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Research and Development of Impression Evidence

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Final Technical Report

Abstract

The collection and preservation of tool mark and impression evidence is an important part of the field of criminalistics. The ability to discern class and individual characteristics and use these to either identify or exclude an item as a possible match is a powerful tool in a criminalist's arsenal. The ability, then, of a casting agent to resolve the fine scale details of a tool mark or impression becomes of the utmost importance.

An innovative approach to this problem is utilizing Magneto-Rheological (MR) fluids as an agent to capture the impression in situ. These materials are fluid under most conditions, but form a solid when a magnetic field is applied to them and can be used in lieu of Dental Stone or Mikrosil for collecting impression evidence. The goals of this project were to establish an optimal formula composition of an MR casting fluid, determine the limitations and benefits of using MR solutions as a casting fluid, and finally, if successful in the prior goals, develop a method of creating 3D images for permanent storage of the casting impressions.

The purpose of this project is to provide a new method for preserving evidence that provides higher resolution casts, which does not need to be prepared at a crime scene, and which has a lower cost than conventional techniques. The trial MR fluid compositions were developed through trial and error by adjusting the concentration of the components in the fluid. Of the trial solutions prepared for this project, the optimal MR fluid was comprised of 25.0 g 325 mesh iron, 0.75 g cellulose, 0.75 g sodium nitrite, 0.15 g sodium chloride, 0.5 g Silicon Dioxide, and 10.0 mL-distilled water. This solution created long lasting, durable, and high resolution casts, which enabled the visualization and analysis of small details not discernible on the original object. With every MR solution, the casting substrate needed to be non-porous so that the solution wasn't absorbed by the substrate, and non-magnetic so the solution was not affected by the magnetic field of the substrate.

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Executive Summary

Introduction

Collection, preservation, and analysis of impression and tool mark evidence are all major components in forensic science. Shortcomings that are associated with collection and preservation factors include improper mixing of materials and environmental factors, which yield bad impressions. These inadequacies result in loss of detail, affecting the interpretation of class and individualizing characteristics, which are used to place a particular piece of evidence at the scene of a crime. With the inherent destructive potential of impression and tool mark casting, it is important to initially make the best cast possible. Occasionally, the conditions of a crime scene affect the accessibility to perform procedures for making casts, contributing to the quality of a cast made. An innovative approach to all these possible drawbacks in impression and tool mark evidence utilizes magneto-rheological (MR) fluids as a capturing agent of such evidence. This liquid could be used in lieu of Dental Stone or Mikrosil for the collection of impression evidence.

This study aims to develop a new technique for the collection of impression and tool mark evidence, eliminating the possibility of loss of detail of impressions. Incorrectly prepared materials, the need for mixing of materials on site, the waiting time needed for a casting to set, and the possible human error associated with such tasks all contribute to the quality of the impression. The primary goal set forth in this research is to employ and standardize MR fluids in a forensic science setting, specifically in impression and tool mark evidence.

Ferrofluids and MR fluids are two general categories that classify magnetically controlled fluids. The size of the magnetic particles suspended in solution is the main distinction between the two. The size difference causes a behavioral modification between the fluids. Ferrofluids have magnetic particles that are nanometers in diameter, while MR fluids contain magnetic particles micrometers in diameter. Ferrofluids remain in suspension by Brownian motion and will not settle out of solution under standard conditions. A surfactant coating the particles in ferrofluids prevents the particles from aggregating, and thus, from settling out of the mixture. It is possible for the ferrofluid to settle after many years and suffer separation of phases, though their shelf life is much longer than that of MR fluids. Once exposed to a magnetic field, ferrofluids are subjected to a very low viscosity level, not allowing suitable work with impression evidence.[1]

The particles in ferrofluids and MR fluids will align along lines of magnetic flux once exposed to a magnetic field. Increasing the strength of the magnetic field results in an increase of viscosity of the fluid forming a visco-elastic solid. Once the MR fluid is released from the magnetic field, the particles are 'unlocked' and relax from the solid state back to the liquid state.[2] Although the shelf life of ferrofluids is much longer than that of MR fluids, ferrofluids lack the high viscosity of MR fluids when exposed to magnetic fields. Viscosity is a critical aspect in dealing with impression evidence castings to create the desired molding replica.[3] MR fluids cannot use Brownian motion to keep particles suspended in solution because the heavy weight of the micrometer iron particles causes the particles to settle over time. Thus, additional additives are required to help maintain homogeneity in the MR solution.[4]

Methods and Procedure

Initial trial solutions were prepared in order to determine if a crude MR fluid composition would be able to retain the details of an impression object when used as a casting fluid. Several bullet shell casings and a 500 gram weight were chosen as original impression artifacts because they contained details of varying sizes. In addition to the casts made with trial solutions, Mikrosil and Dental Stone casts were made of the impression artifacts in order to provide a basis of comparison. For high-resolution visual analysis of the casts, a Leica FSM comparison microscope was used. Several bar magnets were aligned anti-parallel and inserted into a stainless steel case in order to apply the magnetic field to the MR solutions.

To begin experimentation a base MR fluid formula, Magneto-rheological Fluid in Water solvent #1 (MRF.W#1) was developed to serve as a starting point for improvement. After preparation, the solution was applied to the impression artifacts and a cast was formed using the magnetic field. After lifting the cast, it was analyzed first with the naked eye and then under the comparison microscope. In order to analyze a cast made with an MR fluid under the microscope, very little extra work is required. The only additional step necessary is to accommodate for the extra space needed to place the sample and magnet under the lens. After documenting the cast, the magnetic field was removed and the MR solution was allowed to settle. This process was performed several times with each trial to determine the overall quality achievable with each solution. All relevant MR solution formulae are shown in Table 1.

The next trial solutions aimed to improve upon the consistency and homogeneity of the solution through the addition of silica (fumed) or silicon dioxide. Several solutions were prepared containing a broad range, 0.15g through 5.0g, of silica (fumed) or silicon dioxide in order to test the effective concentration of each compound. With each addition of silica (fumed) or silicon dioxide, the viscosity of the solutions increased, which required an increase in solvent concentration, in this case distilled water. In order to achieve the ideal consistency with minimal addition of a silica compound, 0.5g, 10.0 mL of distilled water was required. Trial solution

MRF.W#10 displayed much higher quality casts than the base MRF.W#1 solution and its consistency was better than the other solutions made with silica (fumed) or silicon dioxide.

