Subclass Characteristics: From Origin to Evaluation

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ABSTRACT

Subclass characteristics, which were first brought to the attention of the firearm/toolmark examiner community-at-large in 1992, have long been recognized (even prior to 1992) as a potential obstacle in making reliable common source determinations. The reason is because subclass characteristics have an appearance similar to individual characteristics but, unlike individual characteristics, can be present on a number of tools created in close proximity with one another. Therefore, if not properly assessed, a tool mark on a questioned piece of evidence could be mistakenly linked back to a tool other than the one that made it based on the correspondence of subclass characteristics. Notably, within the last 25 years there have been some excellent research studies in this area that have helped recognize specific machining methods that have a propensity to leave subclass characteristics as well as providing guidance on how to assess tools and tool marks for subclass influences. This article looks to bring together the early historical context with a basic understanding of manufacturing processes and the various studies that have been performed for the purpose of serving as a single, well-referenced resource for the issue of subclass characteristics.

Introduction

Subclass characteristics as a concept was highlighted in 1992 as part of the report of the AFTE Criteria for Identification Committee [1]. This topic was addressed in the report because the Committee recognized that uncritical evaluations of tool surfaces and tool marks could result in non-unique subclass characteristics being confused with individual characteristics. The danger is the potential identification of a tool mark to a tool that did not create the mark.

Since then, subclass characteristics have been the topic of a number of published articles, presentations in scientific venues, and court hearings. Published papers have discussed the topic in a number of contexts. One of these contexts is in the framework of broader issues related to firearm and tool mark identification. Other papers have offered a more in-depth discussion of subclass characteristics. A third context includes the various manufacturing methods used in the production of tools (including firearms) and the impact of these methods on resulting tool marks. Examples of published papers are referenced [2, 3, 4, 5, 6, 7, 8].

In addition to these general discussions, there are scores more papers/articles that address the topic in one form or another, including those that research specific manufacturing methods and whether or not tools produced from that process will leave tool marks that can be identified to the tool that produced them. These more specific articles have allowed examiners to draw conclusions with respect to the potential for subclass characteristics on certain tools depending on the method of manufacture.

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The purpose of this paper is to encapsulate the bulk of what has been published with respect to subclass characteristics into a single source while adding a very critical component, machining fundamentals. This paper will discuss subclass characteristics from the manufacturing process to application in the evaluation of tools and tool marks for purposes of comparative microscopy.

This paper consists of three parts:

- Part 1 – Defining subclass characteristics and their relationship to class and individual characteristics.
- Part 2 – The origin of subclass characteristics to include tool manufacturing fundamentals that will help to explain how and why subclass characteristics are formed.
- Part 3 – The evaluation of tool working surfaces and tool marks (in the absence of tools) for subclass characteristics.

PART ONE - Defining Subclass Characteristics

A review of the literature indicates that subclass characteristics were observed as something of importance with respect to firearm and tool mark identification as early as the 1930's with mention made of the concept in three different seminal texts [9, 10, 11]. Gunther and Gunther recognized it as an issue with hook cutter rifled barrels while Hatcher recognized that a defect in a cutting tool could result in similar marks being produced in multiple barrels rifled with that tool. Burrard actually used the term "family likeness" to describe what he was observing.

The earliest, extensive study dealing with the concept of subclass characteristics appears to be as early as 1949 by Churchman [12]. He referred to these as "B" or "broach series characteristics," observing that they would be present on a number of bores rifled using the same series of broaches. In 1974, Lomoro published an article regarding reproducible marks produced on bullets fired from different .32 caliber F.I.E. Titanic revolvers [13]. In the title of the article he referred to these as "class characteristics". In 1996, Thompson observed reproducible marks on different Lorcin L9 breech faces and referred to them as "family characteristics" [14].

As expected when phenomena are first observed, efforts are made to describe it as best as possible. Unfortunately, this leads to a number of different terms being used by different authors to classify the same basic phenomena, which are manifested in inconsistent and confusing ways.

In 1992, the Association adopted the following definition of subclass characteristics for addition to the AFTE Glossary, based on a recommendation by a combined committee consisting of members from the Standardization and Criteria for Identification Committees [the definition shown here is a modified version of the one originally proposed by the Criteria for Identification Committee in 1990 [15]:

> Discernible surface features of an object which are more restrictive that CLASS CHARACTERISTICS in that they are: (1) Produced incidental to manufacture; (2) Are significant in that they relate to a smaller group source (a subset of the class to which they belong); (3) Can arise from a source which changes over time. Examples would include: bunter marks, extrusion marks on pipe, etc. Caution should be exercised in distinguishing subclass characteristics from INDIVIDUAL CHARACTERISTICS [16].

Even with this definition, the various situations, or contexts, in which the term "subclass characteristics" can be used has created some confusion. Therefore, before moving forward, some clarity to this definition is needed.

The first of these contexts relates to one of the examples used by the AFTE Committee in the definition above: bunter marks. Bunters are tools that produce the headstamp on cartridge cases which are generally indicative of the marketer and caliber of the cartridge. An example of the application of subclass characteristics in this context is:

- Class – all the cartridge cases with "R-P 9mm LUGER" headstamp
- Subclass – all the cartridge cases with "R-P 9mm LUGER" headstamp that were produced using the same bunter
- Individual – a single cartridge case within the subclass set, distinguished by a feature not present on any other cartridge case from that set

Another example in this context is that of cut nails. In 1998, Miller discussed the manufacturing method of cut nails and how the method imparted subclass characteristics onto the nails during the manufacturing process [17]. An example of the application of subclass characteristics in this context is:

- Class – all the cut nails produced by a single machine
- Subclass – all the nails produced during a particular run of the machine before the tool marks on them changed
- Individual – a single nail within the subclass set, distinguished by a feature not present on any other nail from that set

In each of these examples, the use of the term "subclass characteristics" was technically correct by the definition above. However, since headstamps can be linked to a specific bunter that produced it [18] and the nails could be identified to the machine that made them during a specific interval [19], are they subclass characteristics or individual characteristics? The answer depends on the question the examiner is trying to answer.

In these particular instances, the context dealt with the limitations of that type of evidence. In the case of cut nails, the investigator may be seeking to develop a potential link based on a comparison of cut nails in an improvised explosive device to cut nails recovered from a suspect's house. Similarly, investigators may want to see if a link can be established between cartridge cases recovered at a crime scene to cartridges recovered at a suspect's house based on headstamps produced by bunter tools. Since literally thousands of items may share the same *subclass characteristics*, the value of those potential associations with respect to the question being asked is limited.

The second context in which subclass characteristics have been used relates to manufacturer marks. Manufacturer marks refer to marks present on unfired ammunition from the manufacturing process of the ammunition. Examples of such marks are parallel lines observed on primers of shotgun ammunition as discussed by Garten and Neel [20]. These marks can exist on a number of shot shells, can persist after firing and, if not properly evaluated, can result in an erroneous identification.

A third context lies in the continued use of "family characteristics". This term has been used to describe marks that tend to be associated with a specific type of tool. Figure 1 is an example of this.

Figure 1 depicts two different breech faces of the same make and model of firearm. Based on the concentric circular tool marks, the breech faces were milled. The slightly arcing marks around the lower part of the firing pin hole are due to the edges of cartridge case rims striking the breech face during loading and chambering. Such marks are typically observed on firearms of this particular make and model, and for that reason would be typically referred to as "family" characteristics. However, since the source of these similar marks is accumulated damage over the course of the use of the firearm, they do not fit the AFTE definition of subclass which states that they are, "produced incidental to manufacture" [21].

