The Effect of Vibratory Finishing on Broaching Marks as a Function of Time

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ABSTRACT

Previous research has focused primarily on the impact of primary machining processes (i.e. broaching, milling, grinding) on individual and subclass characteristics with speculation as to the impact of the finishing processes. As a result, research on the impact of finishing processes after machining on subclass and individual characteristics needed to be done. Based on the information gathered through research and during firearm manufacturer tours, broaching was used as the primary machining process and the effect of vibratory finishing on broaching marks as a function of time was examined. Vibratory finishing as a function of time did have a significant impact upon the individual markings caused by broaching. The finer, individual stria were removed as finishing time increased causing the grosser, individual marks to appear more pronounced. Subclass characteristics would then also appear more pronounced. An identification between different finishing times could be made; however, this research demonstrates that the firearms and toolmark examiner may need to consider the finishing method when identifications are being made.

Introduction

Firearms and toolmarks examiners readily rely upon class, subclass and individual characteristics when forming conclusions regarding a toolmark and its origin. These characteristics are produced during the manufacturing processes with or without the knowledge of the manufacturer. Specifically, it has been demonstrated that subclass and individual characteristics are formed during the machining and cutting processes. However, little has been done to demonstrate the effect of the finishing processes on these subclass and individual characteristics.

Initial research published in 1974 by John Murdock (reprinted in 1989) demonstrated differences in stapler drivers that were finished versus those that were not finished. His research showed that "Pilot" brand stapler drivers were fabricated, mechanically and chemically cleaned, and then plated. "Swingline" brand stapler drivers were not cleaned or plated. Murdock concluded that individuality was imparted in the "Pilot" stapler drivers because of the finishing process; whereas, the "Swingline" stapler drivers lacked individuality. [1]

In a 1977 study on the OMC "Back Up" pistol, Robert Kennington showed the breechfaces of the pistol were milled and then sand blasted after casting. The milled features of the breechface were "softened" as result of the finishing process. Kennington further noted that the random pattern produced by blasting was reproducible on fired casings and individual in nature. [2]

In a 2010 subclass study on Smith & Wesson breechfaces, Laura Lightstone observed differences in the breechfaces between her study and a 2007 study performed by Gene Rivera. [3] In Lightstone's study, she observed that the breechfaces were granular in appearance and the parallel markings were "less defined", whereas, in Rivera's study the breechface marks were broad, gross, and readily observed as is common with subclass characteristics. [3] When Lightstone further researched this phenomenon she concluded that the differences were most likely due to the finishing processes that followed the broaching of the breechfaces.

In the study done by Lightstone, she noted that after the slides had been broached they were then tumbled, sand blasted, and glass bead blasted to finish the slides. Small changes to the finishing processes in pressure, angles of contact, media selection, machinery employed and even the operator could have caused the differences observed on the breechfaces. Lightstone went further to conclude that the slides may have appeared differently if no finishing had been performed, and only broaching had occurred. Lightstone suggested that without the finishing processes, the subclass characteristics would have been more prominent, but notes that this suggestion is simply a hypothesis. Lightstone further concluded that sand blasting and glass bead blasting broached breechfaces may in fact cause similar, granular markings in spite of make or model.

The previous research has focused primarily on the impact of primary machining processes, such as broaching or milling, with only a brief discussion as to the impact of the finishing processes that followed the machining processes. Until recently, there was only speculation regarding the impact of finishing processes. As a result, further research was necessary to fully understand the impact of finishing processes after machining on subclass and individual characteristics.

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Finishing Processes

Chip and burr formation commonly, and almost always, occurs during the machining and cutting processes. Chips are small pieces of metal (or other material) that are removed during the cutting process by the tool. Burrs, however, are small sharp edges in the workpiece left from the cutting processes (or chips that have not been removed) that can inhibit final assembly, can cause injury, and can increase pressure in the workpiece. With this in mind, machining companies remove burrs through mechanical, thermal and electro-chemical processes. [4] Mechanical deburring or finishing processes include specific cutting processes, power brushing, abrasive finishing, mass finishing, abrasive blasting, and abrasive flow deburring. [4] Mass finishing processes and abrasive blasting are the most common machining processes for deburring firearm parts and household tools, but a brief discussion of the other finishing processes will also be discussed for familiarization.

Cutting processes use tools such as knives, drills, reamers, brushes, etc. to mechanically or manually deburr the workpiece. Power brushing processes use brushes made of metal wire, non-metal or synthetic materials to remove burrs from the workpiece. Abrasive finishing, also known as sanding, uses abrasives made of aluminum oxides, silicon carbide, and zirconia compounds to remove burrs. [4] Abrasive blasting is a wet or dry finishing process that directs an abrasive media, such as sand or glass, on a specific portion of a workpiece or over the entire workpiece or group of pieces. Sand blasting and bead blasting are examples of this type of finishing process. [4]

Mass finishing processes permit multiple workpieces to be finished and deburred concurrently. Mass finishing processes also allow parts to be polished, brightened, and descaled simultaneously. [4] Mass finishing processes use loose, abrasive media and vibrate or tumble (or sometimes both) the parts to be finished in specialized containers. The abrasive media may be manufactured from organic , metallic, ceramic, or plastic materials. The abrasive materials are also manufactured in a variety of shapes. Mass finishing processes normally use water or water-soluble (i.e., soap) solutions. [4] According to the Society of Manufacturing Engineers (SME), "Vibratory finishing is the most common mass finishing method." [4] Other mass finishing processes, include barrel tumbling, centrifugal disk and barrel finishing, and spindle finishing.