The next additives to the trial solutions were cellulose and lecithin. Cellulose was added in order to improve the consistency of the solutions and lecithin was added to coat the iron mesh particles thereby protecting them from oxidation. Again, the optimal concentrations of each were determined through trial and error, and the combination of both compounds was also attempted. Similarly to the cellulose and lecithin trial solutions, trial solutions were prepared containing silicon dioxide and lecithin, due to the similar function of cellulose and silicon dioxide in the solution. Many different trial solutions altering the various concentrations of iron mesh, distilled water, cellulose, silica (fumed), silicon dioxide, and lecithin were prepared and analyzed to determine the optimal MR fluid composition.

The Leica FSM comparison microscope was used to compare each trial solution to the original impression artifact, the Mikrosil cast, and the Dental Stone cast. Under ideal lighting and enhanced optical conditions, the various casts were compared to each other to determine the quality of the MR fluid casts to the casts made with conventional materials.

Results

The main focus of this experiment was to develop a liquid that responded to the magnetic field. After the initial tests determined that the properties of a crude MR fluid made for a successful casting agent, more complex formulas were experimented with. Once a suitable baseline solution, MRF.W#6, was developed, each aspect of the solution was enhanced through additives and adjustments to the formula. MRF.W#6 was set as the starting point of the MR solutions due to the near optimal consistency of the fluid and the large amount of detail it produced once a magnetic field was applied. The consistency obtained was yoke-like, allowing just enough viscosity so when the magnet was applied to the fluid, it would harden adequately resulting in details of the impression shown.

Unexpected results were encountered in the preliminary stages of the study. The iron mesh particles in the initial trial solutions oxidized within several days of preparation, which rendered the MR fluids to be unusable. Regardless of the liquid medium used, oil or water, rusting of the iron particles in the MR solution occurred. This was quickly fixed with the adjustment to the MR fluid formulations by adding sodium chloride and sodium nitrite, which slowed the oxidation of iron particles. Phase separation of the fluid also occurred in both liquid mediums, due to the iron particles settling out of solution. This discovery was dealt with through the use of cellulose and silicon dioxide, keeping the iron particles in solution successfully. The optimal combination of stabilizers in the standard solution volume was 0.75 grams cellulose and 0.5 grams silicon dioxide.

Three different forms of silica: functionalized, fumed, and silicon dioxide, were added to the MR fluids to determine if they would improve the fidelity of the formula's consistency, details it could recover as a forensic science impression casting, and its efficiency. When 0.5 grams of functionalized silica was added to MRF.W#6, the consistency of the fluid became too thin. The magnetic impression casting procedure was still carried out to test if this water-like fluid would hold any amount of detail, but the results were negative, as the fluid would not fully harden and no characteristic details could be recovered. Furthermore, the solutions still separated after several minutes, thus quickly decreasing their overall efficacy. The addition of functionalized silica resulted in marginally better casts, but overall they were grainy and not successful enough to warrant further investigation.

The initial trial solutions including fumed silica became too viscous without the addition of additional water and therefore failed to form significant detail when making an impression cast. In order to compensate for the increased viscosity, solutions MRF.W#2-5 were developed by adding 0.5 ml increments of distilled water until reaching the desired consistency. After each addition of water, the solutions were tested by forming an impression cast and being observed under the comparison microscope. Even with an ideal composition, the solutions utilizing fumed silica produced frail impression cast results. Additionally fumed silica proved to be a difficult compound to work with because of its small particle size and very low mass. With these negatives regarding the usage of silica (fumed) in MR solutions, it was determined that the compound was not suitable for use in order to improve the solution for better impression casting, detail recovery or homogeneity.

The last silica compound tested was silicon dioxide, and in trials MRF.W#7, 8, 9, and 11, it had little to no effect on the solution or casts. Trials MRF.W#12-17 contained far too much silicon dioxide to be of any use. Those solutions were much too viscous and therefore formed flaky and non-resolute casts. Alternatively, the 0.5g of silicon dioxide in MRF.W#10 yielded excellent impression casts with very high-resolution details, mirroring the casting object almost perfectly. The casts made with MRF.W#10 displayed the same level of detail as the casts made with Mikrosil. Solutions #7-9 were too thin and would not harden properly under the magnetic field. In order to compensate for the large amount of silicon dioxide in solution MRF.W#13 an additional milliliter of water was added to form MRF.W#50. While that solution's consistency matched that of the ideal MRF.W#10, the increased silicon dioxide had no noticeable effect on the resolution of the casts it produced.

MR fluids containing lecithin without silicon dioxide produced negative results with their impression casts. Excess water content was an issue due to the fact that each part lecithin added to the solution required two parts water to dissolve it before mixing it into the original MR fluid solution. Silicon dioxide added along with lecithin to the MR fluids stabilized the water content and produced high clarity casting impressions, but the impressions were not of higher quality than those with only silicon dioxide added to the base formula. Because silicon dioxide and lecithin performed similar roles in maintaining homogeneity and improving casting resolution and lecithin proved to be a much more difficult compound to use, any further use of lecithin was abandoned.

Trial solution MRF.W#10, containing 0.5 grams of silicon dioxide in addition to the base formula, produced the best casts of all of the trials. Many of the bullet shell casing's details were seen distinctively and were comparable to the Mikrosil impression cast. As expected, the Mikrosil impression casts showed nearly perfect detail of the casted image under the Leica FSM comparison microscope. Side by side comparison analysis was done between the better MR fluids, primarily MRF.W#10, and the Mikrosil impressions. The MR fluid casts showed a comparable level of detail to that of the Mikrosil impressions and in some cases the MR fluids showed slightly more detail.

Once an MR fluid has hardened in the presence of a magnetic field, the casting substrate can be easily lifted from it, leaving behind the cast or impression image. Because the MR fluid is attracted to the magnet, it leaves behind very little to no residue on the original casting substrate. This is highly desirable to a forensic scientist because the casting method does not alter the original object. Additionally, it allows for further processing of the evidence with other methods after using an MR fluid. As the MR fluid is removed from the magnetic field, the solution will settle back into its liquid form and return to a neutral shape. This particular facet of using MR fluids is one of its strongest features over currently used casting methods. In the case of a user error in forming the cast, the cast can easily be remade by removing the MR fluid with the magnet and then letting the MR fluid settle before performing the method again.