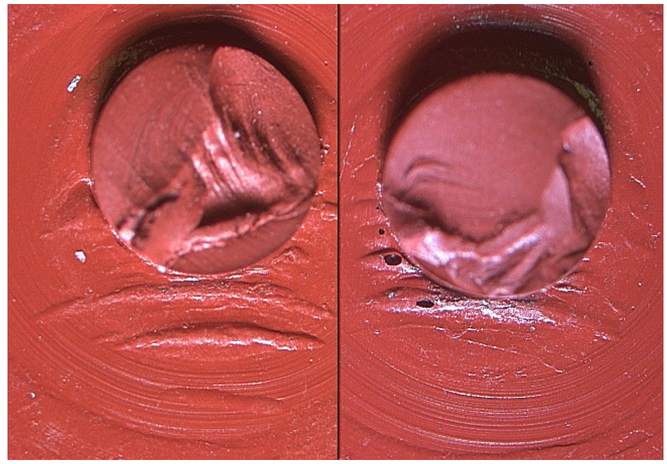

Figure 1: Comparison of two different milled breech faces

Most commonly, subclass characteristics are discussed in the context of misidentifications – attributing a tool mark to a tool other than that which created it. As an example, **Figure 2** depicts the cutting of six hypothetical tool tips that have been finished using a cutter having an individual (i.e. unique) ground edge (although the depicted tool working surfaces are analogous to screwdriver tips, screwdrivers are not typically produced in this manner, nor do their tips exhibit the types of tool marks shown in Figure 2; this illustration shows simplified tool marks for purposes of discussion only). If one were to attempt to identify which cutter from the manufacturer made any one (or all) of those tips, test marks of the cutter would be made and compared with the tips. Provided the cutter had not changed much between the cutting of the tips and the generation of the test marks, the tips could be identified to the cutter based on the tool marks made by the cutter. By definition, these tool marks would be referred to as individual characteristics, since they can be associated with the unique cutting surface used to produce them.

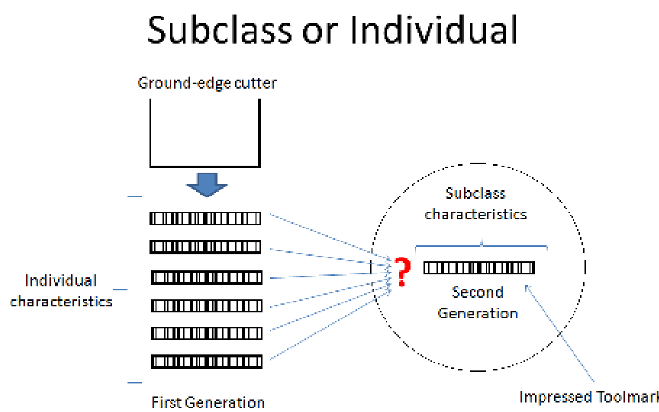

Figure 2: Generations of tool marks

Extending the example, let's assume that one of those six tools is used to make an impressed tool mark onto a surface using the tip. Could the tool mark produced by that tip be uniquely associated to the tool tip that made it? The answer is no, because multiple tool tips (six in the diagram) would have that similar pattern. At this point, the very same characteristics that could be considered individual are now referred to as subclass characteristics.

The key to sorting this out lies in understanding the different generations of tool marks. The tool marks on the tips in **Figure 2** are first-generation tool marks and can be used to identify the tips to the cutter that produced them. The impressed tool mark depicted in **Figure 2** is a second-generation tool mark, produced by a tool which, in turn, was produced by a parent tool. Identification of the impressed tool mark does not identify the particular tool tip, but rather the cutter that produced the tip. In a first-generation tool mark, the characteristics would be considered individual. In a second-generation tool mark, the characteristics would be considered subclass. In casework related to firearm and tool mark identification, the examiner is generally dealing with second-generation toolmarks. However, this does not mean that all second-generation tool marks consist of subclass characteristics, despite inferences to the contrary made by Schwartz [22] and Tobin [23].

It is in this final context that this paper will address the issue of subclass characteristics. The various manufacturing processes of tools will be discussed in Part 2, identifying those processes that can result in subclass characteristics in a second-generation tool mark. The discussion will progress in Part 3 to the recognition of subclass characteristics on tool working surfaces and in tool marks in the absence of tools.

PART TWO

Origin of Subclass Characteristics

Subclass characteristics are produced "incidental to manufacture" [24], meaning they are produced during the manufacturing process. There are metal forming processes that predominantly produce subclass tool marks, but have no impact on the final finished working surface responsible for making the tool mark of interest. An example is the extrusion of metal bar stock intended for use in the manufacture of extractors. The extrusion process may leave subclass characteristics but the bar stock is further cut by other tools to create the extractor. This eliminates the potential of subclass characteristics created from the extrusion process to impact the tool mark of interest, i.e. the extractor mark on a cartridge case. Another example is chisels. During the forging and trimming processes, subclass characteristics may be produced, however, the final grinding process on the tips produces individual tool marks [25]. With respect to manufacturing processes and the origin of subclass characteristics, this discussion will be focused on those processes responsible for the final finishing of tool working surfaces which will produce tool marks typically examined in a comparative analysis.

While the manufacturing process is of critical importance, it is but one factor in the equation when considering whether or not a tool mark may have subclass characteristics. The second factor is the interaction of the tool with the substrate with which the tool is interacting. As discussed in the Cassidy study of broach cut pliers, the actual use of the tool may preclude subclass characteristics (if they even exist) from being reproduced in the tool mark because of the manner in which the tool is used [26]. Therefore, when we discuss the origin of subclass characteristics it is important to discuss them from two perspectives. The first deals with manufacturing processes related to the tool working surface and the second deals with how the tool mark is formed by the tool surface in question.

Manufacturing Processes [27, 28]

When considering the population of firearms and tools, there are many different manufacturers, models, calibers and tool types. However, there are only two ways in which metal can be manipulated into a specific shape and finished – metal is either 1) cut away, or it is 2) formed from an existing block of metal or from molten material. Since subclass characteristics are related to the manufacturing process, it is the metal manipulation process that is significant and where the attention here shall lie.

One common fallacy in thinking regarding subclass characteristics is that these characteristics are only (or usually) produced by damaged tools, which may impart coarse, continuous marks (subclass characteristics) to the workpiece. However, brand new tools with undamaged working surfaces can just as easily impart subclass characteristics to machined surfaces. In fact, it is in a manufacturer's best interest to reduce waste and costs by controlling the surface finish of the final product and extending the life of the tools they use to produce them. This is accomplished by controlling: 1) the ability of the working surfaces of the manufacturing tool to hold a sharp edge (a function of the tool steel's hardness); 2) the hardness of the metal being machined; and 3) lubrication. These three factors influence how fast the manufacturing tool's working surface may wear (change) during use. This, along with chip formation (discussed below), is what determines whether or not subclass characteristics will be formed on consecutively-manufactured items.

Metal Cutting

Metal cutting is a process in which a wedge-shaped tool engages a work piece to remove a layer of material in the form of a chip. As the cutting tool engages the work piece, the material directly ahead of the tool is sheared and deformed under tremendous pressure. The deformed material then seeks to relieve its stressed condition by fracturing and flowing into the space above the tool in the form of a chip. Depending on the cutting conditions, this chip formation can be discontinuous, continuous, or continuous with a built-up edge. This is important because the absence or presence of subclass characteristics is related to chip formation. Each of these types of chip formation is illustrated in **Figure 3**.

Most often, discontinuous chip formation (**Figure 3a**) is the result of brittle metals or poor cutting conditions. This is not to suggest that the cutting conditions are not appropriate given the task, just that they are not optimized with regard to chip formation. As the cutting point cuts the metal, some compression occurs and the chip begins to flow along the chip-tool interface. As more stress is applied the metal compresses until it reaches a point where a break occurs and the chip separates from the surface. The finished surfaces tend to be rather coarse and are not considered ideal, potentially requiring further treatment depending on intended use. The potential for subclass characteristics is low because of the constant and irregular breaking of small chips along the cut surface.

