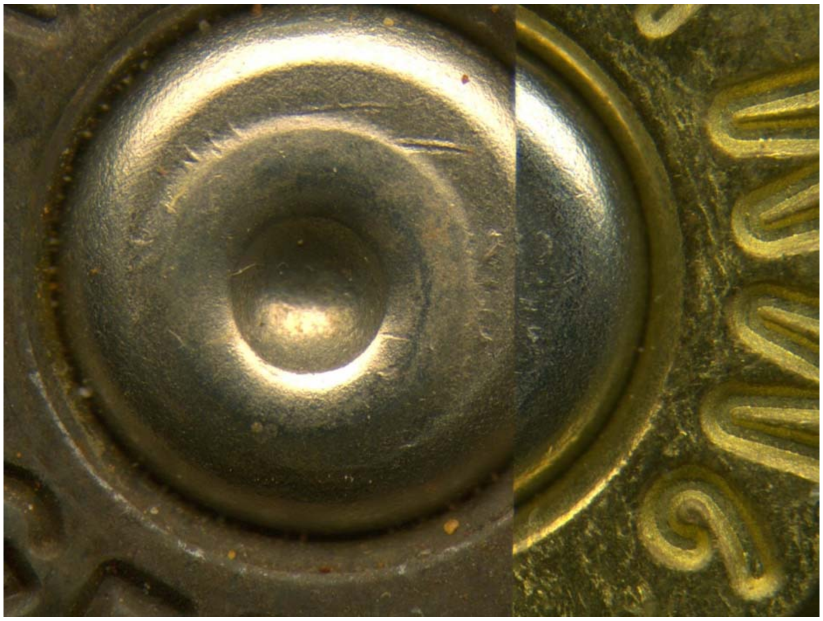
Picture 123: Unknown aluminum sample #15 from open exposed environment after 12 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



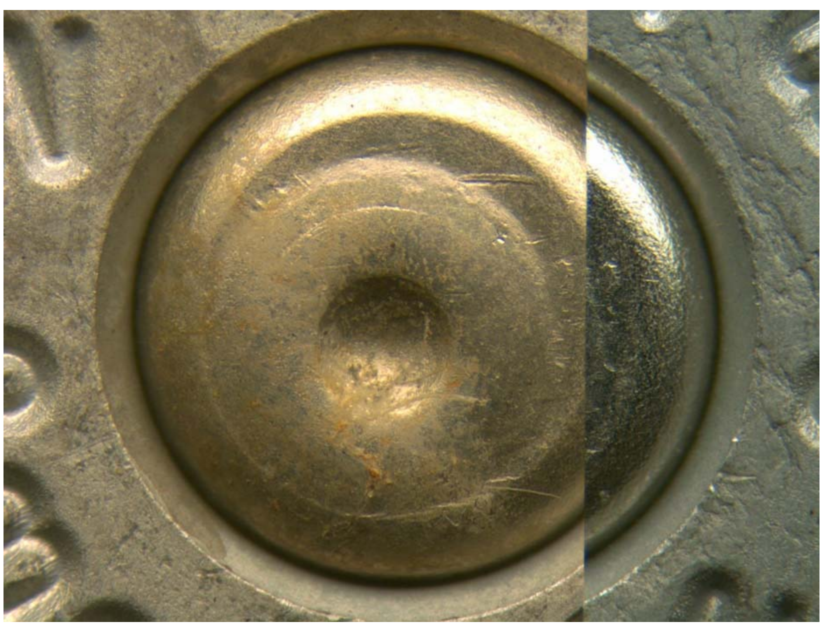
Picture 124: Unknown steel sample #9 from open exposed environment after 12 months (left) compared to known steel sample fired in Beretta model 92FS (right)



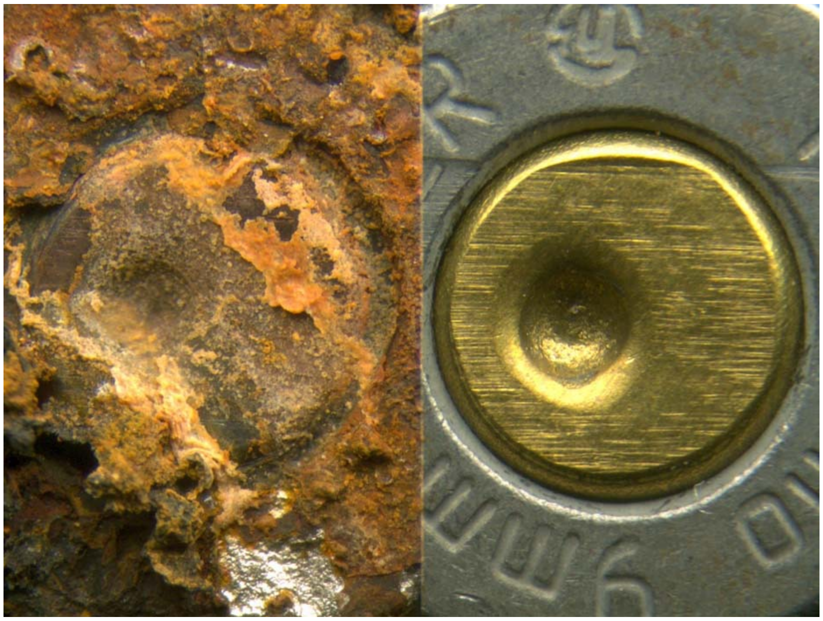
Picture 125: Unknown brass sample #7 from open exposed environment after 12 months (left) compared to known brass sample fired in Beretta model 92FS (right)



Picture 126: Unknown aluminum sample #10 from open exposed environment after 12 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)

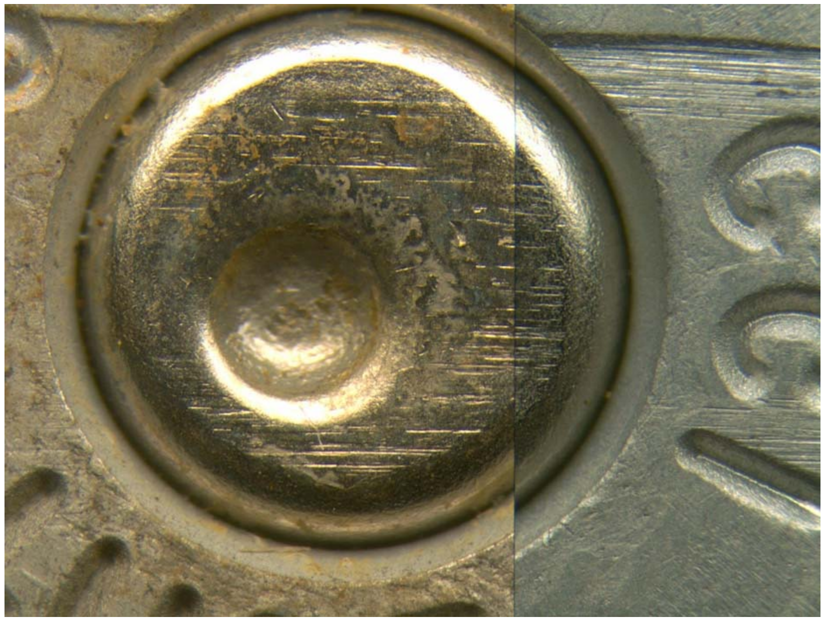


Picture 127: Unknown steel sample #7 from open buried environment after 12 months (left) compared to known steel sample fired in Hi Point model C9 (right)