In order to test the shelf life of hardened casts, trial solutions of MRF.W#10 were left under the magnetic field for one hour, one and a half hours, and twenty-four hours. Each cast remained intact after the magnetic field was removed, but was very susceptible to disruption without the magnetic field holding the cast in place. As water evaporated from the solutions over time, the casts became increasingly brittle and fragile. When the solutions were stored not under magnetic field, they faced the same problem of water evaporation. After twenty-four hours of regular storage, the solution was still suitable for use as a casting solution. Conversely, after one month of storage the solution lost too much water to be used. In an attempt to revive the solution after long storage, 0.5mL of water was mixed into the solution and then impression casts were formed. The reformed solution displayed comparable levels of detail as a freshly prepared solution.

After forming many different casts of several different sizes and shapes, it was observed that as the impression size increased, more MR fluid was necessary in order for the impression to harden correctly and stay intact under a magnetic field. With an insufficient amount of MR fluid filling the impression cast, fewer detailed impression marks are shown. Because of that effect, many trial impression casts fell apart or produced flaky and incomplete impressions with only minimal levels of detail relevant to investigations.

One result of viewing iron particles in solution under bright lighting is their reflective property, which in turn, can cause "hot spots" on the image. These "hot spots" are very similar to traditional "hot spots" that are a concern for all types of forensic photography. They can occur whenever a photo is taken of a reflective surface with large amounts of direct lighting. "Hot spots" cover some details, which reduce the efficacy of the evidence.

Discussion

One of the initial goals of the project was to establish a base MR fluid formula from which the validity of MR fluid use in a forensic setting could be tested. Once that goal was accomplished, the process of creating an MR fluid that was comparable to currently used techniques became trial and error. The best fluid discovered in this research, MRF.W#10, proved to be successful in capturing very fine details from the original impression artifact. In several instances, the amount of detail retained by the optimized MR fluid was greater than that of the Mikrosil casts. Figure 1 shows a spent bullet casing that was used to form impression evidence and Figures 2 and 3 show those casts made from Mikrosil and MRF.W#10, respectively. The optimized MR fluid clearly shows a much higher level of detail than the Mikrosil cast, especially with the finer details of the shell casing. The Mikrosil was unable to accurately capture the sharp edges of the lettering and the impressions from the firing pin into the primer, while the cast made with MRF.W#10 was able to almost perfectly capture the entire image.

In addition to the higher cast resolution, the cast formed instantly once the magnetic field was applied, which is not possible with modern methods. Both Mikrosil and Dental Stone must be prepared shortly before use and then need a substantial amount of time, up to 48 hours, to set once they have been applied to the casting substrate. Mikrosil and Dental Stone are both made by mixing two different components together in a specific ratio, and if not made properly the casting solution can either be too thin to set properly or too brittle and set too quickly. By being able to prepare an MR fluid in a laboratory, this provides the technician with an additional level of quality assurance that is not achievable in the field. Additionally, once a Mikrosil or Dental Stone cast has set, it is permanently formed. This has advantages in some situations, but if there is a problem while forming the cast it cannot be remade. With MR fluid casts, all the user must do in order to reform the cast is remove the magnetic field, allow the fluid to settle, and then re-apply the magnet. MR fluids have the capability to collect and preserve evidence with higher accuracy at lower cost, faster set times, and with fewer user errors than modern methods.

There currently exist many opportunities to improve MR fluids. One major way to change the properties of the MR fluids is to change the liquid medium they are comprised of. Currently, it is thought that an oil medium may improve the consistency and lifetime of the solutions by limiting iron oxidation. Additionally, the power of the magnetic field used should be experimented with to determine the optimal power setting for each solution. Other factors to be improved upon include: the lifetime of the solution due to oxidation of the iron particles or settling of the iron particles, reflection of direct light, and perfecting the resolution of the casts.

The main benefit of Mikrosil and Dental Stone over the current MR fluids is the permanency of the casts and their ruggedness. While the preparation of current casting fluids may be more complicated than MR fluids due to the fact that they must be prepared on-site, the casts they form are permanent and need only minimal care once the cast has set. With MR fluids, any impression details quickly dissipate after the magnetic field had been removed. In order for MR fluids to be used in a professional setting, a commercially available magnetized container would be necessary.

The development of a successful MR fluid has many benefits beyond eliminating the need for on-site mixing of materials. Because of their ease of use, MR fluids could aid in the minimization of human error, thus preventing loss of significant detail from incorrect use of materials. By using MR fluids to preserve evidence detail, there is no wait time for the cast to set, which frees up valuable time for other investigative procedures. These MR fluids are geared towards helping with the collection and preservation of impression evidence in a fast, cost effective, and highly accurate way.

In order to confirm the usefulness of MR fluids they should be taken out of the laboratory and tested in the field in tandem with currently used methods. Furthermore, as the only impression objects tested were non-porous, MR fluids should be tested on porous materials to determine their efficacy in those situations, though they will most likely be unsuccessful without further substrate processing such as waterproofing. The greatest potential for MR fluids lies in the preservation of impression evidence on objects which obfuscate impression evidence. Objects such as bone can hide fine impression marks, and those details may be recovered and more easily visualized through the use of MR fluids. This research has shown that MR fluids can be used to accurately retain impression and tool mark evidence in a manner that is more cost efficient, simple, and accurate than conventional methods. While the potential casting substrate pool may currently be limited, the potential for increasing the usability of MR fluids increases as more research is done with them.

Final Technical Report

I. Introduction

1. Statement of the problem

The purpose of this research was to develop a novel technique to collect both impression and tool mark evidence that eliminates the need to mix materials on-site as well as the possible human errors that come along with it. The research hoped to eliminate the loss of detail of the impressions from incorrectly made materials, and to eliminate the waiting time needed for a casting to set. The ultimate objective was to determine the feasibility of Magneto-rheological (MR) liquids as an agent to capture impression and tool mark evidence.

2. Review of the Literature

The application of magnetic fields has become a widely practiced technique in the materials industry, with many applications in the processing of metals and semiconductors. As a result of this widespread use, new methods of development have resulted in improved quality and process control. In an electrically conducting fluid that contains dispersed metal or metal ion particles, a magnetic field can be used to support the particles instead of a physical container, and can provide a modulation of the rheological properties of the fluid that is both effective and environmentally sound. The magnetic fields also have the ability to reduce turbulence flows and fluctuations that are typically attributed to colloidal dispersions. The observation of these magnetic field effects on solidifying melts is what led to the development of these new magnetically assisted solidification techniques.