Continuous chip formation (**Figure 3b**) is generally the result of a ductile metal and a sharp cutting edge. The crystalline structure of the metal is elongated when compressed by the action of the cutting tool and the chip separates from the substrate in a single plane, extending from the cutting tool to the un-machined surface. The finished surfaces tend to be rather good, may almost appear polished, and generally do not require further treatment. The potential for subclass is highest

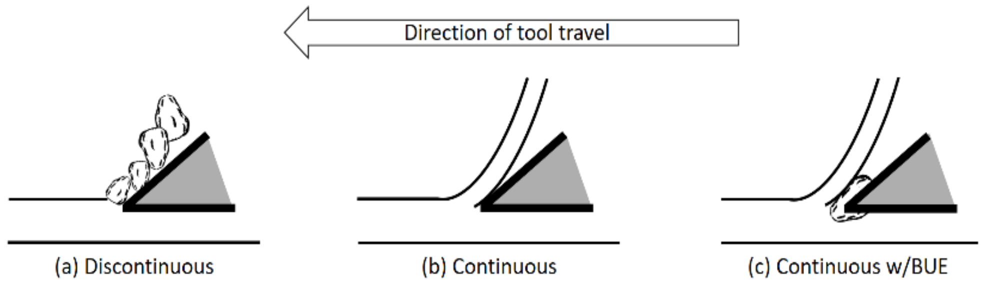

Figure 3: Chip Formation

here because chip formation is very regular and continuous, minimizing individual marks due to chips breaking off the surface. The tool marks left on the machined surface and chip will be primarily due to the cutting surface of the tool. By examining the chip, it is possible to see how often the cutting surface of the tool changes, if indeed it does, over the length of the chip [29].

Continuous with a built-up edge (BUE) (**Figure 3c**) occurs as chips form and flow along the chip-tool interface. As cutting progresses, more and more particles build up until the size is so great that the stress causes a fracture and breaking of the chip, leaving some on the chip, some on the work piece and some on the tool. The cutting surface is continually changing with the built-up edge accumulating, eroding and breaking off. The finished surfaces tend to be rather good and, depending on the intended use, may not require further treatment. The potential for subclass characteristics is lower than continuous because the constantly changing character of the built-up edge is changing the cutting surface of the tool.

A note is important regarding Computer Numerical Controlled Machining (CNC). In general, some confusion exists as to whether CNC increases the likelihood for subclass characteristics to be imparted on tooled surfaces. King provided a concise history of CNC machining when publishing the results of a validation study she performed [30]. In short, CNC is simply a means for multiple machining processes to be performed on a group of items allowing a single individual to be responsible for a number of tooling operations. The internal machining processes involving metal cutting still result in chip formation in one form or another which is what impacts the potential for subclass characteristics. To imply that CNC will result in an increased likelihood of subclass characteristics is not reasonable given that there are no published studies to demonstrate that it does. Indeed, there will be studies discussed later that involved CNC machining and subclass characteristics were not found to be an issue.

There are five general categories of metal cutting processes: single-point machining, multi-point machining, hole-making, abrasive/grinding processes, and electro machining. **Figure 4** highlights some of the machining methods associated within those groups to be followed by a brief discussion of each method.

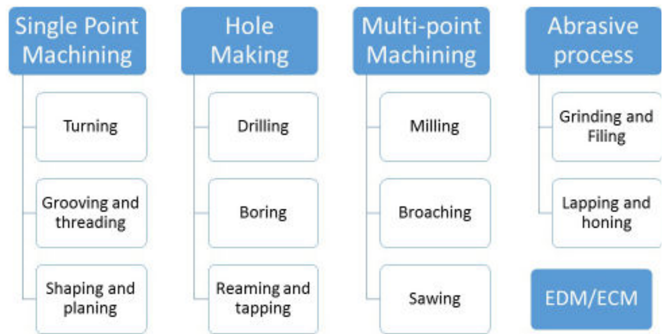

Figure 4: Metal Cutting Methods

Turning is a metal cutting process used to generate cylindrical surfaces. In radial turning, either the tool or the work piece is rotated while the other is held stationary, feeding one into the other, generally to face a work piece. An example of radial turning to face a work piece include an automatic pencil sharpener in which the blade spins as the pencil is fed into the blades. This process will generally result in concentric circles on the face. In axial turning, the tool works perpendicular to the work piece to shape it to a single diameter. Radial and axial turning can be combined to produce tapered and contoured surfaces. In woodworking, the latter two would be used to produce table or chair legs, for example. In either of these, the processes will generally result in light rings around the circumference of the work piece.

Johnson and Matty [31] published an article which clearly showed subclass characteristics present in three consecutively lathe-turned firing pins. At the same time, marks due to the chip formation process were also observed which were sufficient enough to distinguish among the three firing pins.

Grooving and threading involves the passage of a single cutting point over the surface of a rotating work piece several times to remove chips of metal with each pass until the grooves or threads are the desired depth. The tool will move linearly while the work piece rotates. For grooves, it will do so back and forth to cut a groove of the desired width. For threading, the linear movement will determine the lead of the thread. An example of threading is the process of machining threads into the ends of pipe nipples. This process will generally result in rings around the circumference of the worked surface.

A surface that is **shaped and planed** will involve a reciprocating motion between the tool and work piece. The purpose is to reduce planed or sculpted surfaces. For example, through this process a block of wood can be shaped into a letter of the alphabet. This process will generally result in parallel feed marks being left on the surface.

Drilling involves the use of a drill bit which is a rotary, multipoint, end cutting tool for the purpose of creating or enlarging holes in solid materials. The bit cuts by applying pressure and rotation as it is fed into the work piece which forms chips at the cutting edge. These chips are removed through the rear end of the bit via flutes, sometimes with the aid of lubricants.

Gun barrel drilling is a specialized form of drilling in which a cutting tip is placed onto the end of a large drive shaft. There are two basic types of gun drill: the internal chip removal type and the external chip removal type. The internal chip removal involves the use of a hollow shaft with a cutting bit on the front. Coolant is forced around the outside of the shaft, and pours around the front of the drill bit, forcing the chips through the hole in the tip, up through the shaft, and out. The external chip removal bit has a notch cut in the outside of the drill bit tip. Coolant is forced down through the hollow shaft, and forces chips to exit along the notch. Of the two, external chip removal is used more frequently in most gun barrel drilling applications.

Along the sides of a drilled hole, there will be irregular rings circling the long axis of the hole. They may be at angles and tend to be irregular with some ripping and tearing evident depending on speed and movement of the bit through the hole. When considering barrels and the travel of bullets down the bore, subclass characteristics with respect to tool marks left behind by the drilling process is not an issue. Two reasons exist for this. The first is that there are machining processes that take place after drilling (e.g., reaming and honing, among others) for the purpose of finishing the hole. The second reason is that should any drilling marks remain, they are very irregular and the travel of the bullet is generally perpendicular to those marks. Later in this discussion it will be shown how such movement, even if subclass characteristics were present, would not result in the subclass characteristics being transferred to the tool mark from drilling marks remaining on the inside of the bore.

Boring is the process of enlarging a hole that has already been drilled, by means of a rotary single-point cutting tool (or by using a boring head containing several such tools). The purpose is three-fold: sizing the hole to bring it to the proper diameter and finish; straightening the original drilled or cast hole; and to make the hole more perfectly concentric (concentricity). Drilling is not a very accurate way to produce long holes, so holes requiring critical sizing, straightness, and concentricity require further machining. Boring is one means by which a drilled hole is sized prior to rifling. Boring will result in the formation of tool marks similar to the drilling process. The discussion with respect to subclass characteristics and tool marks left behind from the drilling operation also applies here.

Reaming is a machining process that uses a rotary, multi-edged, fluted cutting tool to smooth, enlarge, and/or accurately size an existing hole. The tool is rotated as it is fed into the pre-existing hole until an area of the desired diameter, contour, and length has been cut. Principle support during the cutting action is obtained from the work piece. An example of a reaming process is the formation of the chamber in a pistol or rifle barrel. Along the sides of the reamed hole, there will be rings circling the long axis of the hole. They will tend to be more regular and uniform than those expected with drilling or boring. Reaming is another means by which a drilled hole is sized prior to rifling. The discussion with respect to subclass characteristics and tool marks left behind from the drilling and boring operations also applies here.