Mass finishing techniques will alter a workpiece's overall roughness; however, it should not affect its overall appearance. Mass finishing techniques can remove shallow flaws, but may also cause flaws that could be characteristic of the final finishing of the workpiece. [5] In addition to removing burrs and changing the workpiece's roughness, mass finishing techniques can also radius part edges, change part dimensions, change surface pores in a part, change the surface finish of a part, change a part's flatness, and cause dings, scratches and dents to a part[1]. [5]

The media used for mass finishing techniques is very important when considering the type and degree of finish a manufacturer requires in a workpiece. The primary purpose of media is to grind down the edges and surfaces of a workpiece to obtain the desired end product. There are four main factors to consider when determining what type of media to use in a finishing project – composition, size, shape, and weight of media. [5] Other factors that should be considered when choosing a media are workpiece composition, size, shape, burr size, and finishing requirements. [5]

The composition or type of media will determine if it is a media meant for finishing or for cutting. Some media will contain abrasives that can be used for cutting processes, such as grinding. Media that will be used for finishing processes will contain either very fine abrasives or no abrasive materials at all. Finishing media functions similarly to grinding media. As the abrasive material wears down from contact with the workpiece. The abrasive becomes dull and the abrasive grains break away allowing new abrasive grains to continue cutting or finishing. [5] Higher abrasive content means that the media will cut faster; whereas, media with high contents of clay, will cut slower. Higher abrasive content is employed for workpieces with large burrs, while workpieces requiring smooth finishes require media with slower cutting media. [5]

A common media used for finishing, and in particular in firearms manufacturer, is preformed ceramic media. Ceramic media is manufactured by mixing porcelain, kaolin clay, river clay, and other vitreous materials, with varying amounts of (or with no) abrasive material. [5] The mixture is moistened and formed into the desired shape and heated to vitrify. [5] There are five common grades of preformed ceramic media available for finishing processes – extra fast cut, fast cut, medium cut, moderate cut, and slow-to-no cut.

Ceramic media with approximately 50%, 60 grit aluminum oxide is the quickest material for deburring and general removal of material. [5] The media most commonly recommended for deburring and cleaning is ceramic or steel media.

Media shape will also have an important impact on the final finish of a workpiece. Media shape should offer access to all parts of the workpiece that require deburring or finishing, should not become stuck in the workpiece (i.e. holes, grooves, etc.), and should separate easily from the workpiece when finishing is complete. Media shapes include triangles, cylinders, diamonds, cones, and tetrahedrons, with wedge

[1] For a more comprehensive list of the changes that can be caused by mass finishing see Chapter Four of the Mass Finishing Handbook.

shaped media being the most popular. Triangular shaped media function well for reaching into corners and slotted areas of workpieces, while providing uniform finishing. Cylindrical shaped media, including cones, work best for deburring holes and contours in workpieces.

Media size should match the project for which it is being used. One requirement of size is that it should help keep the workpieces separate from each other during finishing. Another requirement of size of the media is that it should reach all surfaces of the workpiece to be finished without becoming stuck in the workpiece. As the media wears down from use, it must be checked occasionally to ensure that the size has not changed enough that it no longer meets the requirements needed for finishing. [5]

In addition to the media, solutions are added to the mass finishing process for numerous purposes. Compounds and compound solutions (the difference to be explained later) are often added to parts to increase and assist in deburring, clean parts and media, and assist in removing scale and coloring for other processes. [5] Compounds are purchased by the manufacturer and often converted into compound solutions, usually by the addition of water. Most compounds are soluble (dissolve) in water, but may contain additional abrasives that are insoluble in water or the solution. Final "good" compound solutions should include water, water conditioners, cleaners, lubricants, pH buffers, rinse agents, and foam control agents. [5] Other additions to the solution may include metal brighteners and corrosion or rust inhibitors. Water is used in the majority (up to 90%) of compound solutions because it is cheap, easy to attain, and is considered a universal solvent (meaning that most compounds can be dissolved in it). [5] Detergents, or cleaners, are in essence soaps and surfactants. Detergents assist in removing oils and other impediments from the workpiece. Corrosion and rust inhibitors are often added to prevent and/or slow the corrosion of metal. In addition, pH buffers help control and maintain a specific pH level to ensure that the solution remains acidic, basic or neutral during the finishing process. [5]

As previously stated, there are numerous types of mass finishing process available to a manufacturer. These include, but are not limited to, barrel tumbling, centrifugal barrel deburring and vibratory finishing. While vibratory finishing is one of the most common and useful finishing techniques, a brief discussion of barrel tumbling and centrifugal barrel deburring will be provided, as these are also commonly encountered in firearm and industrial settings.

Barrel tumbling is the original mass finishing process. Both the Ancient Egyptians and Chinese used primitive barrel tumbling techniques to produce smooth finishes on jewelry and weapons. [5] Previous names for barrel tumbling included "barreling," "rattling," and "tubbing." Primitive barrel tumbling techniques involved placing the workpiece of interest into a container of some sort with rocks and rolling the container until all the parts were smooth. [5] Barrel tumbling is much more developed than in ancient times; however, the process is still slow making other mass finishing techniques more popular within in the mass finishing community. However, barrel tumbling does have its benefits. Barrel tumbling is a versatile finishing process, is generally inexpensive and very simple to operate. [5]

In barrel tumbling, as the name suggests, the workpieces, media, compound and water are rotated in a barrel. As the components are rotated, the upper portion reaches a certain point (or turnover point) in the barrel where gravity forces the upper portion to break free from the mass and to slide down toward the bottom of the barrel. This is a continuous cycle with the upper portion of components constantly sliding and then rotating upwards.

During barrel tumbling, the barrel contains up to approximately 60% of its capacity in workpieces, media, water and compounds. [5] Higher capacities can be seen in heavier workpieces; however, the length of time for tumbling is increased with higher capacity levels. This is due to the fact that workpieces may not come into contact with as much media or each other to attain the final finish required. Approximately 90% of the finishing action occurs during the sliding portion of the tumbling with the remaining finishing occurring during the rising in the barrel. [5] Additionally, the faster the barrel rotates, the faster the finishing and deburring occur. However, faster tumbling rates may damage the workpieces and decrease the quality of the end product.