Magnetically controlled fluids fall into two general categories, Magneto-Rheological Fluids, and ferrofluids. The difference in behavior between the two is the result of the size of the magnetic particles suspended in the liquids. MR dispersions are composed of micrometer-scale particles suspended in a fluid. These particles are too heavy for Brownian motion to keep in suspension, and as a result will settle with time, due to the density difference between the particle and the liquid. When subjected to a magnetic field, the particles in suspension align along lines of magnetic flux which results in a sudden increase in viscosity, to the point of becoming a visco-elastic solid. Most importantly, by varying the strength of the magnetic field, the yield stress of the fluid can be altered in a very accurate and precise manner.

In a ferrofluid, the particles in suspension are nanometers in diameter, and as such can remain in suspension by Brownian motion and will not settle out under normal conditions. The particles in a ferrofluid are coated with a surfactant to prevent the particles from aggregating and settling out of solution. After years of wear and usage, it is possible for the surfactant to wear off and for the ferrofluid to settle, but this is still a much longer shelf life than that of the MR fluid. The trade off, then, is that ferrofluids have a much lower viscosity than MR fluids when subjected to magnetic fields.

When an external magnetic field is applied on the MR fluid colloidal suspensions, they develop characteristic visual patterning, which is mostly due to the balance between the various energies associated with the structure. The magnetic field induces forces on the magnetic particle that tend to keep them in crystal order. At the same time the particles are subject to viscous drag forces and Brownian forces that are antagonistic to the magnetic interactions. Adjusted external fields (together with temperature) can produce and maintain structure and attributes even on a length scale as small as the nanoscopic one and offer many opportunities for research and forensic applications, especially in trace evidence.[5]

The magnetic particles to be suspended in the fluid will be iron powder of varying mesh sizes. By varying the particle size, the characteristics of the MR fluid can be changed, with larger particle sizes yielding a more solid and durable cast with less detail when in the magnetic field, whereas smaller particles will give more resolution to the cast but at the slight cost of rigidity. A suspending agent will hold the particles in suspension, in this case cellulose. This increases the shelf life of the MR fluid and prevents the iron particles from settling. Lastly, small amounts of sodium nitrate are added to the mixture to prevent the oxidation of the iron powder in the aqueous mixture.[6] This powder mix is then added to a measured amount of water and mixed vigorously, to ensure an even suspension of particles.

Impression evidence is formed when an object comes in contact with another object or surface that is capable of recording its pattern. A tool mark is any impression, cut, gouge, scratch, indentation or other marking left in or on an object by another object being forced into or moved across it.[7] These tool marks fall into one of two categories: compression marks and sliding tool marks. Compression tool marks result when force is applied between two objects in a perpendicular manner.[8] There is no lateral movement and the harder material (generally the tool) will mark the softer material in a three-dimensional impression. Sliding tool marks show striations caused by lateral movement of the harder material (again generally the tool) against the softer material at an oblique angle.[9,10]

When sufficient detail is present in these markings, impression evidence can be examined macroscopically and microscopically for the identification of distinguishing class characteristics and individual characteristics. Class characteristics are general structural properties such as size, shape, pattern and design. Individual characteristics are those that are specific to a particular object.[11] These would include wear, damage, irregularities, and other accidental marks unique to that article as a result of its past.[9,10] While these impressions have a clear evidentiary value, a problem with impression evidence is the loss of detail caused by casting materials and technique. As stated in *Physical Evidence in Forensic Science*, "The impression pattern itself must be recovered by making a positive image of the impression through dental stone or silicone casting material. This replica may yield class characteristics for identification, but will seldom yield the necessary detail for an individualized identification of a tire track or shoe or boot impression."[12] Additionally, William Bodziak expressed that "The examiner should be aware of the variable that can potentially occur in the impression-making process that often misrepresent wear." Dirt and other debris can actually mask the full detail of an object's impression when a cast is made. As the level of evidence detail recovered through casting methods increases, so does the ability to place certain objects or people at a scene. Footwear impressions, fingerprints, tire tracks, cartridge and bullet striations are all types of evidence commonly encountered at crime scenes, which can be investigated and identified by comparing their class and individual characteristics. Improving detail resolution by defining and distinguishing the individual characteristic details of impression and tool mark evidence with MR fluids will create a whole new importance to evidence castings. In addition, the MR fluid's reaction to a magnetic field is uniform, predictable, and perhaps most importantly, instantaneous; this alleviates a potential problem with Dental Stone or other casting agents. Dental Stone requires thirty minutes to one hour before the cast can be removed from the impression at which point it still needs another fourteen hours for the cast to set completely before it can be cleaned.[13]

Defending the Scientific Foundations of the Firearms and Tool Mark Identification Discipline: Responding to Recent Challenges stated several conclusions after extensive research, such as: firearms and tool mark identification has been validated in a manner appropriate for the evidence of the kind to be expected, and the proficiency tests and error rates have been studied and can provide the court and community with a useful guide.[14] All of their conclusions point to the scientific legitimacy of firearm and toolmark identification as a process.[14] Also referenced in this paper were many studies conducted by firearms and tool marks examiners specific to various problems being faced in the field. All of their results agree with the fact that firearms and tool marks identification are based on sound scientific foundation.[14] The development of magneto-rheological fluids as a tool in the arsenal of tool mark examiners will further strengthen their affirmations, as the MR fluid's resolving capabilities and ease of handling will provide clearer molds and casts, which would in turn allow for easier and more definitive characterizations and matches.

3. Statement of purpose

The current techniques for collecting and preserving impression and tool mark evidence fall short of the ideal method in several ways. They are mostly incapable of recording individualizing characteristics from the evidence, they require on-site preparation by the user, they require a waiting period for the cast to set and then fully harden, and they are not re-usable. We believe that given the proper casting substrate, magneto-rheological fluids can overcome all of the traditional shortcomings of current casting fluids.

II. Methods

Preliminary trials were performed to demonstrate whether or not MR fluids have the ability to retain the shape of an impression, in sufficient detail, when used as a casting agent. Different bullet shell casings with center fire rims, a 500 gram weight, and automotive tires were used to create the impressions and tool marks. Clay was chosen as the soft medium for which the impressions were made in for observational purposes. Two bar magnets, aligned anti-parallel and placed on a galvanized steel plate, were used to apply the magnetic field to the MR fluids.