Tapping is a process for producing internal threads using a tool called a tap. The tap has teeth on its periphery to cut threads in a pre-drilled hole. It uses rotary and axial motion between the tap and the work piece with the axial feed determining the lead of the thread. This process will tend to leave circular marks on the thread surfaces.

Milling is a process of generating machined surfaces by progressively removing a pre-determined amount of metal or stock from the work piece using a milling cutter rotating at a relatively high speed. Milling can be used to face a work piece either flat or contoured, cut an internal or external slot, or remove a portion of a side, forming a ledge. For example, a combination of milling cutters can be used to form a single piece of metal bar stock into an extractor. Depending on the type of milling that is being performed, the tooled surface can have concentric circular marks (face or end milling) or straight and parallel marks (side milling).

Several reference articles are available with respect to milling operations [32, 33, 34, 35, 36, 37, 38 , 39]. In general, milling can result in the formation of subclass characteristics. At the same time, the referenced studies have also demonstrated that individual characteristics due to chip formation and tool movement can be present in the midst of the subclass characteristics. The authors of these studies do stress the importance of looking for marks due to chip breakage and abrasion, processes which leave their traces but can be more difficult to detect.

Broaching is used to machine internal and external surfaces such as circular, square, or irregular shaped holes, and gear teeth. It is accomplished using a broach, a tool having multiple cutting teeth, which is designed to accomplish the machining in one pass of the tool. Broaches can be a push or pull type. They are also classified as internal, to shape previously drilled holes, or external, for purposes of cutting a flat surface, also known as a surface broach. Broaching will result in straight and parallel tool marks in the direction of travel of the broach.

Numerous studies have been done with respect to broaching because of the number of different tool surfaces that can be broached, including rifling grooves in barrels (and lands in some Ruger barrels, as will be discussed below), sizing of drilled holes in barrels, breech faces, and jaws of pliers and wrenches [40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55]. In general, broaching can result in subclass characteristics. At the same time, numerous studies have demonstrated that individual characteristics due to chip formation and tool movement may also be present in the midst of the subclass characteristics. In addition, the length of the tool surface is important because, hypothetically, there could be more change expected in the cutter tool over a four-inch surface than the change expected over a one-half inch surface, for example.

One thing worth noting has to do with barrels that have been drilled and then sized with a broach instead of a boring/reaming operation. ***If present***, subclass characteristics from this broach-sizing operation will be present on the land-engraved areas of the bullets, an area that has long been regarded as free from subclass. In the report by Norris presented at the 46th Annual AFTE Training Seminar in Dallas, TX [56], he discussed how consecutively-manufactured Ruger pistol barrels that had been sized with a sizing broach showed significant subclass on the lands of the barrels and land-engraved areas of the bullets fired from those barrels. Norris stated that if all the bullets from the barrels were examined, they could be linked to the correct barrel. The reason is that the subclass characteristics were offset a bit from the shoulders from barrel to barrel due to a slight shift when the rifling broach was introduced after the sizing broach. This demonstrates the need for the examiner to have a critical eye, lest he or she dismiss the significance of this slight shift because of the level of similarity observed or assuming the shift is just an effect of deformation if the questioned bullet is damaged.

Sawing is a reciprocating action in which a blade having multiple teeth is used to cut a narrow slit (called a “kerf”) into the work piece, generally with the intent to remove or cut-off a portion of the work piece. Sawing will generally result in coarse, straight marks irregular in length, spacing, and direction, and thus these marks should be free of subclass influence.

Grinding is an abrasive process in which metal is removed from a work piece in the form of minute chips by the action of irregularly shaped abrasive particles. Important considerations include the abrasive type, the grain size, the structure or density of particle distribution, and the bonding type which is the manner in which the abrasive is bonded to the surface of the grinding tool. As the grinding process takes place, not only may abrasive particles break off, but spaces between the particles may be filled by substrate particles both of which constantly change the character of the cutting surface. Grinding results in marks that are straight and irregular in length, spacing and direction with studies demonstrating that the process results in individual characteristics with no subclass influence [57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67]. However, occasionally, under the right circumstances (e.g., a relatively soft substrate vs. a hardened grinding tool working surface), grinding marks can be reproducible, and thus a potential source of subclass characteristics [68].

Filing is a similar process to grinding except that the abrading surface is more fixed than the surfaces used in grinding. While abrasive particles may not break off as readily as in grinding, particles of the substrate can fill in spaces between the raised areas of the filing surface. In addition, filing operations are done primarily by hand, which lends to the individuality of the resulting tool marks. Filing results in marks that are straight and irregular in length, spacing, and direction. Studies have demonstrated that filing results in individual characteristics with little to no subclass influence [69,70].

Lapping is a final abrasive finishing operation which produces extreme dimensional accuracy, corrects minor imperfections in shape, and refines or polishes the surface finish. It is often used to produce a close fit between mating pieces. Lapping uses loose abrasive material in a liquid “vehicle” or substrate. This process will tend to result in very fine, irregular scratches on the final work piece.

Honing is a final abrasive finishing operation which is a low-velocity abrading process. The removal of the material is accomplished at lower cutting speeds, reducing heat and pressure. The advantage is that excellent size and geometry control can be gained. Honing is accomplished using a mandrel with mounted abrasive sticks and is commonly used to finish internal cylindrical surfaces. Honing will generally result in a pattern of crosshatching lines, each at an angle to the long axis of the hole, due to the rotating and reciprocating action of the tool.

Lapping and honing are often used after drilling and sizing (reaming) of the hole in a gun barrel. The marks left by these two processes tend to be relatively fine. In addition, these finishing processes do not entirely eliminate other marks in the bore. When combined with the movement of the bullet across the surface of any lapping and/or honing marks left in barrel, there is no expected subclass potential.

There are two types of **electro machining**, electro discharge machining (EDM) and electro chemical machining (ECM). While metal is technically not cut away in either process, the processes are closer to being cut than formed. In EDM, the desired shape is obtained using recurring electrical discharges between two electrodes (the tool serving as one and the work piece serving as the other) separated by dielectric liquid and subjected to an electric voltage. The tool does not touch the surface; cutting is accomplished using electric sparks to vaporize and melt undesired/excess material away. EDM is also referred to as spark machining.

ECM is very similar to EDM except that a conductive fluid (the electrolyte) is responsible for cutting the work piece, not electrical sparks. The fluid literally eats away (or dissolves) the excess metal, leaving the desired surface. Either process generally results in a surface that is irregularly pebbled.

There are several advantages to using electro machining. They include:

- The ability to cut complex shapes that would otherwise be difficult to produce with conventional cutting tools
- The ability to cut extremely hard material to very close tolerances
- The ability to cut very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure
- Delicate sections and weak materials can be machined without distortion because there is no direct contact between the tool and work piece
- A clean surface finish can be obtained without further finishing needed
- Very fine holes can be easily drilled

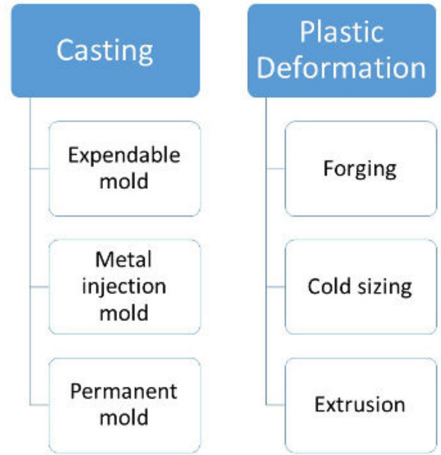

Figure 5: Metal Forming Methods

As discussed, electro-machining is used for the manufacture of bunters. In addition, it can be used to impart rifling into a barrel. Because of the manner in which electro-machining takes place and the tool marks left behind, subclass characteristics are not anticipated and published studies support this [71, 72, 73, 74].