In centrifugal barrel finishing, the workpieces, media, compound, and water are rotated in a barrel through the use of centrifugal forces. The machines in centrifugal barrel deburring contain multiple drums that are mounted on the outer portion of a turret. As the turret rotates in one direction, the drums slowly rotate in the opposite direction. Like in normal barrel tumbling, the drums in centrifugal barrel deburring are loaded to 60-80% capacity with the workpieces, media, water, and compound. [5] The centrifugal force that is produced from the process causes the mixture to compact down into the drum preventing the workpieces from hitting each other. The rotation of the drums also causes a sliding action which further finishes the workpieces. The finishing process for centrifugal barrel deburring is approximately 20 to 50 times faster than vibratory finishing and produces reproducible finishes that are accurate and consistent. [5] Overall, the centrifugal barrel deburring is a faster finishing process; however, it is also an expensive operation and more difficult to operate than barrel tumbling or vibratory finishing.

Vibratory finishing is one of the most common and popular types of mass finishing processes. Vibratory finishing is used for numerous processes including, but not limited to, cleaning, deburring and descaling. [5] Additionally vibratory finishing accommodates workpieces of a variety of sizes, shapes, and compositions. It can also be used for large batch or continuous workpiece finishes. As with all finishing processes, vibratory finishing removes burrs, rounds edges, smoothes or roughens surfaces, and changes a workpiece's dimensions. There have been numerous studies completed that demonstrate the effect of vibratory finishing on burrs, edge rounding and size changes; however, since this is not the central focus of this research, the author will only refer the reader to the *Mass Finishing Handbook* for more information. Research on the effect of vibratory finishing on the surface finish demonstrates that the effect is dependent upon the workpieces hardness and the initial finish. [5]

Vibratory finishing has two major arrangements, both of which are seen in firearm manufacturers – rectangular tub and round bowls types. The rectangular tub type was first produced commercially in 1957, and the round bowl type was produced five years later. [5] Either type uses an open top configuration with a chamber that contains the workpieces, media, compound, and water. As the chamber is vibrated, deburring, cleaning, and other processes are completed by the media and compound on the workpieces.

The tub type vibratory machine is an open top container with straight or parallel walls and a U-shaped bottom. The container is mounted on springs or coils. The container is vibrated through three possible means. First, the container may have a vibratory motor with counterweights on its shaft attached to the bottom of the container. Second, the container may have one or two shafts with eccentric weights located on the side(s) and a standard motor. Third, the container may have an electromagnetic vibratory generator located slightly offset of the bottom. [5] The vibration in the containers causes the media, water, compound, and workpieces to rotate vertically within the container in a circular pattern. Unlike in barrel tumbling, the work against the workpieces occurs within the entire workload (or the entire container). The media rubs against the workpieces as it continually rotates and turns in the container. One of the differences between barrel tumbling and tub-type vibratory finishing is that cycle times are significantly shorter with vibratory finishing because of the method in which the media and workpieces interact in the container. Other benefits of tub-type vibratory finishing are the capability of being able to inspect the components and make changes as the machine processes the workpieces. [5] Tub-type vibratory finishing can also assist in finishing grooves and depressions in workpieces more readily that barrel tumbling, Additionally, tub-type vibratory finishing can finish larger workpieces.

The machinery used in round bowl vibratory finishing, also known as toroidal vibratory finishing, is an open top doughnut shaped container. The bottom of the container is either flat or spiral. The doughnut shape of the container allows the media and workpieces to move circularly within the container as it vibrates the mixture. Vibration of the container occurs by either a vibratory motor or an eccentric weight system located in the center of the bowl. [5] Either system controls three primary factors in round bowl vibratory finishing. First, the system controls the way in which the media interacts and finishes the workpieces. Secondly, it controls how fast the mixture (media, water, compound, and workpieces) rotates vertically in the bowl. Thirdly, the system controls how fast the mixture rotates around the bowl. In other words, the workpieces and media rotate vertically within the bowl as they do in the tub-type vibratory finishing process, but they also rotate around the bowl.

<u>Machining and Finishing the Firearm</u>

Three common metal removal techniques in regards to firearms and toolmarks analysis are grinding, milling, and broaching. These cutting techniques are often used to machine and in some cases, finish the breechface of a slide or bolt and other portions of a firearm or tool. More often grinding is employed as a finishing process rather than a cutting process in firearm and tool manufacture. Marks from grinding are often observed as irregular, discontinuous marks on the breechface of a bolt or slide, and on tools such as screwdrivers, wire cutters, and axes. These markings are very individual in nature. Milling marks are often observed in the form of fine and/or broad circular, arched, or parallel marks on the breechface of a bolt or slide and on some tools. These marks may contribute to subclass and/or individual characteristics. Broaching marks are commonly observed as fine and/or broad parallel marks across the workpiece and may contribute to either subclass and/or individual characteristics.

(Note: Manufacturing tours taken by this author in 2011 provided the following insight regarding finishing techniques practiced by current manufacturers.)

Numerous firearm manufacturers used one of the previously discussed primary machining techniques when manufacturing their firearms. For example, both Sig Sauer and Ruger machine broach the breechfaces on some of their slides. Smith & Wesson also machine broaches the breechface of their SW40VE Sigma pistols; whereas, Colt mills the breechface on some of their bolts.

After machining slides or bolts, most firearms manufacturers will finish their products either in-house or through an outside vendor through multiple processes. Finishing processes performed on firearms and firearm components are similar for most firearms manufacturers; however, there may be slight variations in the order of and types of finishing processes, the media used, the length of time the workpieces are finished, and how aggressively the parts are finished.

Many firearms manufacturers use a mass finishing process such as barrel tumbling or vibratory finishing prior to additional finishing. The lengths of time the workpieces (slide, bolt, receiver, etc.) are tumbled or vibrated depend upon the workpiece composition. Aluminum components are finished for shorter periods of time than steel components. One firearm manufacturer used a round bowl vibratory finisher to process aluminum workpieces for 30 minutes, while stainless steel workpieces were vibratory finished for 45 minutes. Length of time for this manufacturer was also dependent on the media used. At the time the manufacturer was using a ceramic preformed media of unknown shape. Another firearm manufacturer finished slides in a round bowl vibratory finisher for 45 minutes to 1.5 hours depending upon the size of the workpiece. The media used was also a ceramic preformed media of unknown shape. The solution utilized was a soap solution with an anti-rust additive. Another firearm manufacturer tumbled (the type of tumbling is unknown to author) receivers for approximately two hours, but it was also pointed out that tumbling times depend upon the workpiece and process. This same manufacturer also used polishing stones for their media.