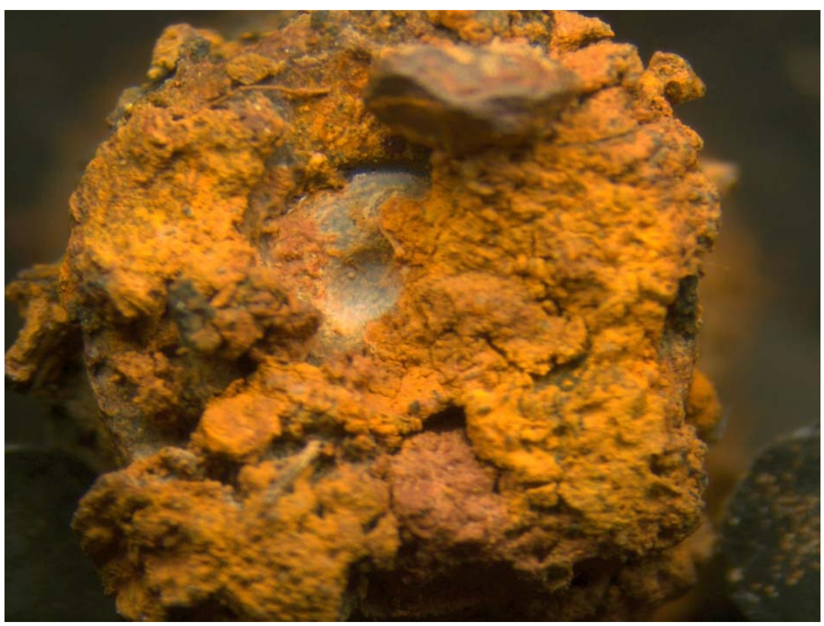


Picture 128: Unknown brass sample #12 from open buried environment after 12 months (left) compared to known brass sample fired in Hi Point model C9 (right)

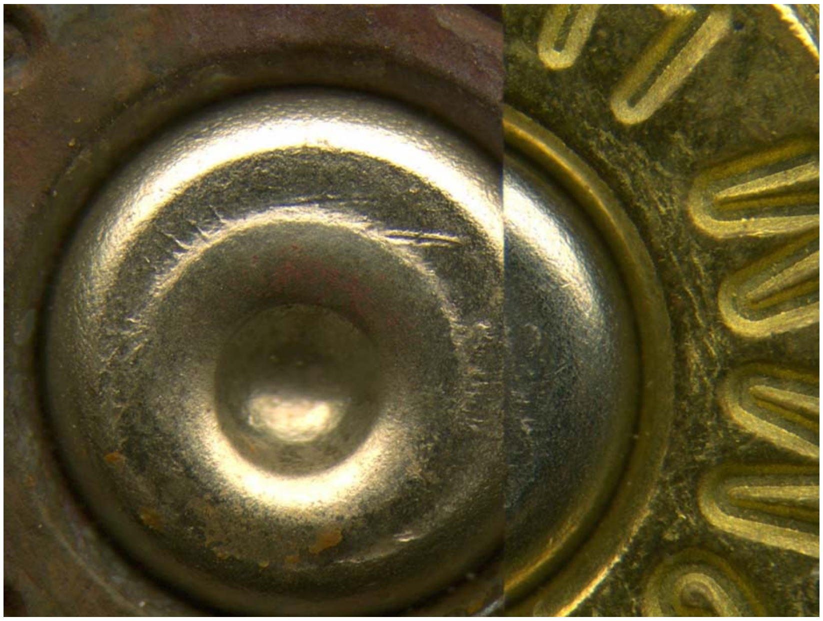
Picture 129: Unknown aluminum sample #6 from open buried environment after 12 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



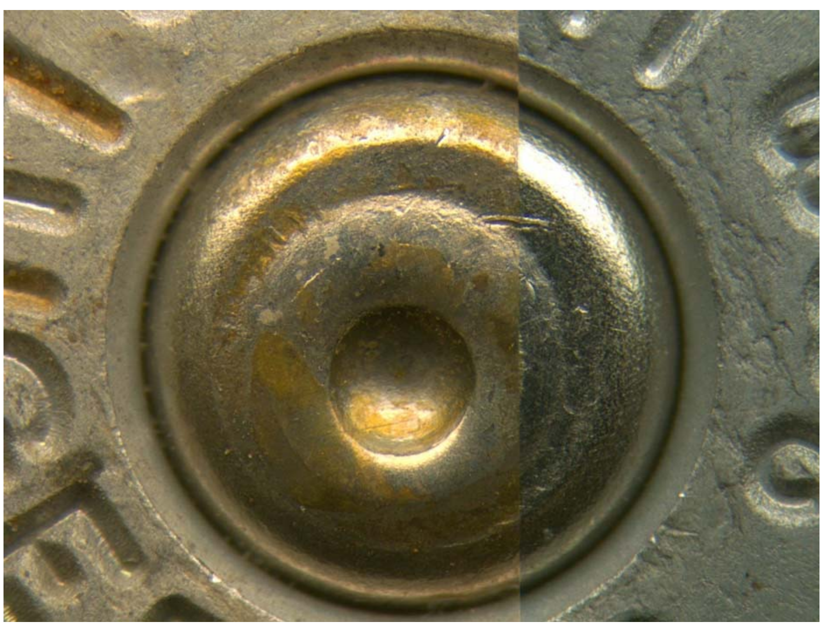
Picture 130: Unknown steel sample #4 from open buried environment after 12 months; due to debris and corrosion, unable to determine if was fired in Beretta or Hi Point



Picture 131: Unknown brass sample #9 from open buried environment after 12 months (left) compared to known brass sample fired in Beretta model 92FS (right)



Picture 132: Unknown aluminum sample #16 from open buried environment after 12 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



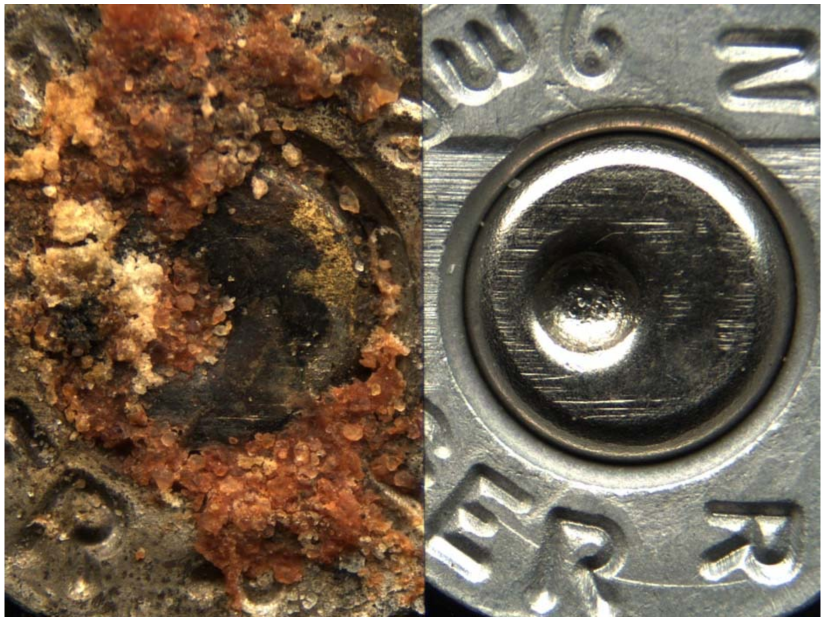
Picture 133: Unknown steel sample #9 from pig buried environment after 12 months (left)

compared to known steel sample fired in Hi Point model C9 (right)