Metal Forming

Metal forming is simply reshaping the work piece into the desired shape or configuration. There are two basic groupings of metal forming processes. The first is casting; creating a work product through the use of a mold. The second is plastic deformation which occurs when metal is forced under tremendous pressure to be reshaped. **Figure 5** highlights the various metal forming processes within each group.

Expendable mold casting (sometimes referred to as investment casting or the "lost wax" process) is when a mold is created from a positive wax mold of the desired work product. Multiple wax positives are generally linked using a sprue so that multiple pieces can be made at the same time. The wax positive is coated with layers of a sand mixture which will serve as an expendable mold. Once the mold is prepared, the wax is melted away leaving a cavity. Molten material is then poured into the mold cavity and, when sufficiently hardened, the piece is freed by breaking apart the mold. If several pieces are linked by a sprue, they will be cut away and cleaned. Except for the possible presence of remnants of a previously attached sprue, there is little that distinguishes an item as having been produced by this method apart from pre-existing knowledge and the lack of other tooling processes.

Expendable mold casting is commonly used by Ruger for the manufacture of their revolver frames. Ruger calls this process investment casting. There was a report of it being used for the manufacturer of a frame and barrel [75]. The report was brief but an examination of the photograph in the article depicting the rifling in the bore indicated that subclass characteristics would not be a concern when coupled with the movement of the bullet down the bore.

Permanent mold casting uses a mold that has been created through a machining process in which the cavity has either been cut (see metal cutting above) or formed from a replica of the desired work product. These molds are permanent in that they are generally very durable and can be used multiple times to create multiple work products. A common mold would be for the production of lead bullets in which lead is melted and then poured into the cavities in the mold block. The process of permanent mold casting generally leaves traces of flashing; in the absence of flashing one may observe mold marks from the mold seams [76, 77]. Depending on how the mold cavities are machined, it is possible that consecutively machined cavities may have subclass characteristics which might preclude the identification of a cast bullet to a particular cavity.

Another type of permanent mold casting is **metal injection molding (MIM)**. Using heat, metal powders are mixed with binders to form a mixture in which every metal particle is uniformly coated. The mixture is cooled and granulated to form the feedstock for the injection molding machines. The feedstock is fed into the injection molding machines where heaters melt the binder to a toothpaste-like consistency and push it into the mold. These molds are commonly produced using electro-machining and, depending on the part being molded, can serve to mold an average of 250,000 pieces [78]. Once cooled, the piece is ejected from the mold. Any excess material is removed and recycled. The molded part is still not complete because it contains both the original metal and binder material. The binding material is removed through a process of de-binding and sintering. In de-binding, a fixed amount of binder material is removed either thermally or chemically. The remaining binder is removed through a sintering process in which the piece is placed in a furnace and heated to within 85% of the metal's melting temperature. The remaining binder is removed and the metal particles fuse together, shrinking to form a solid metal part that is 98% dense and meets the desired design specifications. If necessary, the part can be further processed through machining, plating, heat treating, polishing, etc. Similar to permanent mold casting, traces of flashing or mold marks from the mold seams may be visible. Commonly encountered metal injection molded parts are firing pins and ejectors.

Concern over the possible presence of subclass characteristics appears warranted in the case of tools manufactured using metal injection molding. In a published report by Hunsinger on Smith & Wesson firing pins, she reported that while there were similarities from firing pin to firing pin, a careful examination precluded a misidentification because when the potential subclass were positioned appropriately, other marks fell out of alignment [79]. This could be due to the shrinkage of each firing pin during de-binding and sintering, causing a shift in the alignment between marks from the mold surface. However, Kramer reported no such distinction in his brief report where firing pins from two Smith & Wesson Sigma series, .40 caliber pistols and one firing pin from a Smith & Wesson MP Series 9mm Luger caliber pistol displayed subclass characteristics [80]. A study in which test fires from 1,260 Smith & Wesson M&P Series, 9mm Luger pistols were compared showed the potential presence of subclass characteristics on a number of firing pins that extended into the resulting firing pin drag marks as well [81]. However, the striated shear mark at the 6 o'clock location produced by a milled area on the breech face below the aperture (designed to facilitate primer movement out of the firing pin hole during extraction and ejection) showed no potential subclass characteristics.

Thompson published what appeared to be a case study that examined the breech face of a Taurus revolver in which the frame was manufactured using metal injection molding [82]. Based on information he received from the factory, Thompson believed that the subsequent bead blasting treatment was not only responsible for the pebbly appearance on the breech face, but would also eliminate any potential subclass influence from the metal injection molding process. Concerns with this conclusion exist for two reasons. The first question is how the molds were produced and whether the texture on the inside surfaces of the molds were pebbly. The second has to do with how much individuality was imparted onto the breech face surface from the bead blasting process. Thompson references the published work of Coody [83] in support of this individuality and other published work supports this assertion as well [84]. However, considering the work of Winn [85], it is unknown how much of the metal injection molded breech face was impacted by the bead blasting without further study.

There are a number of manufacturing processes that implement forging in one form or another. **Drop hammer forging** is used to produce many tools such as wrenches and handles for pipe wrenches, bolt cutters, and slip joint pliers. In drop hammer forging, a metal cylinder or rod called a billet is heated and sequentially placed in a series of progressively-detailed dies; the billet is struck by a hammer exerting tons of force, which compresses the billet into the die cavity, forming it to the desired shape. The first die is a roughing die, to form an overall shape. Sequential dies are then used to continue to refine the shape until the finished product is produced. Any flashing is trimmed away or removed as necessary, which can sometimes leave subclass characteristics in the form of trimming die marks (such as on the sides of flat screwdriver blades) [86]. Depending on the die design, the tool may have an elongated mark from the seam where the dies came together. Depending on the tool, further finishing might be needed, such as broaching the jaws of pliers and wrenches.

Cold hammer forging is a common process used to rifle barrels and involves the use of a mandrel that has the desired rifling pattern on its surface. The mandrel is fed into an already drilled and sized barrel, which is positioned between opposing hammers. The hammers rapidly forge the barrel onto the mandrel as one or the other is rotated and moved linearly such that the barrel gains the rifling characteristics of the mandrel. The grooves of the mandrel will serve to form the lands of the barrel and the raised areas of the mandrel will serve to form the grooves of the barrel.

Typically, cold hammer forging simply polishes the tool marks already on the surface of the bore from the hole-making processes without introducing tool marks of its own. This would seem to alleviate the concern of subclass characteristics because the resulting striations imparted to the surfaces of the land and groove engraved areas on fired bullets from a newly hammer-forged barrel would, in theory, be created by the remaining tool marks from the drilling and boring/remaining operations. Two published studies discuss observations made with manufactured hammer-forged barrels [87, 88].

At the same time, subclass characteristics have been reported for hammer-forged barrels on the lands of the barrels [89]. The reason for this is that grooves on the mandrel (which correspond to lands in the bore) are cut using a diamond cutter. Due to the hardness of the diamond cutter, it can leave elongated striations in the mandrel groove which can be transferred to the land surfaces of the barrel. Depending on how quickly the diamond cutter changes between cutting the grooves on the mandrel (which may not be very quickly, due to the relative hardness of diamonds compared to the mandrel material), subclass characteristics can exist in adjacent grooves on the mandrel which would correspond to adjacent lands in the bore.

Cold forming and **stamping** are processes by which barrels can be sized and inserts for breech faces can be formed. Reports have indicated that there is potential for subclass characteristics in these instances, although they are not necessarily present each time [90, 91, 92, 93, 94, 95, 96, 97]. Even in instances in which subclass characteristics were present, individual characteristics could also be present.