Weighing paper was used over the magnet, as the surface for lifting the impression casted in the clay, when emitting the magnetic field. Mikrosil and Dental Stone casts were made to determine if the details obtained by the MR fluid casts were comparable or greater than those already in use. Functionalized silica, silica (fumed), lecithin (granular), and silicon dioxide were all added to the base MR fluid recipe, to observe their effects on the consistency of the fluid. A heater was used to boil water to dissolve the lecithin, before it was mixed with the other components of the fluid. For further analysis of the trial solutions, a Leica FSM comparison microscope was used. All results could be viewed at different angles, heights, and lighting aspects for comprehensive assessment. Pictures were taken of the original impression objects in addition to side-by-side photos of their positive impression casts in order to perform direct comparison.

The major challenge regarding the magnets used for the instant solidification of the MR fluids was that in order to have a uniform (or quasi uniform) magnetic field a pair of magnets is required. This is practically impossible in our application. Alternatively we employed a special array of small magnetic bars, introduced by K. Halbach, shown in Figure 7.[15] This array was an application of John C. Mallinson in 1973, and it results in a one-sided magnetic flux, shown in Figure 8.[16] Small commercially available magnetic bars were inserted into a steel case, in the proper order, to make this composite magnet. Each magnetic bar had an average magnetic strength of 2,500 Gauss. Using excessively strong fields could lead to a separation of the magnetic iron particles of the fluid. The size of the magnetic field is customizable and can be changed to fit the need of the user. Magnets can be added to increase the size and strength of the field as long as the magnets are placed in the sequence shown in Figure 7, or, more simply the strength of each individual magnet can be increased if necessary.

The conventional forensic impression evidence casting agent, Mikrosil, was used to make a casting as the control for comparison with the MR fluids impression castings. An impression was made in clay using a fired bullet shell casing head stamp. The Mikrosil casting procedure was conducted by mixing the components and then applying the mixture to the impression made in the clay. Once hardened, the impression casting was lifted from the clay and details were analyzed under the Leica FSM comparison microscope and noted. Two trials of the Mikrosil method were conducted using different bullet shell casing head stamps for comparison. Many different MR fluids were prepared in an attempt to optimize their casting quality and consistency. Each trial of the various MR fluid composition mixtures were prepared multiple times, making new impressions each time to experiment with different amounts of MR fluid actually poured inside the impression. All relevant MR fluid formulae are shown in Table 1.

To begin experimentation a base MR fluid formula, MRF.W#1 (Magneto-rheological Fluid in Water solvent #1) was developed. This fluid would serve as a starting point for further adaptation in order to have a basis for comparison. MRF.W#1 was poured into the impression that was made with a detailed object into clay. The magnet, with weighing paper placed over its surface, was applied to the impression, immediately hardening the solution. The cast was then lifted, with the magnetic field applied. This same procedure for lifting of the hardened impression cast created by the magnetic field was used for all trials involving an MR fluid mixture throughout these research experiments. Comparison microscope analysis was also performed after each experimental trial MR fluid cast was lifted. Side by side comparison of the MR fluid casts to both the Mikrosil castings and the original artifacts was performed.

In the next set of trial solutions the addition of silica (fumed) was tested in an attempt to improve the consistency and stability of MRF.W#1. Additions of 0.15 grams, 0.3 grams, and 0.5

grams, and 5.0 grams of silica (fumed) were made to MRF.W#1, creating four new trial solutions (MRF.W#2-5) representing a broad range of silica content. The addition of silica caused an increase in fluid viscosity so in order to maintain ideal consistency extra water was added to the solutions where necessary. Based on the results of these solutions, the amount of water deemed necessary to obtain an ideal fluid consistency was determined to be 10.0 mL. The new base formula for further trial solutions, MRF.W#6, would reflect that change. Silicon dioxide was tested in a similar fashion as silica (fumed). Ten trial solutions, MRF.W#7-17 containing between 0.2 grams and 5.0 grams of silicon dioxide were prepared.

Due to the early positive results of MRF.W#10, it was used to determine the effect of time on a hardened cast. Several casts were prepared and kept under a magnetic field for periods of 1 hour, 1.5 hours, and 24 hours. Furthermore, many of the MR fluid solutions were left in storage in liquid form in order to determine how long their shelf life would be. The solutions were used to make new casts after 24 hours and again after one month. As their resting time increased, water evaporated from the solutions and many became too thick for use, but 1 mL additions of water rejuvenated them.

Lecithin (granular) was prepared for mixture into the MR fluids by dissolving it in hot distilled water at a ratio of one gram lecithin to two milliliters of water. This procedure was determined through trial and error working with the lecithin and different amounts of water. The addition of the lecithin increased the viscosity of the solution, so in an effort to maintain the proper consistency, MR fluids #18-23 were prepared with varying concentrations of water and lecithin in solution. The magnetic casting impression method was applied to this mixture and the results were analyzed.

Because cellulose and lecithin were used to keep the water from separating from the iron in the mixture, experiments that involved altering the ratio of cellulose to lecithin were performed. For the first trial solution, MRF.W#24, a mixture of 5 grams cellulose to 1 gram lecithin in 2 mL hot water was added to MRF.W#6, along with 20 mL of distilled water. MRF.W#24 was further adapted by increasing the iron content while dropping the total amount of water in solution.

Silicon dioxide was the next additive tested along with lecithin in the MR fluids. A 1:1 ratio of 1 gram of silicon dioxide to 1 gram of lecithin, dissolved in 1mL of hot distilled water, solution was mixed to observe how the two compounds reacted together. Once it was determined that the combination of both compounds benefited the MR fluid solutions, trial solutions #26-48 were prepared in order to maximize the resolution of the impressions they formed. The ideal thickness and homogeneity in solution were established by altering the amounts of silicon dioxide, cellulose, and lecithin. Next, the water and iron levels were adjusted to obtain a solution that maintained rigidity under a magnetic field while still providing optimal impression resolution.

A Leica FSM comparison microscope was used for the analysis of all impression casts lifted of the Mikrosil and MR fluids after observation with the unaided eye. The microscope was equipped to view the casts under ideal lighting conditions, with an enlarged view of the results, and also enabled the direct comparison between the actual objects used to create impressions and the different casting methods or MR fluids. Pictures were taken with the Leica FSM comparison microscope of all comparisons and trial results.