After tumbling or vibratory finishing, some firearm manufacturers heat treated the workpieces. This was followed with further finishing – usually through sand blasting or wet blast deburring, glass bead blasting, manual hand filing, or a combination of any of these. One firearm manufacturer sand blasted their slides with a mixture of calcium oxide and sand at high velocities and followed this with glass bead blasting at high velocities. During any of these finishing processes there was the potential for the finishing media and the workpieces themselves to come into contact with the breechface of the slide or bolt perhaps altering the subclass or individual characteristics that were present.

Materials and Methods

Based on the information ascertained through research and during the firearm manufacturer tours, it was decided that the experimental portion of the research project would use broaching as the primary machining process and focus on the effect of vibratory finishing on broaching marks as a function of time. Broaching was decided upon because it has the potential to produce subclass characteristics and, as has been stated previously, is a common machining process used in the industry. The workpieces created from broaching were to simulate a breechface on a slide. Vibratory finishing was decided upon because it was commonly one of the first finishing processes that a workpiece goes through. To determine the impact of vibratory finishing on broaching marks, the only variable considered for this research was time of finishing. Vibrating times were selected to encompass both extreme timeframes (0 and 180 minutes) of finishing, and common, or "normal," finishing times. Media, solution, and workpiece size were all maintained during the finishing process. No other additional finishing (sand or glass bead blasting) was performed as the author did not want to introduce additional variables.

All machining and finishing processes were performed at CW Industries owned by Chuck West and located in Clovis, California. Machining processes (lathing, broaching, cutting) were performed by or under the supervision of Mr. West. The author was not present during these processes due to safety and privacy concerns. Finishing processes (vibratory finishing) were performed by the author with the assistance of Nancy McCombs at CW Industries.

Prior to broaching, one toroidal (i.e. doughnut) shaped piece of steel was turned on a lathe to obtain the correct inner and outer diameters for machining. The top and bottom of the toroidal workpiece was also machine lathed prior to broaching. The toroidal shaped piece of 10/20 steel was then keyway broached consecutively ten times vertically within the inner diameter of the steel workpiece. The keyway broach used for this project was 14" in length and had a 0.5" face width. The broach had seventeen cutting edges, with each edge increasing 0.004" in depth of cut.[2] The keyway broach was positioned in a Press Master 50-Ton machine press. The press moved the broach down the inner diameter of the steel workpiece for a single pass of the keyway broach. (See **Figure 1**) The workpiece was then repositioned for a new cut and the process repeated for a total of ten cuts around the inner diameter. After the piece was broached, each broached section was cut away from the metal to produce ten individual workpieces. (See **Figure 2**) Each side was then rough milled to smooth out any rough edges or burrs from cutting. The ten broached pieces were then cut in half using a saw to produce a total of twenty broached steel pieces, or ten top pieces and ten bottom pieces. (See **Figure 3**) It is unknown and unclear to the author as to why Mr. West cut the ten broached pieces in half. The machining processes previously described were done over the course of a week and as stated previously, without the author present during the process.

Unfortunately, the completed steel pieces were not indexed during the machining process to demonstrate the order in

[2] Mr. West was asked to consider and rate the condition of the broach prior to cutting. On a scale of 1 to 10, with 1 being a new broach, Mr. West ranked it as a 3.

which they were broached. Additionally, the completed tops and bottoms had to be physically matched prior to any finishing processes. The physical matches were made by using the rough milled and sawed sections of the steel pieces. Then the physically matched pairs were engraved on the rough milled side as either top (T) or bottom (B) and also numbered 1 through 10 to distinguish between the pairs (i.e. T1, B1, T2, B2…T10, B10). (See **Figure 4**) The physical matches were later confirmed at the laboratory using the comparison microscope.

Each piece of broached steel was examined under the stereoscope for an evaluation of the machining with special concentration on the broached section prior to any finishing. Each piece of steel (20 pieces total) was cast using brown ForensicSil® and represented time zero. These casts were then set aside for microscopic examination in the laboratory. The twenty pieces of steel were then placed in a "Mr. Deburr" vibratory tumbler[3] with ceramic media (trapezoidal, medium to fine grit, measuring approximately ½" by 13/16"), and "Trim® E206" emulsion solution and vibratory finished for a total of 15 minutes. After 15 minutes, the steel pieces were removed, cast with brown ForensicSil®, marked as time 15 minutes, and returned to the vibratory finisher. The pieces were vibratory finished for another fifteen minutes resulting in a total vibrating time of 30 minutes. The steel pieces were then removed, cast with brown ForensicSil®, marked as time 30 minutes, and returned to the vibratory finisher. This was repeated for total vibrating intervals of 45, 60, 90, 120 and 180 minutes, a total of eight time intervals. After each vibrating period, general observations were made regarding the overall appearance of the steel pieces. At 45 minutes, the steel pieces were re-engraved with their identifying marks into the metal pieces as they were becoming difficult to read. Corresponding top and bottom pieces and casts were placed in a coin envelope together for microscopic examination and comparison. A single set included *all* ForensicSil® casts from a pair (top and bottom steel pieces – T1, B1…T10, B10) from time zero to time 180 minutes.

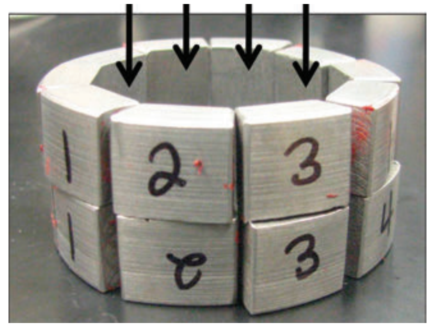

Figure 1: Demonstration of how toroidal workpiece was broached.