Cold sizing is a common means by which manufacturers impart rifling into the bore of a barrel using a "button". A rifling button is a double-tapered metal plug with the widest diameter in the middle of the piece. This part of the plug also contains the desired rifling pattern on its surface. The plug is pulled through a prepared bore while being rotated at the desired twist rate of the rifling; the rifling is formed by moving and displacing the metal (a process called "swaging") with the button as it passes through the bore.

Like cold hammer forging, cold sizing generally polishes the tool marks already on the surface of the bore from the hole making processes without introducing tool marks of its own. An imperfection on the button can result in elongated marks along the groove surfaces of the bore, parallel with the rifling. However, this is not necessarily common and several studies have reported on the lack of subclass characteristics present on bullets fired from button-rifled barrels [98, 99, 100, 101, 102, 103, 104].

Bead blasting is a common means to smooth and finish a surface machined by other methods. While at times it can scratch away metal or be used to remove flashing, it most often pounds the metal, softening the coarseness of any cutting type tool marks that may be present. Bead blasting can result in tiny scratches or a slightly pebbled surface; the size of the pebbling dependent on the bead size. Studied in conjunction with other manufacturing processes already mentioned, bead blasting has been reported to impart individual marks. However, the level of individuality can vary depending on many variables and it should not be assumed that in all instances bead blasting or other similar finishing processes will eliminate all subclass characteristics if present.

Extrusion is a process by which objects having a fixed cross-sectional profile are produced. The material, which can be either hot or cold, is pushed or pulled through a die having the desired cross-sectional profile. Extrusion can be continuous, producing a single long piece, or semi-continuous, producing multiple pieces. Items commonly formed through extrusion include copper wire and plastic pipe. This process will leave straight lines from the dies as the material is pushed or pulled through the die. These lines will be long and continuous, changing when the character of the die changes as a result of wear or accumulation of substrate as it passes through the die.

Depending on the final finishing that is employed on any given work product (tool), tool marks from the manufacturing process used to produce that tool can generally be observed on the tooled surface(s) of the tool. It has been demonstrated through a review of the manufacturing processes, published research, and reports that while subclass characteristics may be present in tool marks encountered in casework, their presence is generally not to an extent that precludes examiners from correctly identifying a questioned tool mark back to the tool that created it.

Tool-Substrate Interaction

As mentioned previously, the manufacturing process is but only one factor to consider when evaluating whether or not a tool mark may have subclass characteristics. It is possible that even if subclass characteristics were present on the tool surface that they would not be imparted into the tool mark produced by that tool. The reason for this has to do with the manner in which the tool interacts with an object. **Figure 6** represents a small section of a tool's working surface that has been cut using a broach, which, as previously discussed, is a manufacturing method that has been linked to subclass characteristics.

There are three different manners in which this surface may interact with a substrate:

- The working surface or the substrate may move parallel (in the same direction) as the striations (Red Arrow)
- The working surface or the substrate may move at an angle across the striations (Green Arrow)
- The tooled surface may simply be impressed onto the surface of the substrate (Black Arrow)

If the movement is parallel to the striations, there is a possibility that any subclass characteristics that are present on the tool may transfer onto the substrate. The reason is because the only factors impacting the formation of striations on the substrate are the distance between the peaks and the depth to which the peaks dig into the surface of the substrate. The resulting striations in the substrate will tend to be relatively thicker, longer, and continuous, with consistent and almost predictable spacing. Depending on the tool manufacturing method, these may not be very discriminating factors from tool surface to tool surface.

However, if the movement is at any angle to the striations, there will be minimal subclass influence in the resultant tool marks, even if subclass is present on the tool surface. The reason is that as the tool and substrate move against each other, it is the combination of the irregular topographies of the individual peaks in the striae that produce the striations observed on the substrate. As can be suspected from looking at the diagram, the resultant striations will likely be finer, irregular and changing over the course of the interaction.

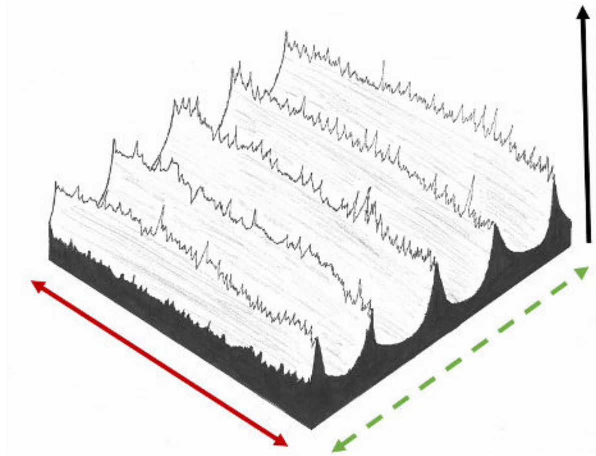

Figure 6: Three-dimensional view of striated tool marks on a tool working surface (peaks along ridges, representing individual characteristics, are exaggerated for illustration purposes)

This also helps to provide support for the fact that tool marks can change from interaction to interaction because these topographies can be rather fragile and accumulation of substrate particles can take place on, within, and in between the peaks. This concept is highlighted in the work performed by Moran when he examined the subclass potential on the lips of ammunition magazines [105].

Finally, if the tool surface is simply impressed into the substrate, there is a high likelihood that any subclass characteristics that are present will be reproduced in the substrate. The reason is because there is no significant interaction that would cause anything but a replica of the tool surface to be impressed into the surface of the substrate.

PART THREE

Evaluating Tool Working Surfaces and Tool Marks for the Presence of Subclass Characteristics

Having a tool provides the firearm and tool mark examiner with the best opportunity for determining whether or not subclass characteristics are present. An examination of the tool working surface coupled with an understanding of the tool substrate interaction will permit an examiner to make an appropriate conclusion as to whether or not subclass characteristics will be a potential issue in the examination.

Evaluation of the Tool Working Surface for the Presence of Subclass Characteristics

The evaluation of the tool working surface has three components:

- The first is the determination of the manufacturing method because the potential for subclass characteristics is directly related to how the tool's working surface is manufactured.
- The second is an evaluation of the markings to determine whether or not they might be subclass characteristics. Although a particular manufacturing method may result in subclass characteristics, it does not mean that subclass characteristics exist on the tool.
- The third is to evaluate the surface for marks appearing to be either unrelated to the manufacturing process (e.g., damage, wear, corrosion, etc.), or due to chip breakage or other tool movement from the manufacturing process.

Component One – Determination of the Manufacturing Method

Based on the tool marks that are present, the surface being examined, and a knowledge of typical manufacturing methods, it is possible to determine the manufacturing method used to finish a given tool working surface. One simply has to evaluate the marks observed and work backwards, given a knowledge of manufacturing methods and the types of marks that they would produce, as detailed in the second part of this paper.

An example of such an evaluation is offered using the cast breech face from an H&R Standard, 32 S&W caliber revolver (**Figure 7**). The tool marks are straight and have irregular spacing, length, and directionality. This would tend to indicate that the finish was filed or ground, a finish that is not usually influenced by subclass characteristics.

Component Two – Evaluation of Tool Marks to Assess for Presence of Subclass Characteristics

The second component in the evaluation of the tool working surface is to determine whether or not subclass characteristics are actually present. Simply because a method is linked with the potential for producing subclass characteristics does not mean that it does produce subclass in every, or even most, instance(s). The key in determining this lies in the definition of subclass characteristics. By definition, the marks have to be reproduced in their entirety on another tool. For striated tool marks, this means that the striations have to persist throughout the entirety of the tool mark.