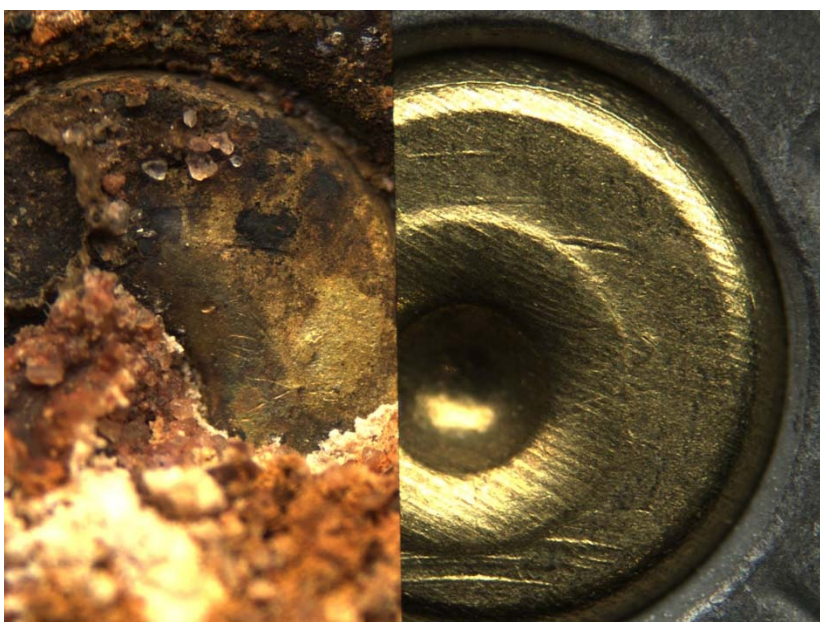
Picture 134: Unknown brass sample #10 from pig buried environment after 12 months (left)

compared to known brass sample fired in Hi Point model C9 (right)

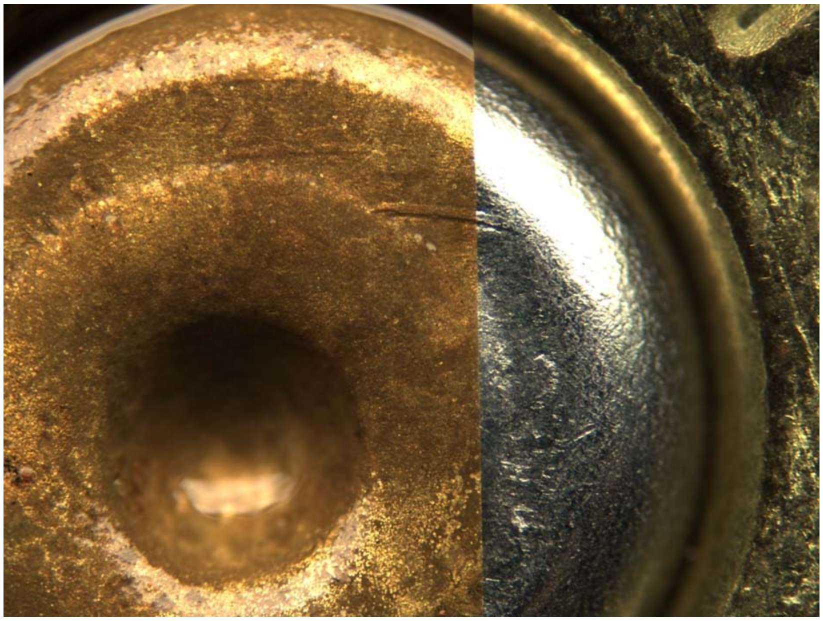
Picture 135: Unknown aluminum sample #2 from pig buried environment after 12 months (left) compared to known aluminum sample fired in Hi Point model C9 (right)



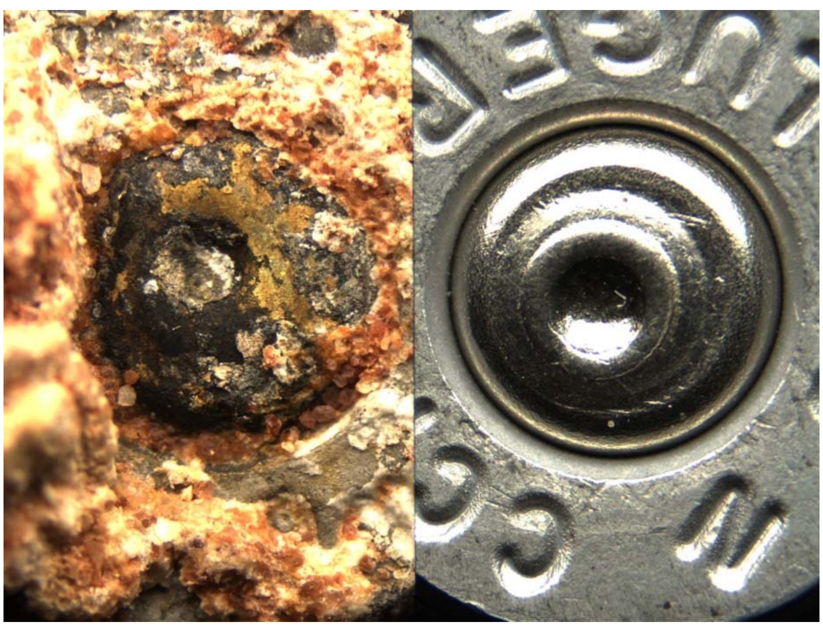
Picture 136: Unknown steel sample #13 from pig buried environment after 12 months (left) compared to known steel sample fired in Beretta model 92FS (right)



Picture 137: Unknown brass sample #17 from pig buried environment after 12 months (left) compared to known brass sample fired in Beretta model 92FS (right)

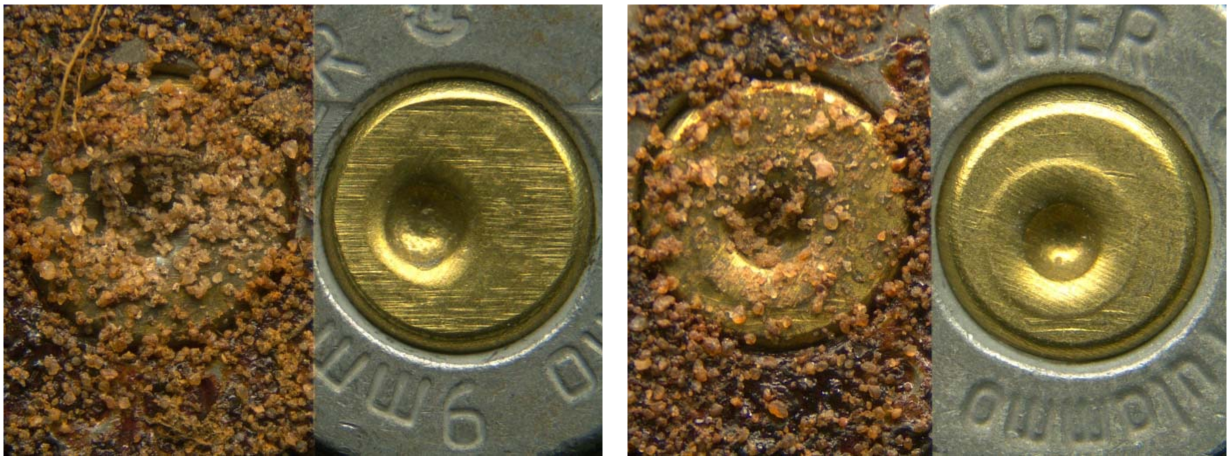


Picture 138: Unknown aluminum sample #8 from pig buried environment after 12 months (left) compared to known aluminum sample fired in Beretta model 92FS (right)