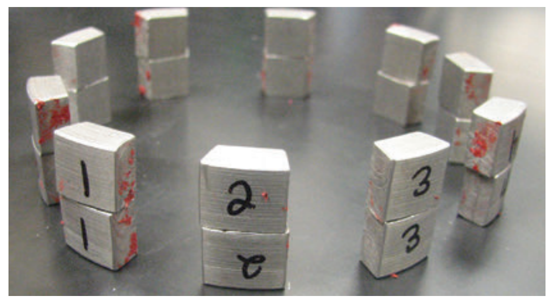

Figure 2: Demonstration of how workpiece was cut by sawing and then milled after broaching to generate ten individual workpieces.

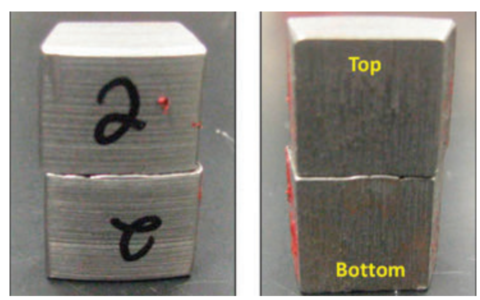

Figure 3: Demonstration of how workpiece was cut by sawing after broaching to generate twenty individual workpieces.individual workpieces.

In the laboratory, sets 2, 5, 7 and 10 were randomly selected for microscopic comparison. The ForensicSil® casts for a specific set were examined under the comparison microscope using a Leica FSC comparison microscope with LED lighting and incorporated Leica DFC 420 camera. Prior to each microscopic examination, the casts were gently cleaned using compressed air. The top metal piece cast from set 7 at time zero was compared to the same cast at vibrating interval times 15 through 180 minutes. This method was repeated for the bottom pieces from set 7 and the remaining three sets. Observations were recorded as to the general appearance of the markings, the possibility of subclass carryover, the presence of individual characteristics, and whether an identification could be made between the same steel pieces at different vibratory finishing times.

Following this comparison, the time zero bottom pieces from sets 2, 5, 7, and 10 were selected for additional microscopic examination and comparison. The bottom pieces were compared to each other and observations were made as to whether identifications could be made between the consecutively broached steel pieces and for the presence of carryover.

[3] The tumbler was used by CW Industries for deburring processes. The process was utilized at the machine shop to minimize the cost of hand labor.

Results and Discussion

The general appearance of the machined steel pieces prior to finishing was initially examined. The initial steel pieces were shiny and had a mirror-like appearance. The edges and corners were rough and sharp to the touch. The machined areas of the steel pieces, especially in the milled and sawed portions, both appeared and felt rough to the touch.

The machined steel pieces were additionally examined using a stereomicroscope to examine the markings left by the machining process with particular interest in the broached portions. The sides of the steel pieces that had been rough milled were marked with circular and semi-circular markings. These markings were very deep, broad, gross and subclass in appearance. These markings, because of their gross appearance, were also used to physically match the top and bottom portions of the steel pieces. The area of the steel piece that had been lathe turned contained markings with a slightly arched appearance. These markings appeared to be very fine in nature and did not appear upon initial observations to contain any subclass characteristics. The portion of the steel that had been sawed contained markings that were both fine and coarse in nature. The overall appearance of the sawed portion was jagged and rough, with some pieces being more uneven and rough than others. The uneven and rough portions of the metal pieces were also used to physically match the top and bottom portions of the steel pieces.

The broached portions of the steel pieces were observed to contain fine and apparently coarse stria from the top to the bottom of the pieces. There appeared to be some coarse stria, but mostly discontinuous stria and other unknown markings were observed on the pieces. In initial observations, it was concluded that there was the potential for subclass in the markings; however, closer examination was required. The bottom piece, where the broach had last made contact with the metal piece, had large burrs and rough, uneven areas at the end of the piece. These bottom pieces felt sharper as a result of the burrs.

General observations were made as to the general appearance of the machined pieces after each of the vibratory finishing intervals. The observations are documented in **Table 1**.

As was stated in the experimental section, ForensicSil® casts were taken after each vibratory finishing interval and the casts were grouped into sets. Sets 2, 5, 7, and 10 were randomly selected from the ten sets for microscopic comparison. Observations between the comparisons were recorded as to the general appearance of the striae, the possibility of subclass carryover, the presence of individual characteristics, and whether an identification could be made between the same steel pieces at different vibratory finishing times. The top and bottom metal piece casts from set 7 at time zero were compared to the same casts at vibrating interval times 15 through 180 minutes.

Figure 4: Demonstration of how workpieces were physically matched and designated as sets 1 - 10.

The top and bottom casts for set 7 were microscopically examined for the general appearance of the markings at time zero. The markings observed were a combination of fine and coarser stria. (See **Figure 5**) These initial casts demonstrated good potential for identification. In fact, the author would consider the observed stria ideal for comparison. Surprisingly, there was little to no subclass observed. Another observation of the markings on the casts was a "feathering"[4] appearance on the casts. (See **Figures 5 and 6**) This "feathering" appearance is most likely due to the formation of chips as the broach passed over the metal and the breaking off of these chips. Although microscopically gross in general appearance, these "feathering" marks are individual in nature as they are random imperfections caused by the machining process.

For set 7, the microscopic comparison between time zero and time fifteen minutes demonstrated no overall difference between the two casts and an identification was made between

[4]The term "feathering" was created by the author.

Time	Observations
15	Felt smoother to touch, sharp edges and burrs were softening, no changes to surface appearance.
30	No additional observations made.
45	Engraved numbers showed signs of wear, pieces began to lose mirror-like finish, appeared dull. Engraved numbers re-etched.
60	Edges and corners had been rounded out.
90	Pieces continued to lose mirror-like finish.
120	Pieces continued to lose mirror-like finish.
180	Surface appearance did not appear significantly changed. Engraved numbers showed signs of wear. Unable to distinguish between 3, 6, and 9.