Figure 8 is a diagram of a breech face that has been cut by a broach. The striations marked with the red arrows are continuous along the full length of the broach marks. It is possible, therefore, that these same marks could have also been produced on the previously cut or subsequently cut

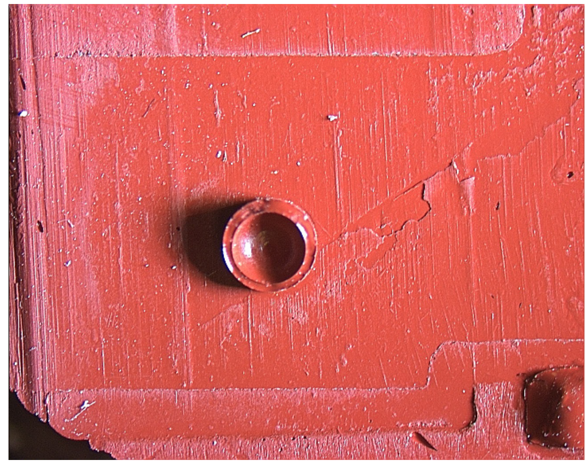

Figure 7: Cast of breech face of H&R Standard, 32 S&W caliber revolver

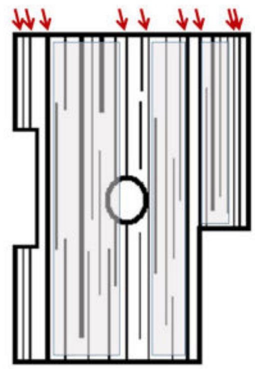

Figure 8: Diagram of a breech face that has been cut using a broach

breech face(s). The remaining marks, enclosed in the shaded areas, are not continuous, which means that chip breakage is happening or the tool surface in that area is changing. Regardless of the reason, the discontinuity eliminates any opportunity for subclass reproduction of that mark. In this particular model, there is a combination of individual and possible subclass characteristics present on the same surface. The individual characteristics (starting and stopping points of the discontinuous striae) can be used for identification; the possible subclass toolmarks cannot.

However, in order to accurately evaluate the subclass potential of a machined surface using the method described above, the striae that run to the opposing edges of the surface must be the product of a continuous tooling operation (e.g., a single pass of a step broach that contacts the entire machined surface from one edge to the other) that includes the specific working surface of interest (e.g., the area immediately surrounding a firing pin aperture in the middle of a breech face would be the working surface of interest if the individuality of aperture shear marks were being evaluated). If a secondary tooling operation was performed on the working surface that produced a shorter run of parallel striae in the area of interest (i.e. the secondary tool did not contact the workpiece from edge to edge, as the primary tool did), comparing only the parallel striae at the opposing edges of the machined surface would not alert the examiner to potential subclass in the area of interest if it was assumed that all of the parallel manufacturing marks on the surface were homogenous. **Figure 9** is a diagram demonstrating this secondary operation marked by the arrow that has subclass characteristics even though the tooling operation for the breech face did not result in subclass characteristics. In a situation such as this, due to the short and continuous nature of the tool marks, it cannot be assumed that the pattern of striae resulting from the secondary tool operation will not appear similarly on another working surface and therefore must be treated as potential subclass characteristics. Although such a secondary patch of tool marks is not expected on some working surfaces (e.g., gun barrel rifling, the parallel striae of which are typically produced with a single-pass tooling operation), other relatively larger, flatter surfaces (such as the area around firing pin apertures on some breech faces) may not be as straightforward. Therefore, a careful assessment of the potential origin of tool marks on a given working surface is essential prior to evaluating them for subclass carryover.

It can be difficult, at times, to assess whether or not a particular striation is long and continuous. This is especially the case when the tool working surface is elongated and there is an abundance of tool marks present along the surface. **Figure 10 (top)** depicts a cast of a portion of a land in a Bryco, 32 Auto caliber pistol with a 2-1/2 inch barrel rifled with a left twist. An examination indicates that there are many striations that are not long and continuous while others appear that they might be. One way to determine whether or not they are, is to cast the breech and muzzle ends of the barrel and compare them to see what, if any, toolmarks persist from one end of the barrel to the other. **Figure 10 (bottom)** depicts this comparison. There are some tool marks in the center area of the land that appear long and continuous, but away from this center portion the marks are discontinuous, which reflects the absence of subclass characteristics in these areas. Marks that are determined to be long and continuous have the potential to be subclass characteristics and therefore cannot be used for identification purposes. A cast of these continuous marks can be compared with test-fired bullets to determine if the marks in the barrel correspond to specific striae on the bullets. If they do, these striae must not be relied upon for identification when comparing test-fired and questioned bullets.

Continuity also applies to concentric circular marks produced by a milling operation. To determine whether or not the marks are continuous, two casts of the surface can be prepared and compared 180 degrees apart. Any marks that do not correspond would not be subclass characteristics.

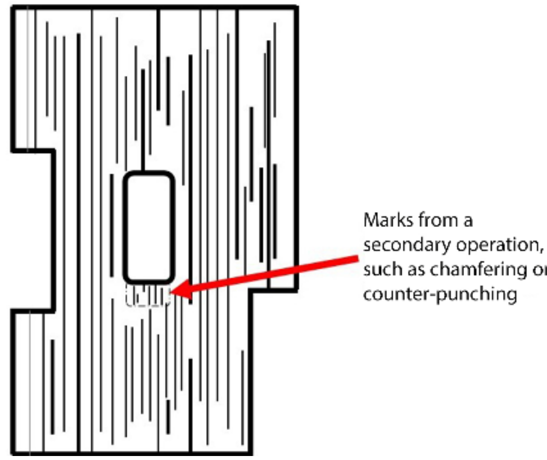

Figure 9: Diagram of a breech face cut with a broach and having a secondary tooling operation

Figure 10: (Top) Cast of the middle portion of a land in a Bryco, 32 AUTO caliber pistol; (Bottom) Comparison of casts of muzzle (left) and breech (right) ends of a land in the Bryco, 32 Auto caliber pistol

For non-striated markings, an evaluation for the actual presence of subclass characteristics is more challenging.

Anything that would appear associated with repetitiveness, such as mold marks or regular seam marks, would have to be approached with caution. In addition, it may be difficult to discern whether or not some features could be reproduced from a permanent mold master (such as in metal injection molding) because that master could have a small, irregular imperfection on it. However, these marks typically would be found near the edge of the mold pieces. The examiner should be familiar with the various manufacturing processes and remember that many of these parts are machined individually. For example, firing pins are machined apart from breech faces which are machined apart from chambers. As a result, cartridges and cartridge cases have a variety of individually machined tools interacting with them as them as they are chambered, fired, extracted, and ejected, or in the case of unfired cartridges, as they are worked through the action and ejected. For this reason, multiple regions of interest should be examined to help avoid misidentifications attributed to subclass characteristics [106].

Component Three – Evaluation of Other Miscellaneous Marks

In an article dealing with consecutively machined Ruger bolt faces, Lopez and Grew determined that while the milling process did result in subclass characteristics being imparted onto the consecutively machined bolt faces, there were other marks that they classified as abrasion and chatter marks that could be used to differentiate the bolt faces [107]. These marks are caused by vibrational movement of the milling tool as well as chip breakage; therefore, they will not be reproduced as subclass characteristics.

Other marks unrelated to a machining process may be observed on the tool. This can include damage to the working surface, including nicks or abrasions, chips in any plating on the working surface, and particles that have accumulated on the surface which cause a change in the original working surface of the tool. **Figure 11** is an example of accumulated damage over the course of use. The concentric circular marks observed on the cast breech faces are the result of milling. The broader, slightly downward-arcing marks designated by the arrows are due to the edges of cartridge case rims striking the breech face during loading and chambering. This is accumulated damage over the life of a firearm that can be used to correctly associate a tool mark to the tool that made it.

Tool-Substrate Interaction

Once the three components of the tool surface examination have been addressed, if necessary, the interaction between the tool and the substrate to produce the tool mark is determined. As previously discussed, it is possible for a tool working surface to have subclass characteristics which may not reproduce in tool marks made by that surface. The diagram in **Figure 6** and accompanying discussion clarified why that is the case.