Appendix 3: Results before and after restorative techniques applied to samples

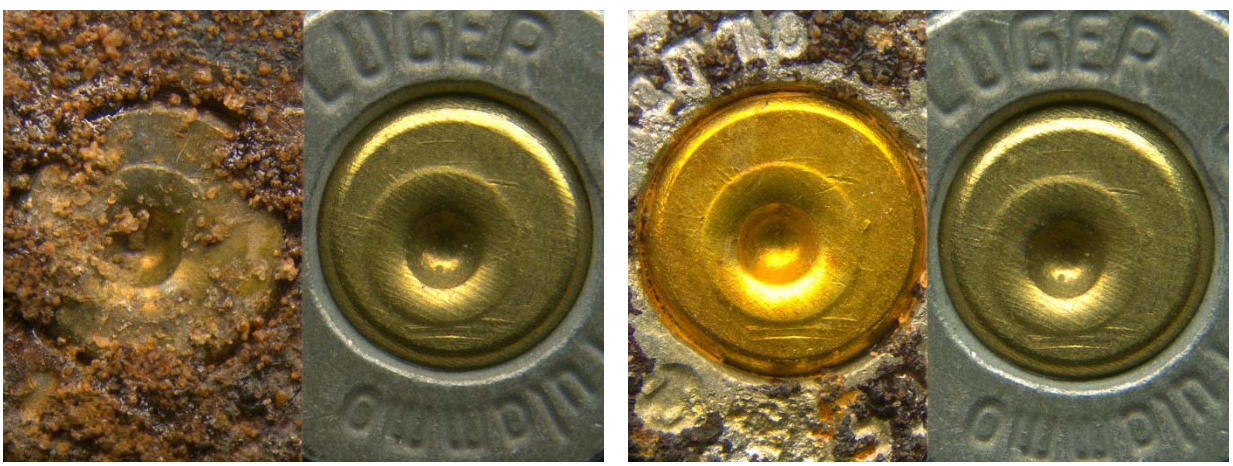
Picture 1: Unknown steel sample #5 before (left) and after cleaning with jewelry cleaner (right) after 9 months in shaded buried environment



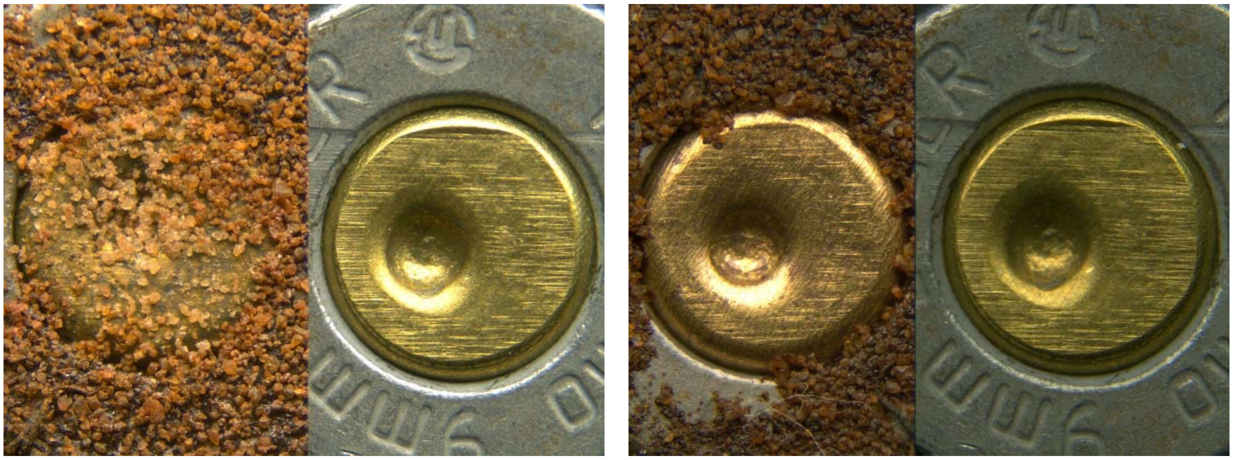
Picture 2: Unknown steel sample #1 before (left) and after cleaning with jewelry cleaner (right) after 12 months in shaded buried environment

Picture 3: Unknown steel sample #12 before (left) and after cleaning with Randich method (right) after 9 months in shaded buried environment

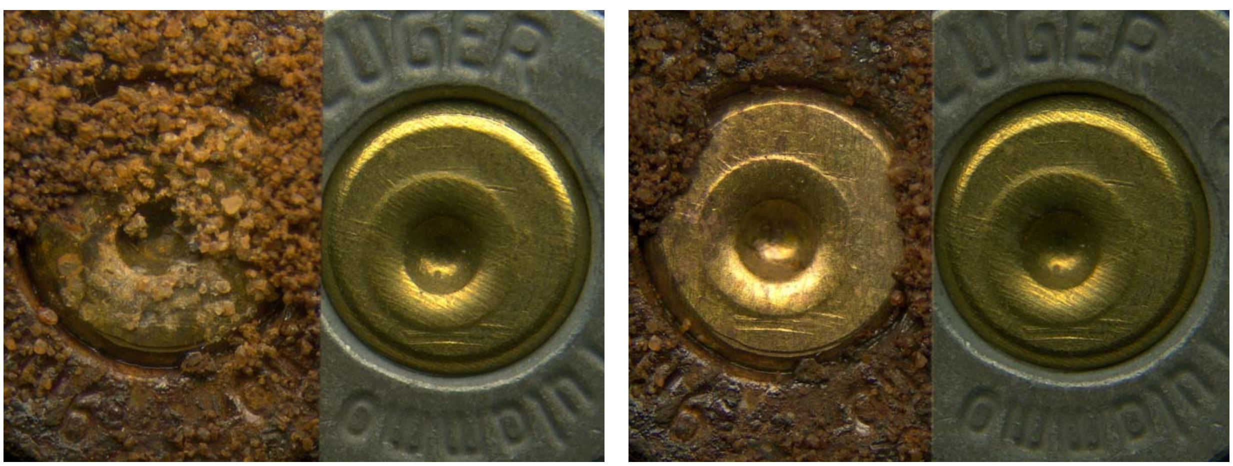
Picture 4: Unknown steel sample #5 before (left) and after cleaning with Randich method (right) after 12 months in shaded buried environment



Picture 5: Unknown steel sample #8 before (left) and after cleaning with Aqua Regia (right) after 9 months in shaded buried environment