III. Results

1. Statement of Results.

After establishing a base formula, MRF.W#6, which successfully proved the plausibility of MR fluids as a casting solution, many more trial solutions were prepared to improve upon the solution's consistency, homogeneity, lifetime, and casting resolution quality. One of the critical aspects of the MR solutions is their lifetime prior to oxidation. Prior to the establishment of the base solution, the iron particles of the MR fluids oxidized within several days of preparation. The rusting of the solutions rendered them unusable for creating accurate casts. This problem led to the discovery of using sodium chloride and sodium nitrite in solution, which significantly extended the usable lifetime of the solutions by slowing the oxidation of the iron particles in solution. Another problem with the preliminary fluids was the relatively quick phase separation occurring after their preparation. The iron particles settled out of solution, requiring the regular mixing of solutions when not directly in use. Through the addition of cellulose and silicon dioxide, the homogeneity of the solutions was vastly improved. All relevant formulae are shown in Table 1.

The addition of silicon dioxide was justified through a process of trial and error involving other compounds such as silica (fumed) and functionalized silica. Functionalized silica thinned the consistency to such a degree that the solutions would not correctly harden even when a lower concentration was added. Also, despite the presence of the functionalized silica, the solution still separated within several minutes of preparation. The casts obtained with MR fluids containing functionalized silica appeared grainy and they did not retain enough clarity in detail to warrant further testing. Fumed silica had the opposite problem of functionalized silica, as the addition of silica (fumed) to the MR fluids drastically increased the viscosity of the solutions. The increase in viscosity necessitated an increase in water, so additions of 0.5 mL distilled water were made until the desired consistency was achieved. Despite achieving a desirable consistency, the casts produced with fumed silica were unacceptable due to their frailty.

Conversely, the casts made with silicon dioxide proved to be sufficiently rugged and were capable of retaining very fine details from the impression objects. As with fumed silica, additions of silicon dioxide increased the viscosity, which was compensated for by adding increments of distilled water. The optimal consistency of a fluid containing silicon dioxide was achieved by adding 0.5g of silicon dioxide and 4 additional milliliters of distilled water to the base solution (MRF.W#10). The level of quality achieved with trial fluid MRF.W#10 was comparable to that achieved with Mikrosil, and in some cases the MR fluid retained higher levels of detail.

Lecithin was added to the compounds in many different concentrations in order to maintain the homogeneity and slow the rate of oxidation of the MR fluids, but proved to be overcomplicated to work with, while only providing marginally better casting quality. Achieving a suitable consistency was difficult when using lecithin because the granular lecithin was first boiled in distilled water in order to be used. This caused an excess amount of water to be present in the base solutions. When the amount of water was reduced to compensate for the liquid lecithin, the casts produced were of similar quality to those produced with MRF.W#10, but the lifetime of the solution and overall cast quality did not improve enough to justify the additional effort required to produce the MR fluids.

To determine the lifetime of a hardened cast, several casts were prepared using MRF.W#10 and left under the influence of a magnetic field for intervals of one hour, 1.5 hours, and 24 hours.

None of the casts lost image quality as they rested, but as water evaporated from the solutions they became increasingly brittle. Similar to the fluids left under a magnetic field, those left in regular storage lost water to evaporation over time. As long as the iron particles in the solution had not rusted, the solutions stored for extended periods could be revived using small additions of water until achieving the desired yolk-like consistency. Rejuvenated solutions provided comparable levels of detail to those that were freshly prepared, provided that there was little to no oxidation of the particles in solution.

2. Tables.

Table 1 – Compositions of Relevant Trial Magneto-rheological Fluids Prepared

MR Fluids	Iron Mesh (g)	Water (mL)	Cellulose (g)	Sodium Nitrite (g)	Sodium Chloride (g)	Functionalized Silica (g)	Silica (fumed) (g)	Silicon Dioxide (g)	Lecithin (g) / Water (mL)
MRF.W#1	25.0	6.25	0.75	0.75	0.15	-	-	-	-
MRF.W#2	25.0	6.25	0.75	0.75	0.15	-	0.15g	-	-
MRF.W#3	25.0	7.25	0.75	0.75	0.15	-	0.3g	-	-
MRF.W#4	25.0	8.25	0.75	0.75	0.15	-	0.5g	-	-
MRF.W#5	25.0	9.25	0.75	0.75	0.15	-	5.0g	-	-
MRF.W#6	25.0	6.0	0.75	0.75	0.15	-	-	-	-
MRF.W#7	25.0	10.0	0.75	0.75	0.15	-	-	0.2	-
MRF.W#8	25.0	10.0	0.75	0.75	0.15	-	-	0.3	-
MRF.W#9	25.0	10.0	0.75	0.75	0.15	-	-	0.4	-
MRF.W#10	25.0	10.0	0.75	0.75	0.15	-	-	0.5	-
MRF.W#11	25.0	10.0	0.75	0.75	0.15	-	-	0.6	-
MRF.W#12	25.0	10.0	0.75	0.75	0.15	-	-	1.0	-
MRF.W#13	25.0	10.0	0.75	0.75	0.15	-	-	1.5	-
MRF.W#15	25.0	10.0	0.75	0.75	0.15	-	-	2.0	-
MRF.W#16	25.0	10.0	0.75	0.75	0.15	-	-	2.5	-
MRF.W#17	25.0	10.0	0.75	0.75	0.15	-	-	5.0	-
MRF.W#18	25.0	10.0	0.75	0.75	0.15	-	-	-	1.0 / 2.0
MRF.W#19	25.0	8.0	0.75	0.75	0.15	-	-	-	1.0 / 2.0
MRF.W#20	25.0	0.0	0.75	0.75	0.15	-	-	-	5.0 / 21.0
MRF.W#21	25.0	10.0	0.75	0.75	0.15	-	-	-	5.0 / 21.0
MRF.W#22	25.0	0.0	0.75	0.75	0.15	-	-	-	5.0 / 10.0
MRF.W#23	25.0	10.0	0.75	0.75	0.15	-	-	-	5.0 / 10.0
MRF.W#24	25.0	20.0	5.0	0.75	0.15	-	-	-	1.0 / 2.0
MRF.W#25	27.0	18.0	5.0	0.75	0.15	-	-	-	1.0 / 2.0
MRF.W#26	25.0	10.0	0.75	0.75	0.15	-	-	0.5	5.0/21.0
MRF.W#27	25.0	10.0	0.75	0.75	0.15	-	-	0.5	5.0/10.0
MRF.W#28	25.0	10.0	0.75	0.75	0.15	-	-	1.0	1.0/1.0
MRF.W#29	25.0	0.0	0.75	0.75	0.15	-	-	0.5	5.0/21.0
MRF.W#30	25.0	0.0	0.75	0.75	0.15	-	-	0.5	5.0/10.0
MRF.W#31	25.0	0.0	0.75	0.75	0.15	-	-	1.0	1.0/1.0
MRF.W#32	25.0	20.0	5.0	0.75	0.15	-	-	0.5	1.0/2.0
MRF.W#33	27.0	20.0	5.0	0.75	0.15	-	-	0.5	1.0/2.0
MRF.W#34	25.0	15.0	5.0	0.75	0.15	-	-	0.5	1.0/2.0
MRF.W#35	25.0	10.0	5.0	0.75	0.15	-	-	0.5	1.0/2.0
MRF.W#36	25.0	10.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#37	25.0	0.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#38	25.0	9.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#39	23.0	10.0	0.75	0.75	0.15	-	-	0.5	5.0/10.0
MRF.W#40	23.0	0.0	0.75	0.75	0.15	-	-	0.5	5.0/10.0
MRF.W#41	25.0	0.0	0.75	0.75	0.15	-	-	0.5	5.0/10.0
MRF.W#42	23.0	10.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#43	24.0	7.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#44	26.0	8.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#45	28.0	9.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#46	30.0	10.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#47	32.0	11.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#48	33.0	12.0	0.75	0.75	0.15	-	-	0.5	0.5/1.0
MRF.W#49	25.0	10.0	0.75	0.75	0.15	0.5g	-	-	-
MRF.W#50	25.0	11.0	0.75	0.75	0.15	-	-	1.5	-