Table 1: General observations after finishing.

the two casts. The microscopic comparison between time zero and time thirty minutes yielded the same results and an identification was made. The microscopic comparison between time zero and time forty five minutes demonstrated the first changes observed in the markings on the surface of the steel pieces. At forty five minutes, individual detail, specifically the smaller, finer stria, began to be removed and fade from the surface of the steel pieces. Regardless of the slight loss in individual detail, an identification was still made. At time sixty minutes, more individual detail (in the form of smaller, finer stria) was lost, but an identification was made. At times ninety minutes, 120 minutes, and 180 minutes, more individual detail was lost. The steel pieces appeared to have gaps and completely smooth areas where finer stria had once been. The coarser, broader stria, however, remained. The "feathering" appearance, most likely because of the reduction of the fine stria, appeared more prominent and exaggerated in the final vibrating times. At first look, these pieces, especially at 180 minutes, appeared completely different than the pieces at time zero. Regardless, the comparisons made between the steel piece casts at time zero to the casts at times ninety minutes, 120 minutes, and 180 minutes were all identified to each other. This was done by utilizing the "feathering" markings and the remaining broad stria. (See **Figures 7 through 14**.)

The examination was repeated for sets 2, 5, and 10. Similar observations were made during the comparisons. Once again, there was little to no subclass markings observed in the sets. At time forty five minutes individual detail, specifically the smaller, finer stria, began to fade and be removed from the surface of the steel pieces. As time continued in all sets, the fine, individual stria continued to deteriorate and the appearance of "feathering" increased. Identifications were made between all comparisons.

The degree of deterioration of the finer markings was slightly different in all sets. For example, in set 5, there was not initially (at time sixty minutes) the same amount of deterioration of the fine stria as in set 7 at the same time. Set 10, on the other hand, had more initial deterioration of the fine, individual stria at time forty five minutes than the other sets examined. This could be due to variances in the degree of contact of the workpieces with the media, and the amount of water and solution being cycled throughout the media and workpieces.

The time zero bottom steel portions from sets 2, 5, 7, and 10 were compared to each other to determine if consecutively manufactured broached pieces could be identified to each other. The results were as one would hope. There was little to no subclass carryover between the broached pieces and the broached pieces could not be identified to one another. (See **Figures 15 and 16**.)

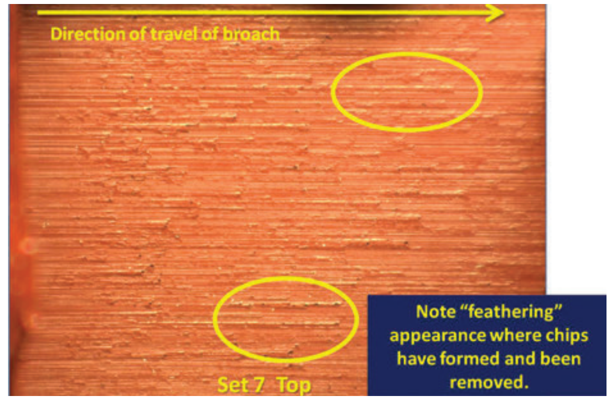

Figure 5: Top steel piece from Set 7 prior to any finishing (T0). Note areas of fine stria, coarse stria, and areas of "feathering."

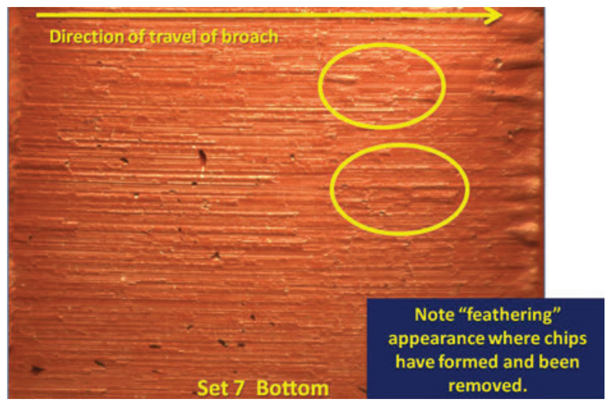

Figure 6: Bottom steel piece from Set 7 prior to any finishing (T0). Note areas of fine stria, coarse stria, and areas of "feathering."

After the initial microscopic examination, the first question that arose was why this broach did not create subclass characteristics that have been observed with other machine broaches. First, broaching does not always create subclass. In fact, subclass happens infrequently in machined surfaces, but it does occur. Secondly, the broach used was in fairly good condition and was sharp. Subclass is most often observed in cutting tools that have been worn down over time or are defective in some manner.

The second question that arose was why the finer stria would deteriorate more readily and more quickly than the coarser stria and markings. The initial thought was that the coarser, grosser markings would be more readily removed or changed because they would be coming into more contact with the media, water and solution and other workpieces. However, this was in fact not the case. The reason for the deterioration of the finer, individual stria and characteristics, in the author's opinion, was that the finer stria were simply easier to remove during vibratory finishing. With the stria that were removed,

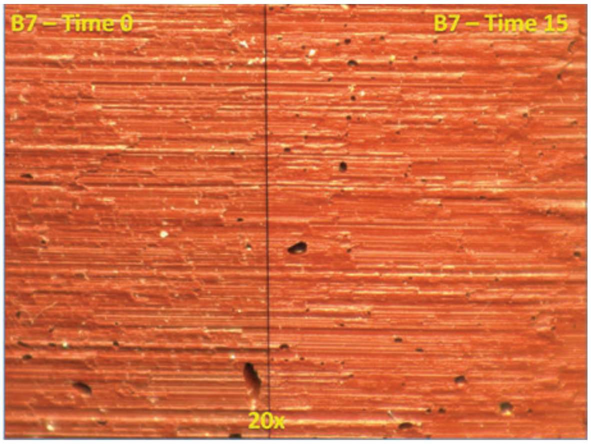

Figure 7: Comparison and identification of pieces at 20x at time zero (T0) and after fifteen minutes of vibratory finishing (T15).