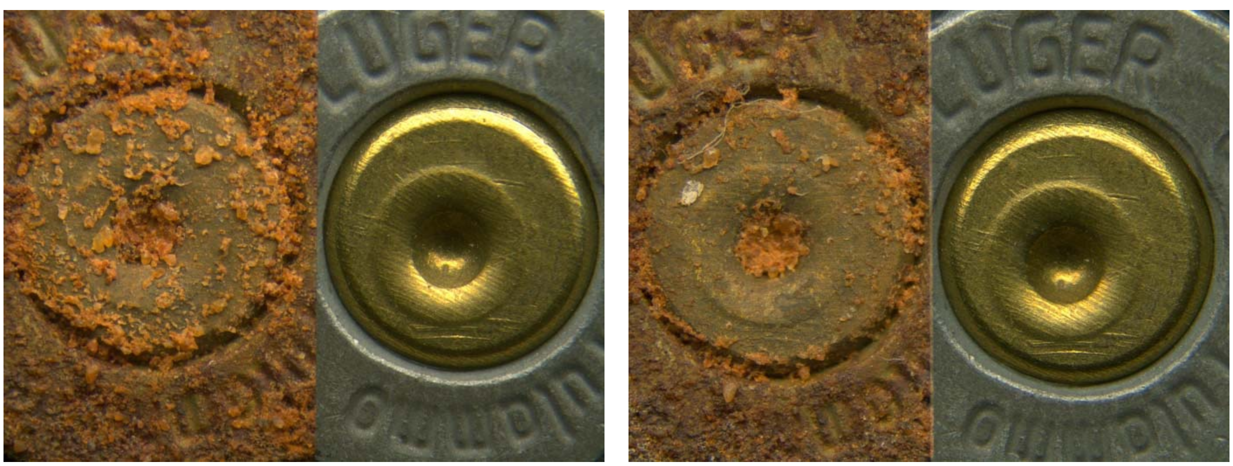


Picture 6: Unknown steel sample #17 before (left) and after cleaning with Aqua Regia (right) after 12 months in shaded buried environment

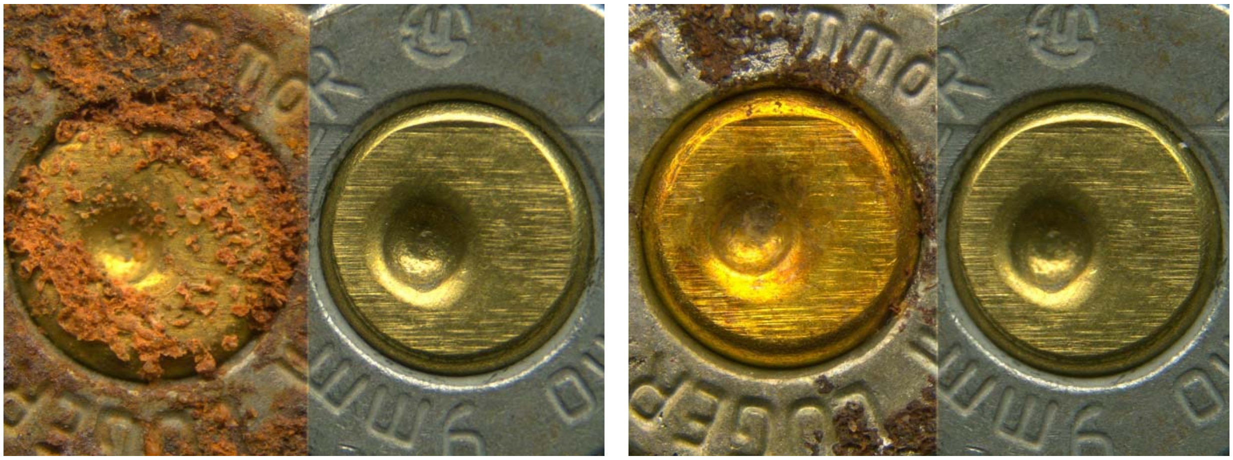


Picture 7: Unknown steel sample #13 before (left) and after cleaning with jewelry cleaner (right) after 6 months in open exposed environment

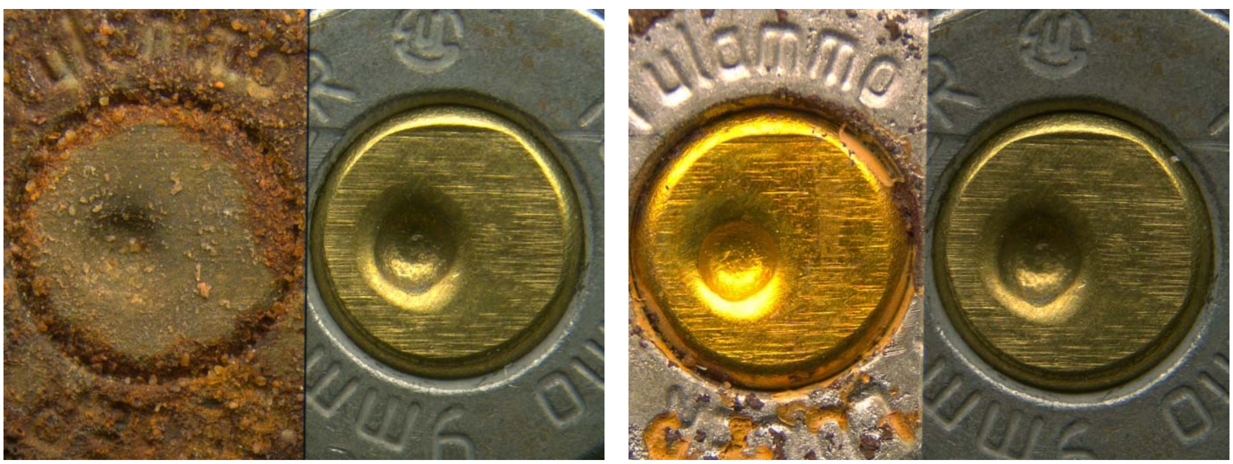
Picture 8: Unknown steel sample #9 before (left) and after cleaning with jewelry cleaner (right) after 12 months in open exposed environment



Picture 9: Unknown steel sample #17 before (left) and after cleaning with Randich method (right) after 9 months in open exposed environment



Picture 10: Unknown steel sample #17 before (left) and after cleaning Randich method (right) after 12 months in open exposed environment



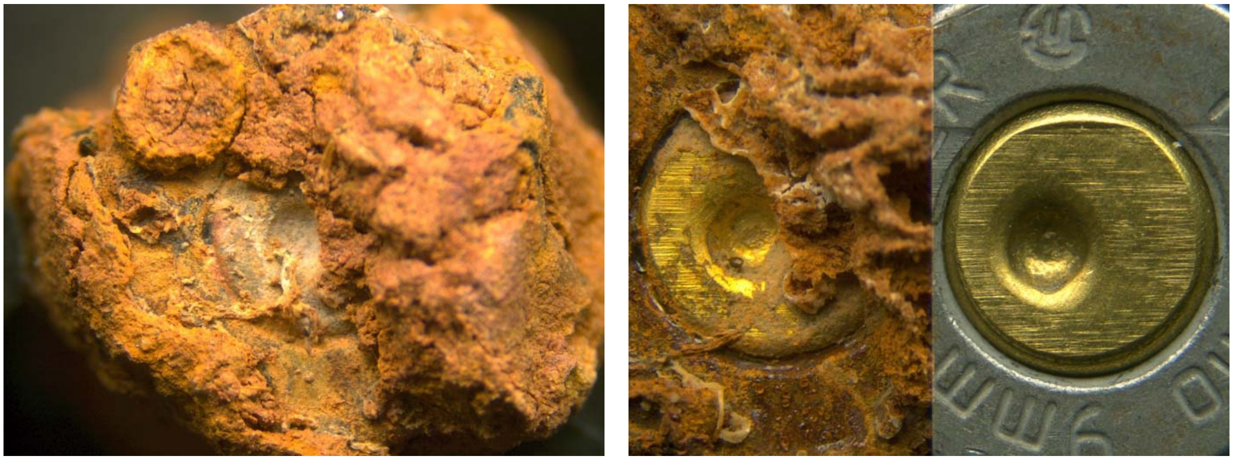
Picture 11: Unknown steel sample #11 before (left) and after cleaning with Aqua Regia (right) after 6 months in open exposed environment