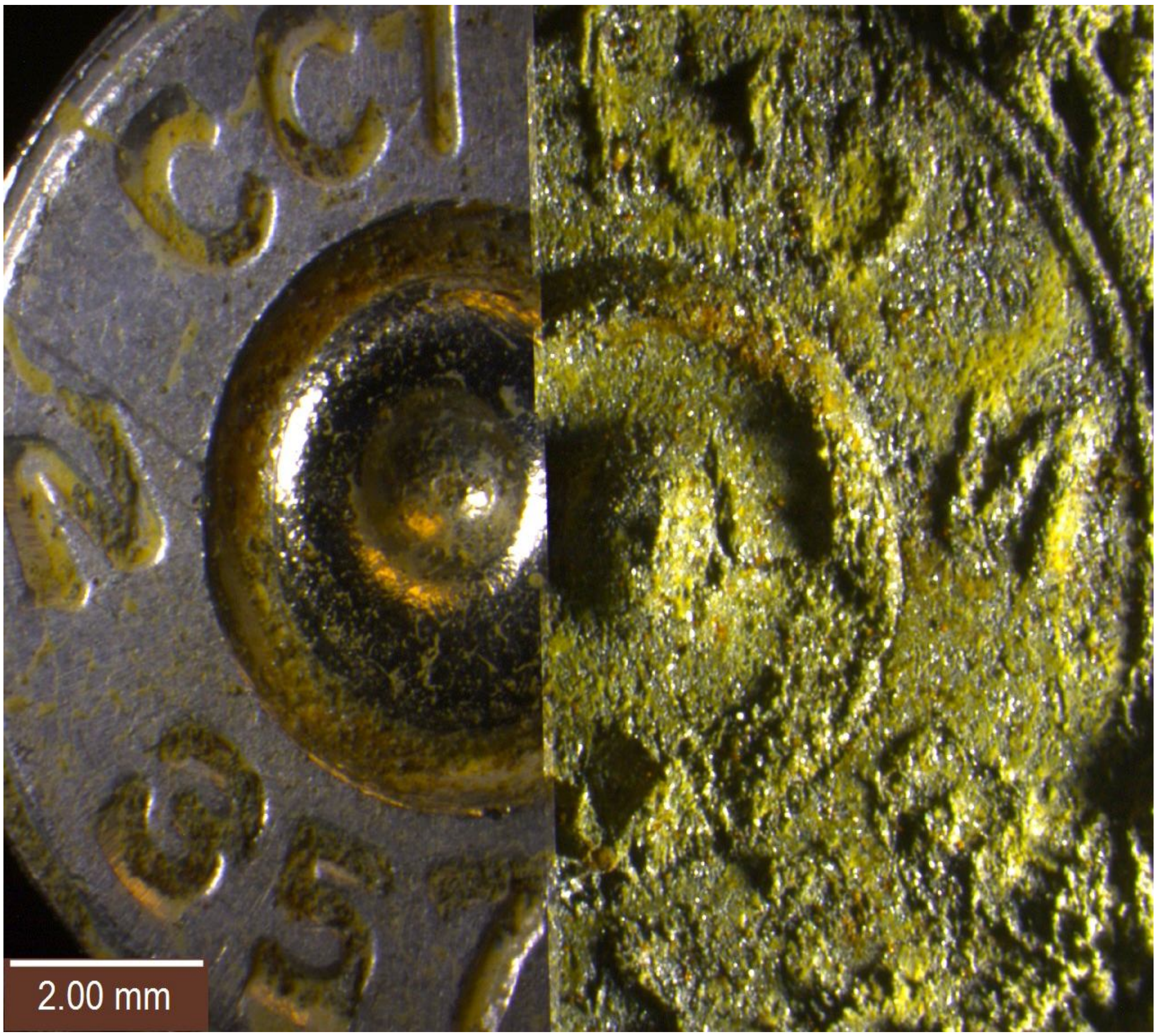
3. **Figures.** The following figures are photographs of various trial MR fluids, the Mikrosil casts, and impression artifacts.

    1. Figure 1 – This image shows one of the main bullet shell casings that was used to create finely detailed impressions, and was used to determine the level of quality captured in detail of the MR fluid casts.

2. Figure 2 – This photograph contains a cast made of the bullet shell casing in Figure 1, made with Mikrosil. The image is horizontally flipped in order to be more easily comparable to the original impression artifact.