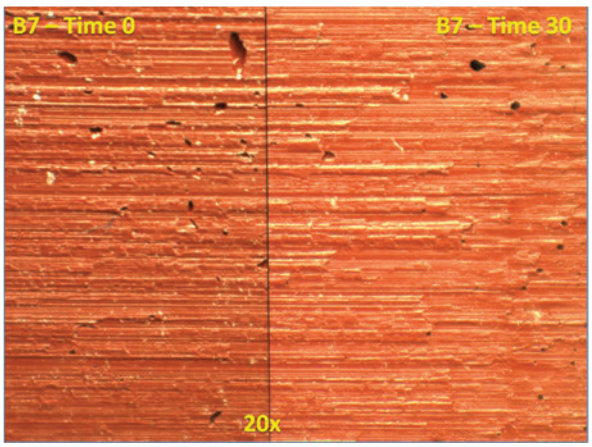

Figure 8: Comparison and identification of pieces at 20x at time zero (T0) and after thirty minutes of vibratory finishing (T30).

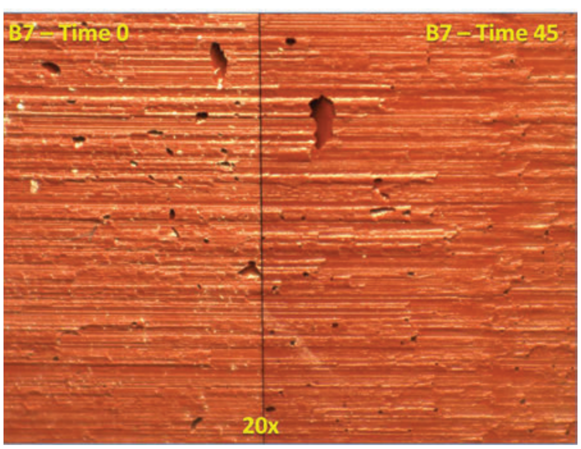

Figure 9: Comparison and identification of pieces at 20x at time zero (T0) and after forty five minutes of vibratory finishing (T45).

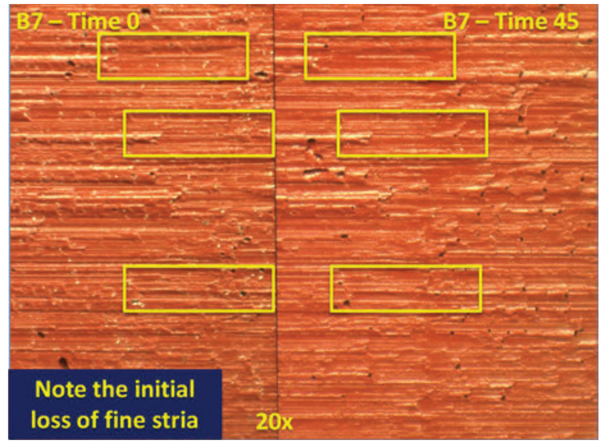

Figure 10: Comparison and identification of pieces at 20x at time zero (T0) and after forty five minutes of vibratory finishing (T45). Note the beginning of the loss of fine stria.

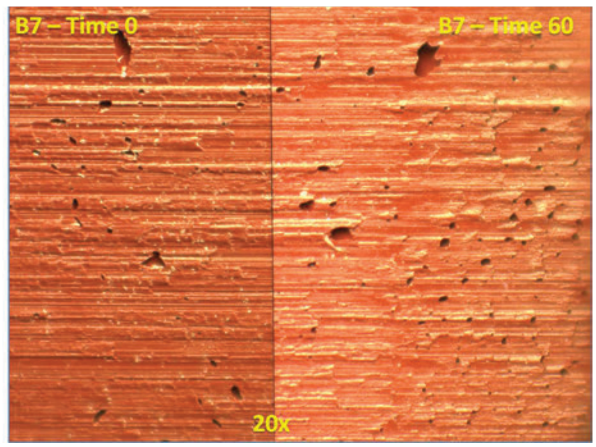

Figure 11: Comparison and identification of pieces at 20x at time zero (T0) and after sixty minutes of vibratory finishing (T60).

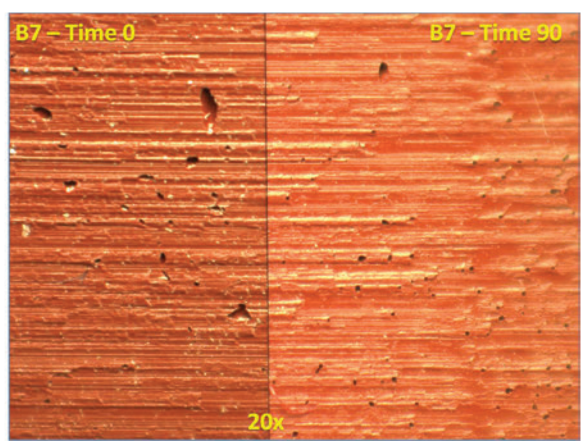

Figure 12: Comparison and identification of pieces at 20x at time zero (T0) and after ninety minutes of vibratory finishing (T90).

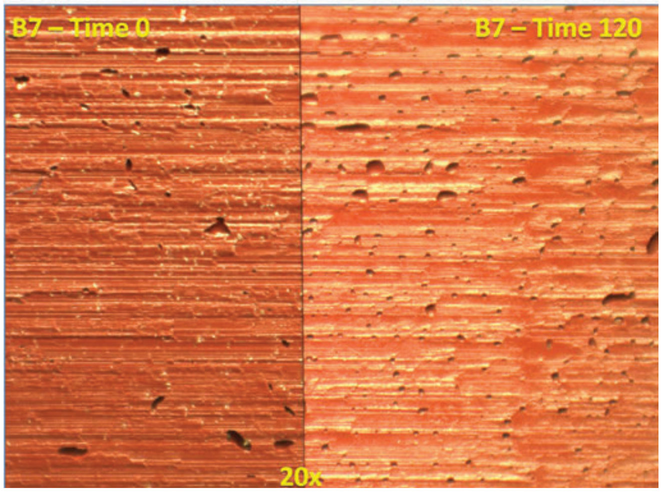

Figure 13: Comparison and identification of pieces at 20x at time zero (T0) and after 120 minutes of vibratory finishing (T120).