Picture 12: Unknown steel sample #16 before (left) and after cleaning with Aqua Regia (right) after 12 months in open exposed environment

Picture 13: Unknown steel sample #7 before (left) and after cleaning with jewelry cleaner (right) after 9 months in open buried environment

Picture 14: Unknown steel sample #3 before (left) and after cleaning with Randich method (right) after 6 months in open buried environment

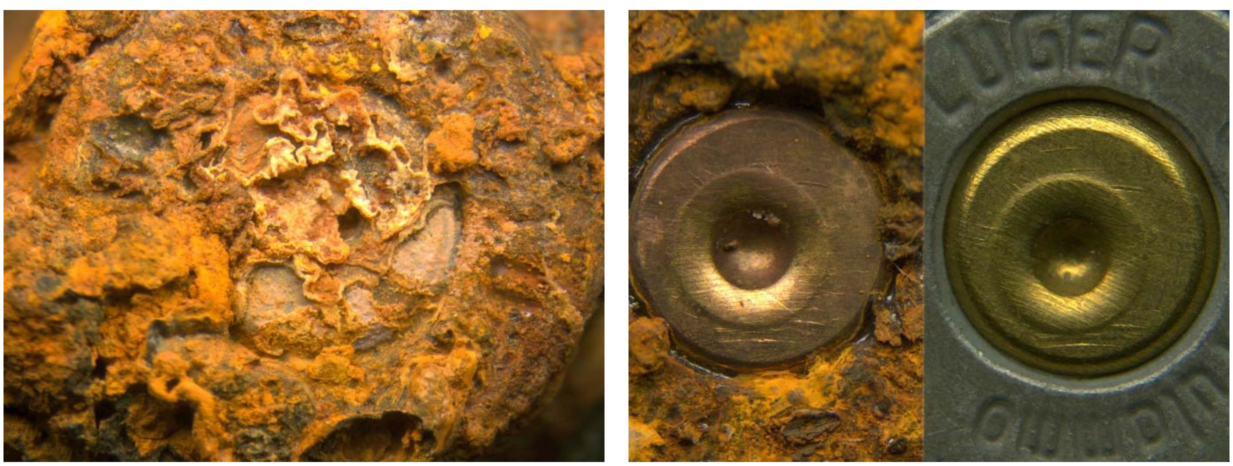
Picture 15: Unknown steel sample #3 before (left) and after cleaning with Randich method (right) after 9 months in open buried environment



Picture 16: Unknown steel sample #7 before (left) and after cleaning with Randich method (right) after 12 months in open buried environment

Picture 17: Unknown steel sample #6 before (left) and after cleaning with Aqua Regia (right) after 6 months in open buried environment

Picture 18: Unknown steel sample #1 before (left) and after cleaning with Aqua Regia (right) after 12 months in open buried environment



Picture 19: Unknown aluminum sample #4 before (left) and after cleaning with jewelry cleaner (right) after 3 months in water environment

Picture 20: Unknown steel sample #1 before (left) and after cleaning with jewelry cleaner (right) after 6 months in water environment

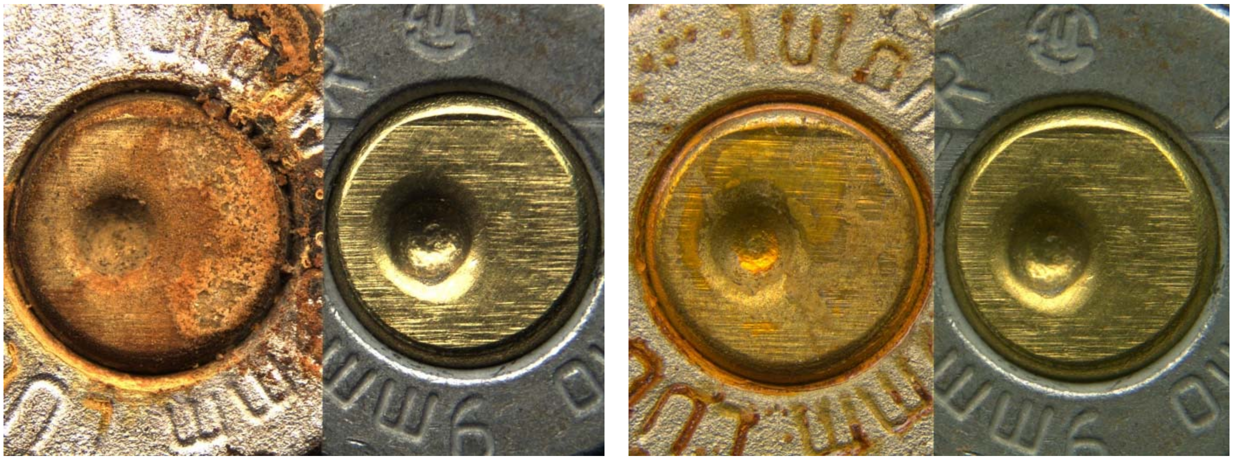
Picture 21: Unknown aluminum sample #11 before (left) and after cleaning with jewelry cleaner (right) after 9 months in water environment

Picture 22: Unknown steel sample #10 before (left) and after cleaning with jewelry cleaner (right) after 9 months in water environment

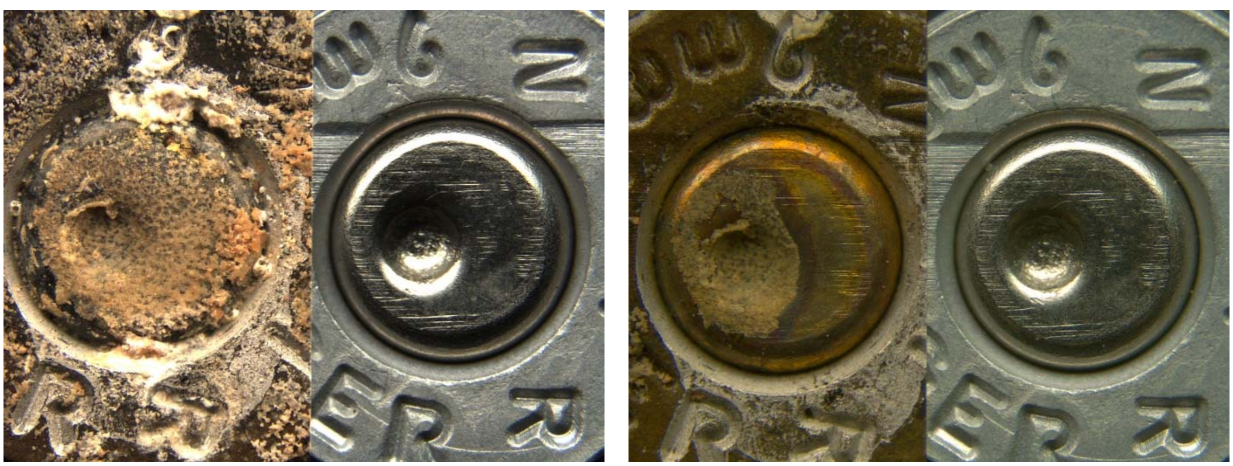
Picture 23: Unknown steel sample #1 before (left) and after cleaning with Randich method (right) after 3 months in water environment