3. Figure 3 - This photograph contains a cast made of the bullet shell casing in Figure 1, made with the optimized MR fluid formula, MRF.W#10. The image is horizontally flipped in order to be more easily comparable to the original impression artifact.

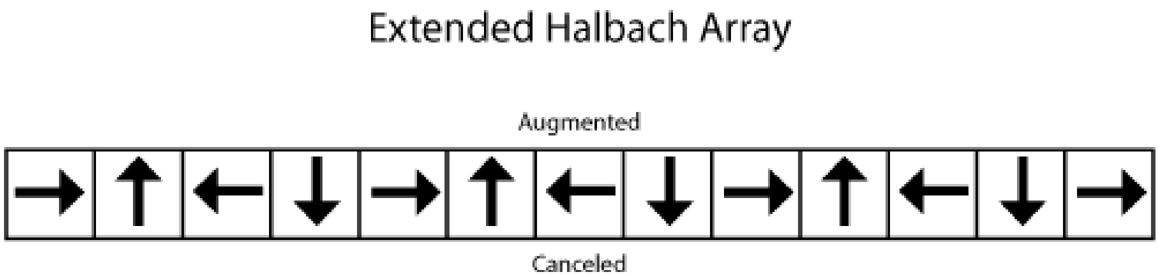
4. Figure 4 – This image displays the effect of using an MR fluid in which the iron particles have begun to oxidize. The image shows the original impression artifact for comparison. There are also MR fluid remnants clearly visible on the original artifact.



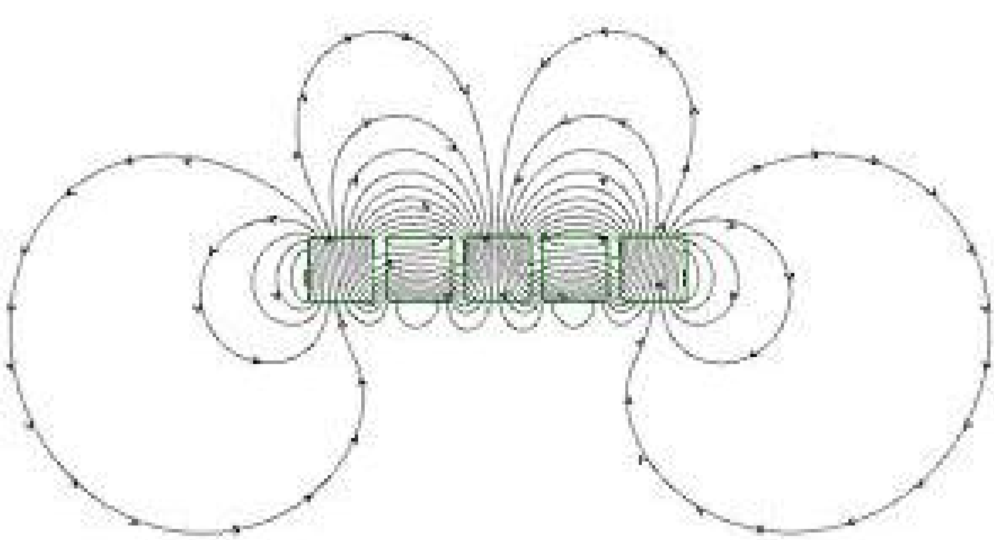
5. Figure 5 – This image displays a zoomed in side-by-side comparison of the “5” ridge of a 500 gram weight and the impression it left in a cast made with MRF.W#10. The image shows that impressions on the sub-millimeter level may be retained with MR fluids.

6. Figure 6 – This image highlights the level of detail achievable using MR fluids as a casting agent. A unique mark was made on the “N” of the bullet casing, in order to give the researchers a way to judge the resolution of the trial MR fluids. Using the optimized fluid formula, MRF.W#10, a cast was made. The scale indicates that the fluid is able to capture fine details down to approximately 0.2mm in size. The image has been flipped vertically for ease of visualization.

7. Figure 7 – The magnets used to capture evidence with the trial MR fluids were placed into an arrangement called the Extended Halbach Array. The arrows point towards the North Pole of the magnet.[15]



8. Figure 8 – The Extended Halbach Array arrangement of magents results in a one sided magnetic flux which is depicted in this image.[16] This combination of the fields of the individual magnets minimized the flux of the magnetic field below the array and amplifies it above. The dynamic lines represent the strength and directionality of the magnetic field.



IV. Conclusions

1. Discussion of findings.

The primary goal of this research was to develop a magneto-rheological fluid that could be used to record impression and tool mark evidence. The ideal MR fluid composition identified in this research was comprised of 25.0 g 325 mesh iron, 0.75 g cellulose, 0.75 g sodium nitrite, 0.15 g sodium chloride, 0.5 g silicon dioxide, and 10.0 mL-distilled water. This fluid produced casts that displayed high levels of clarity and minute details that matched or surpassed the casts made with Mikrosil, and greatly surpassed the casts made with Dental Stone. Magneto-rheological fluids like the ones discussed in this research have the opportunity to improve the field of forensic science through decreasing the cost of casting fluids, decreasing the potential for error inherent in on-site prepared substances, and reducing the waiting time necessary to capture evidence.

2. Implications for policy and practice.

Public policy and practice regarding the use of MR fluids as a casting fluid is limited by the potential applications for the fluids. Currently, MR fluids can only be used on non-porous and non-magnetic casting substrates. This limits the types of evidence that may be recorded using MR fluids, but the opportunity cost associated with them is overcome by the high resolution of the casts made on suitable impression artifacts. As more research is done with the fluids, additional applications of MR may be identified.

3. Implications for further research.

The most important goal for further research should be to identify areas in which MR fluids can be used to preserve and document evidence. The greatest potential for MR fluids lies in the field of Forensic Anthropology. This is because not only are bones non-porous and non-metallic, but also fine markings on bones are difficult to visualize on the bones themselves.

V. References

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VI. Dissemination of Research Findings

1. Sorrentino, E., Salmonese, L., Athanasopoulos, D., 2010. “Research and Development of Magneto-Rheological Fluids.” Presentation at the Impression and Pattern Evidence Symposium, Clearwater Beach, Fl. August.
2. Salmonese, L., Sorrentino, E., Athanasopoulos, D., 2011. “Magnetorheological Fluid Impression Evidence.” Powerpoint Presentation at the NIJ Grantees’ Meeting at the Annual Academy of Forensic Scientists meeting, Chicago, Il. February.