Figure 15: Top and bottom portions from a single pass of broach. Note that the stria have changed from beginning to end.

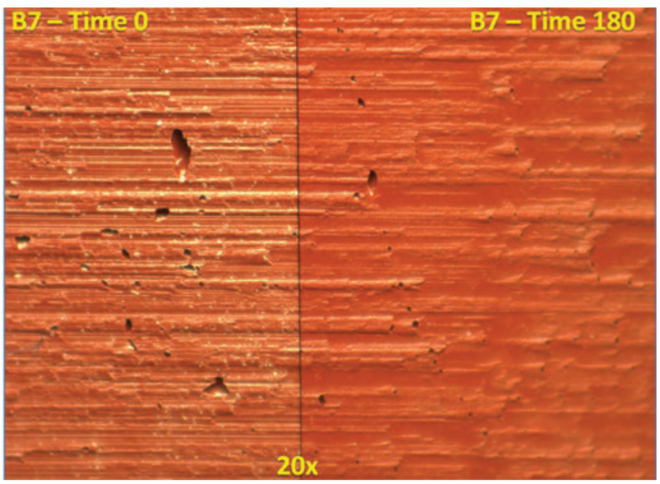

Figure 14: Comparison and identification of pieces at 20x at time zero (T0) and after 180 minutes of vibratory finishing (T180). Note similarities and further reduction of fine, individual stria. Also note that the coarser, broader characteristics remain and appear more prominent.

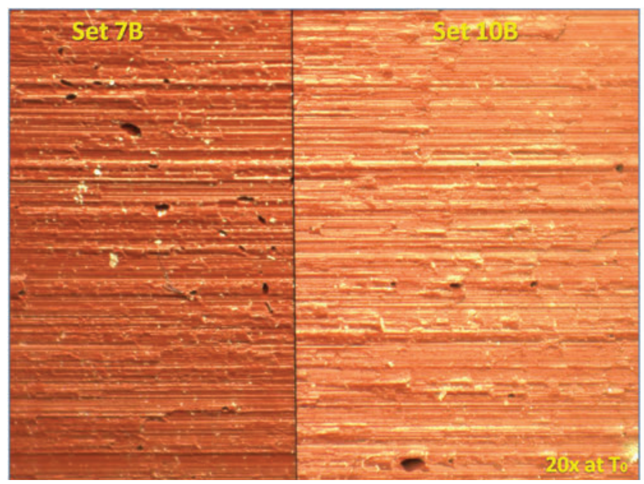

Figure 16: Comparison of Set 7 to Set 10 with no finishing process completed. With the possible exception of a gross stria, there is no subclass carryover between the sets.

there was less metal adhering to the surface area of the metal pieces. As water, solution, and media continually vibrated and worked against the workpiece, the finer stria were worn down and removed more quickly than the grosser markings.

In regards to subclass and individual characteristics, vibratory finishing did have a significant impact on the machining marks caused from broaching. Over time, vibratory finishing changed and removed the finer, individual markings observed from the broaching process. As a result, the grosser, individual markings appeared more prominent. These observations suggest that had there been coarse subclass markings present, these markings would not have been removed during the finishing process. These marks may have also appeared more prominent or perhaps been changed in some manner.

There are a few factors that should be considered regarding the final conclusion. First, only vibratory finishing as a function of time was tested. Most firearm manufacturers finish their products through multiple steps including sand and glass bead blasting following heat treatment. This experiment did not address these three additional steps. Most likely, the additional finishing processes would further change the appearance of the workpiece as a function of time, pressure, and media used.

Both sand and glass bead blasting are more likely to come into contact with the surfaces of interest than vibratory finishing, causing more metal to be finished and removed during the process. Additionally heat treating changes the stability of the metal workpieces making the surface more difficult to alter, and this should be taken into account as well.

In this experiment there are numerous variables that may have had an additional impact on the final results. First, 10/20 steel was used for the workpiece; however, each firearms manufacturer has specific steel and metal requirements for their firearms. Aluminum can also be utilized and most likely would have very different results. Broaching was used as the primary machining process, but other machining processes, such as milling and grinding, could have been used as well. Furthermore, the broach used was in fairly good condition. Broaches can be used for thousands of workpieces and differences in the quality of the broach could affect the markings on the workpiece.

The media used was a general deburring media meant for use with numerous types of metal workpieces. It was unknown what type of media firearms manufacturers use for their finishing processes, but this information would have been useful to provide a more comprehensive experiment. The liquid solution used may or may not have had an impact on the final conclusion; however, some firearms manufacturers use an acidic solution that may further remove burrs and in turn, individual and subclass markings. Vibratory finishing was used; however, some firearm manufacturers use barrel tumbling. Although the process is still generally the same, there may be slight differences as length of finishing time changes between the two processes.

Another important factor to consider is that this experiment was designed to create an extreme or "worst-case" scenario. The metal pieces were designed to represent a breechface; however, most breechfaces that will be finished are a part of a slide. The breechface on a slide is located within a recess on the slide and protected by the walls of the slide. The tumbling or vibratory media would have a more difficult time of making contact with the breechface than what occurred in this experiment. The simulated breechfaces in this experiment were created to purposely come into contact with the media and solution. If the breechfaces had been located on a slide, the amount of metal lost may have differed from what occurred in this experiment.

Conclusion

Until recently, there was only speculation regarding the impact of finishing processes. As a result, further research needed to be done to fully understand the impact of finishing processes after machining on subclass and individual characteristics. Based on the information ascertained through research and during the firearm manufacturer tours, broaching was used as a machining process and the effect of vibratory finishing on broaching marks as a function of time was examined. Vibratory finishing as a function of time did have a significant impact on the individual characteristics. Vibratory finishing changed and removed the finer, individual markings over time, increasing the prominence of the grosser individual markings. This change began within the normal timeframe of finishing processes used in the firearms industry. These conclusions suggest that had there been subclass markings present, these markings would not have been removed during the finishing process, but instead enhanced. Regardless, in this study identifications could still be made. The author encourages the further study of finishing processes as it may be an important consideration in the identification of a firearm or toolmark.

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