Picture 24: Unknown aluminum sample #2 before (left) and after cleaning with Randich method (right) after 3 months in water environment

Picture 25: Unknown steel sample #8 before (left) after cleaning with Randich method (right) after 6 months in water environment



Picture 26: Unknown aluminum sample #16 before (left) and after cleaning with Randich method (right) after 6 months in water environment



Picture 27: Unknown steel sample #7 before (left) and after cleaning with Randich method (right) after 9 months in water environment

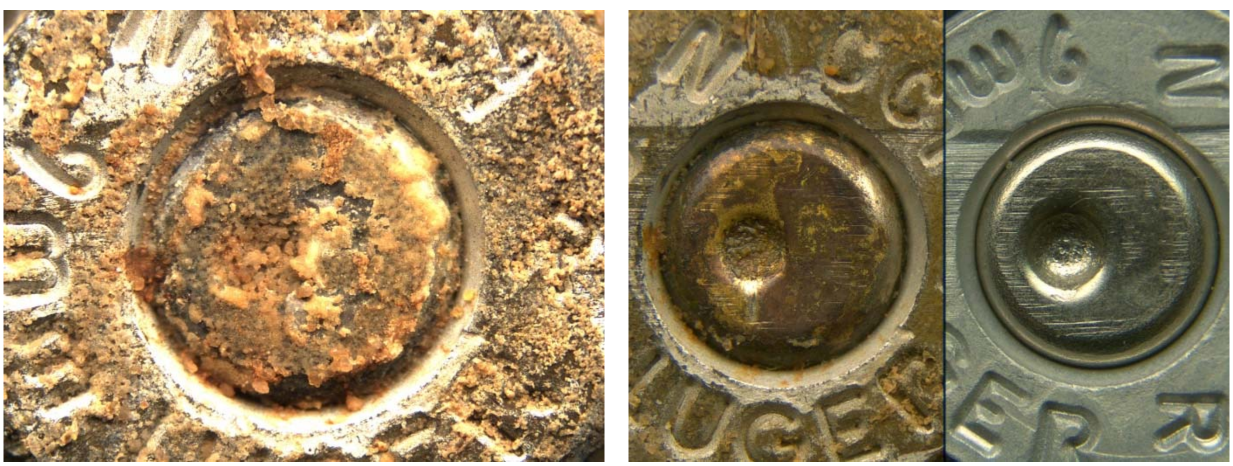
Picture 28: Unknown aluminum sample #14 before (left) and after cleaning with Randich method (right) after 9 months in water environment

Picture 29: Unknown steel sample #6 before (left) and after cleaning with Aqua Regia (right) after 3 months in water environment

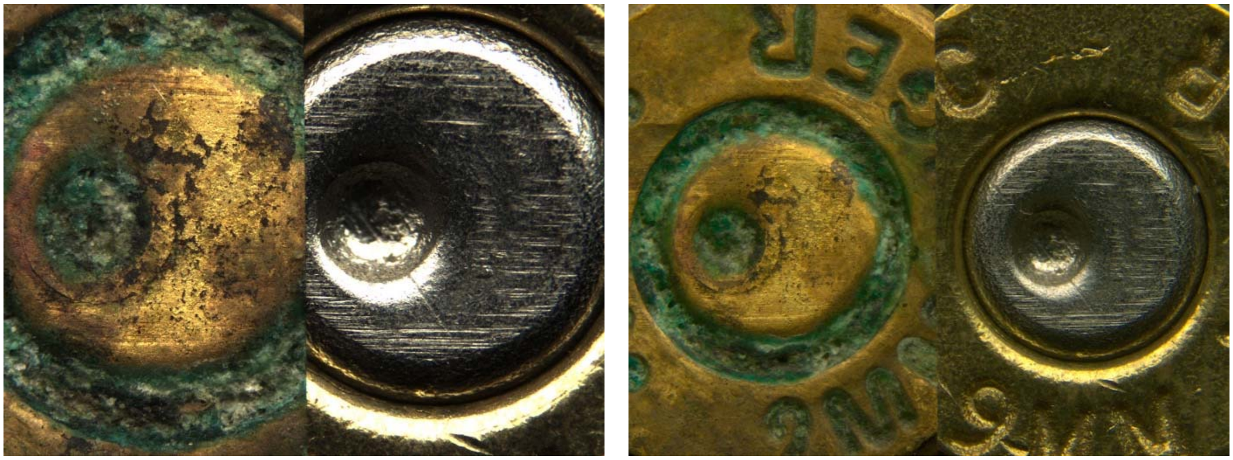
Picture 30: Unknown steel sample #5 before (left) and after cleaning with Aqua Regia (right) after 6 months in water environment

Picture 31: Unknown steel sample #18 before (left) and after cleaning with Aqua Regia (right) after 9 months in water environment

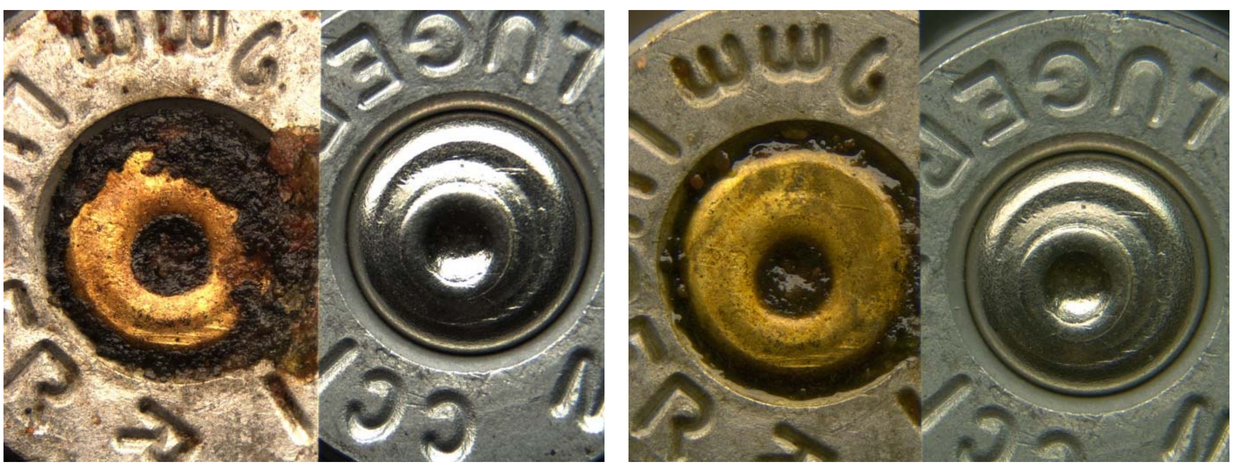
Picture 32: Unknown aluminum sample #4 before (left) and after cleaning with Aqua Regia (right) after 9 months in water environment



Picture 33: Unknown brass sample #2 before (left) and after cleaning with jewelry cleaner (right) after 3 months in pig buried environment



Picture 34: Unknown aluminum sample #17 before (left) and after cleaning with jewelry cleaner (right) after 6 months in pig buried environment



Picture 35: Unknown brass sample #18 before (left) after cleaning with jewelry cleaner (right) after 6 months in pig buried environment

Picture 36: Unknown steel sample #4 before (left) and after cleaning with jewelry cleaner (right) after 9 months in pig buried environment

Picture 37: Unknown brass sample #11 before (left) and after cleaning with jewelry cleaner (right) after 9 months in pig buried environment

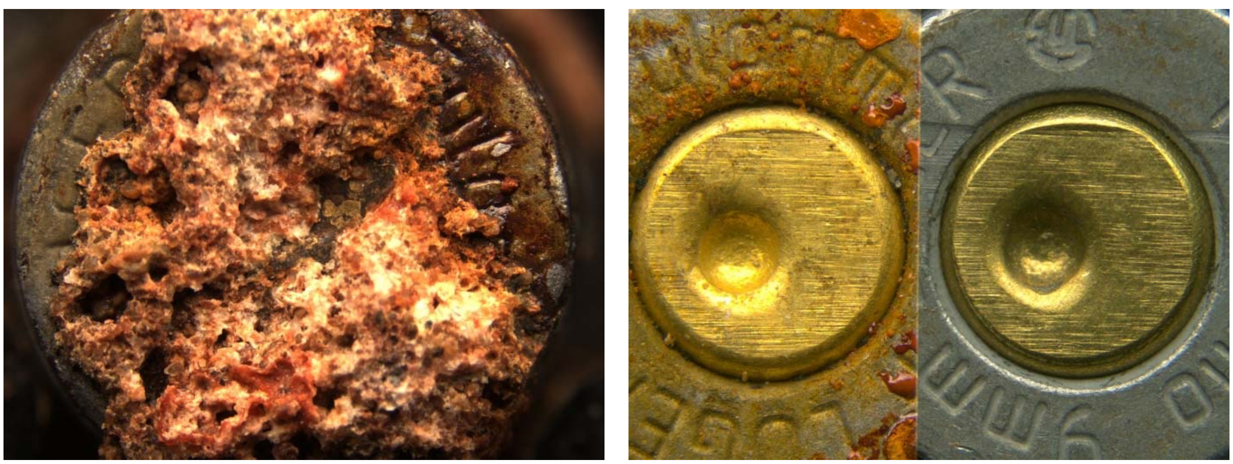
Picture 38: Unknown brass sample #1 before (left) and after cleaning with jewelry cleaner (right) after 12 months in pig buried environment

Picture 39: Unknown brass sample #13 before (left) and after cleaning with Randich method (right) after 3 months in pig buried environment

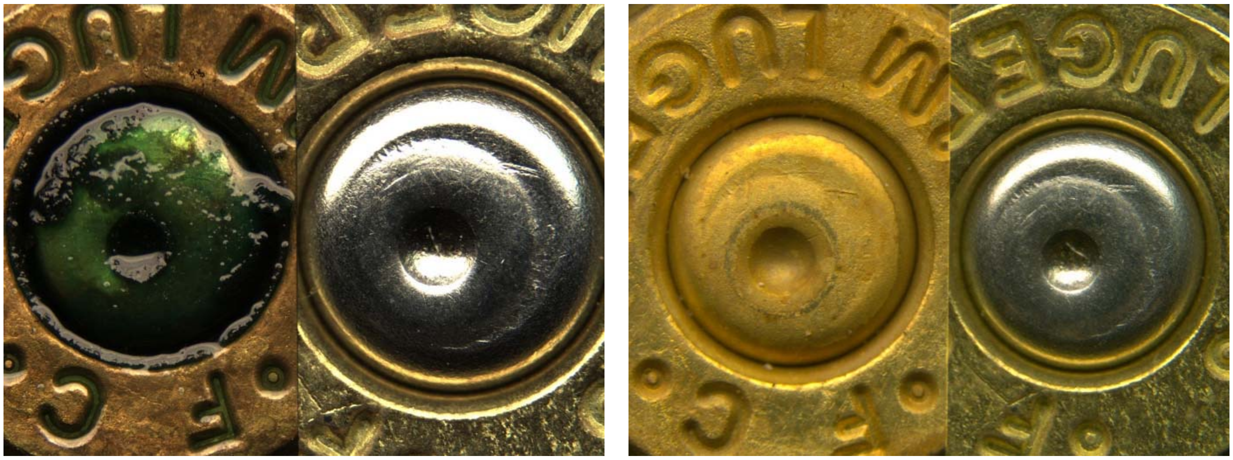
Picture 40: Unknown aluminum sample #4 before (left) and after cleaning with Randich method (right) after 6 months in pig buried environment

Picture 41: Unknown brass sample #6 before (left) and after cleaning with Randich method (right) after 6 months in pig buried environment

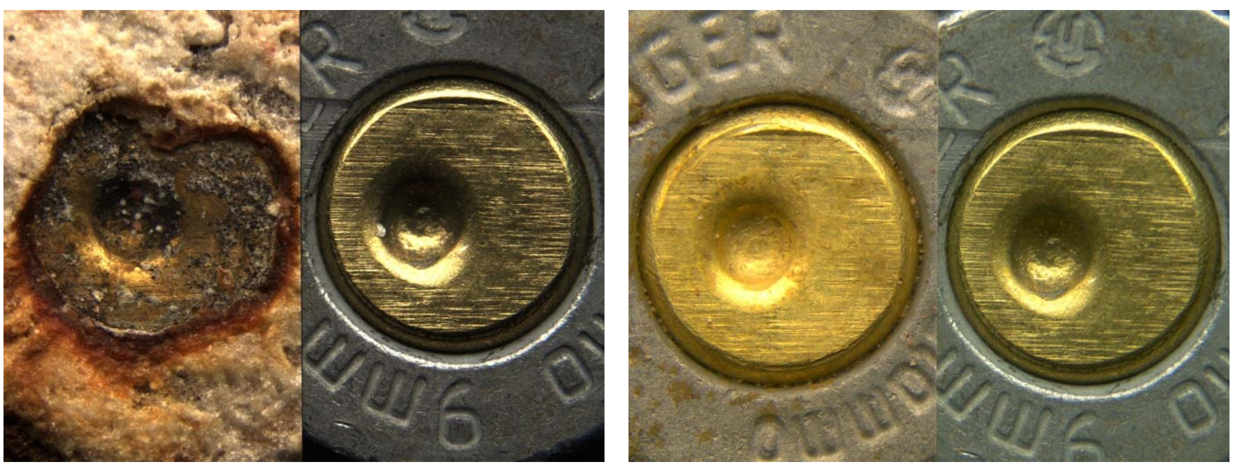
Picture 42: Unknown steel sample #13 before (left) and after cleaning with Randich method (right) after 9 months in pig buried environment



Picture 43: Unknown brass sample #14 before (left) and after cleaning with Randich method (right) after 9 months in pig buried environment



Picture 44: Unknown steel sample #9 before (left) and after cleaning with Randich method (right) after 12 months in pig buried environment



Picture 45: Unknown brass sample #7 before (left) and after cleaning with Randich method (right) after 12 months in pig buried environment

Picture 46: Unknown brass sample #14 before (left) and after cleaning with Aqua Regia (right) after 6 months in pig buried environment

Picture 47: Unknown steel sample #8 before (left) and after cleaning with Aqua Regia (right) after 9 months in pig buried environment

Picture 48: Unknown brass sample #1 before (left) and after cleaning with Aqua Regia (right) after 9 months in pig buried environment

Picture 49: Unknown steel sample #4 before (left) and after cleaning with Aqua Regia (right) after 12 months in pig buried environment

Picture 50: Unknown brass sample #10 before (left) and after cleaning with Aqua Regia (right) after 12 months in pig buried environment