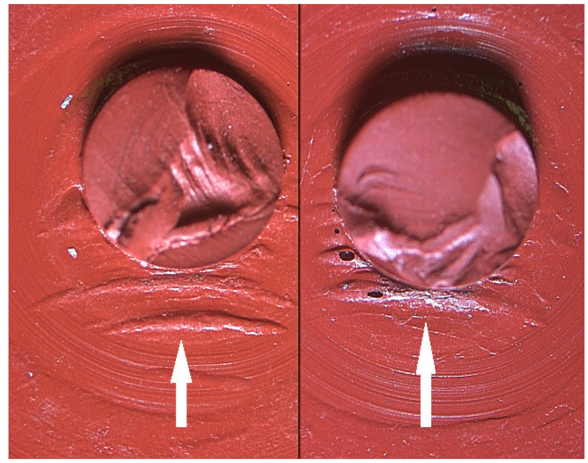

Figure 11: Comparison of two different breech faces, each milled.

The simple diagrams in **Figure 12** again illustrate how a tool with subclass characteristic potential may not produce a striated tool mark containing subclass characteristics. When the tool or substrate moves in a motion parallel to the subclass characteristics on the tool (downward arrow), the subclass may be reproduced in the resulting tool mark because some or all of the striations in the mark are produced by the position and surface features of the subclass characteristics. However, if the motion of the tool or substrate is at a perpendicular (horizontal arrow) or oblique angle to the length of the subclass characteristics, then the resultant striations in the tool mark will be formed by a combination of the topographies of the individual and subclass characteristics.

Finally, it is also important to understand which surface of the tool is producing the tool mark. In an article discussing the subclass potential of ten consecutively-manufactured extractors that had subclass characteristics present on multiple sections of the extractors, this author determined that the subclass characteristics did not impact the final marks on fired cartridge cases because the marks were produced by the corner of two independently machined surfaces [108]. While the adjacent surfaces may each have subclass characteristics, the corner of those surfaces was very irregular and produced striations that were not influenced by the subclass characteristics. This same general concept applies to firing pin aperture shear marks *if the edge of the firing pin aperture (hole) is irregular and meets the breech face at a 90-degree angle*. However, if the edge of the corner formed by the adjacent 90-degree surfaces is very smooth

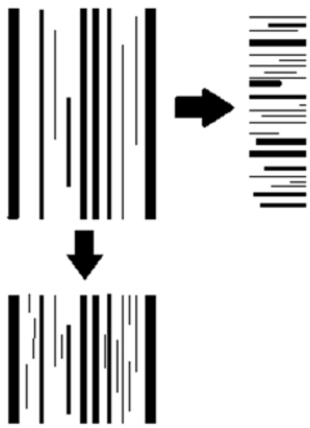

Figure 12: Tool-substrate interaction

(not irregular), subclass characteristics may be imparted to a tool mark produced by this edge if parallel manufacturing tool marks with subclass influences exist along the smooth edge on either of the adjacent surfaces. Subclass-influenced firing pin aperture shear marks have been recently shown to be produced in this manner [109]. Some firearms have an area underneath the firing pin aperture that has been chamfered, serving as an angled transition between the aperture and the breech face to help facilitate the movement of the primer material out of the aperture. This chamfered area may have subclass characteristics from the machining process used to create the chamfer (**Figure 9**).

Evaluation of Tool Marks in the Absence of Tools for the Presence of Subclass Characteristics

The challenge is much greater when evaluating tool marks for the possible presence of subclass characteristics in the absence of a tool. There are several reasons for this. The first is that the determination of a specific tool type may not be possible based on the tool marks alone, which makes a determination of the manufacturing process very difficult. A second is that tool marks are not necessarily representative of the whole tool surface and what may be an individual characteristic on a tool surface could appear as a potential subclass characteristic in a tool mark. Finally, subclass characteristics can mimic individual characteristics very well and without the responsible tool, it can be difficult to discern individual tool marks versus those with subclass influences.

The keys to successfully evaluating tool marks for the presence of subclass characteristics include all of the following:

- Having a good knowledge of manufacturing methods
- Understanding how subclass characteristics would appear on the tool working surface
- Understanding the source of the tool mark – includes tool/substrate interaction
- Looking for other marks that appear unrelated to the manufacturing process but incidental to damage or wear
- Being conservative when in doubt

This evaluation is especially critical when the examiner is being asked whether or not tool marks can be traced to the same tool, absent the tool being present. Commonly this is requested for cartridge cases and/or bullets recovered from crime scenes. Less often, an examiner may be asked to determine whether non-firearm-produced tool marks were made using the same tool. These frequently encountered situations will be addressed in turn.

Cartridge Cases

Fired cartridge cases are a rather unique type of firearms-related evidence because during the cycle-of-fire process a number of different tool surfaces are acting upon the cartridge case; some related to the firing process and others unrelated to the firing process. Examples of the former include the firing pin, breech or bolt face, the chamber, and the outline of the firing pin aperture - resulting in firing pin impressions, breech face marks, chamber marks, firing pin aperture outlines, firing pin drag marks, and firing pin aperture shear marks, respectively. Examples of marks unrelated to the firing process include the magazine lips, extractor, and ejector - resulting in magazine marks, extractor marks, and ejector marks. Each of these has to be evaluated independently and it is important to differentiate between firing and non-firing marks so that the appropriate conclusions can be reported.

Each region of interest (ROI) present on a fired cartridge case should be evaluated according to the following scheme:

- How is the specific tool surface responsible for the ROI manufactured?
- Which of the manufacturing methods is possible given the observed tool marks in the ROI?
- Given the manufacturing method and the tool-substrate interaction, is there a potential for subclass characteristics?
    - If no, continue with comparison or another ROI evaluation as needed
    - If yes, continue with scheme
- Evaluate ROI further:
    - For impressed striated marks, subclass characteristics will be long and continuous throughout the ROI; look for non-continuous marks along with other isolated markings that may be due to chip formation,

vibrational movement of the tool, or appear to be unrelated to the manufacturing process.

- ◦ For non-striated impressed marks, further evaluation of the ROI may not be helpful depending on suspected manufacturing methods; it will be especially important to look for marks that appear unrelated to the manufacturing process.
- ◦ Given a further evaluation of the ROI, is there a potential for subclass characteristics?
  - – If no, continue with comparison or another ROI evaluation, if needed
  - – If yes, continue with another ROI

Some keys to remember with respect to the evaluation of ROI on fired cartridge cases:

- Marks produced by a corner of two independently machined surfaces will generally not have subclass influence. At one time, one could cite a firing pin aperture shear mark as a clear example of this. These marks occur when primer material is dragged downward against the bottom corner of the firing pin aperture as the barrel drops in a recoil-operated firearm. However, as mentioned, some manufacturers are chamfering this area underneath the aperture so that the aperture and breech face no longer meet at a corner. Additionally, if the bottom edge of the aperture is very smooth, any subclass characteristics that may exist on the breech face in the form of parallel striae along this edge have the potential to be transferred to any primer shear marks created by this area [109]. So, while a firing pin aperture shear mark is likely to be free of subclass characteristics, in the absence of a firearm, it cannot be assumed to be *completely* free of subclass characteristics.
- Impressed, striated marks have a potential for subclass if the part has been turned, milled, or broached, especially if the part being machined is relatively small.
- In a recoil-operated firearm, the firing pin drag is formed by movement of the face of the firing pin against the primer material as the barrel drops. If the left and right half of the drag (with the mark oriented at the 12:00 position) appear as mirror images of one another, the examiner is cautioned that the striated marks may be due to the spacing of concentric circles on the face of the firing pin, which would be indicative of subclass characteristics. An example of this is illustrated in **Figure 13**.
- Metal injection molding may be difficult to discern in an ROI and is being used to manufacture firing pins, extractors, and ejectors; therefore, it is important that the whole of the cartridge case be evaluated as suggested by Bonfanti and De Kinder [110].

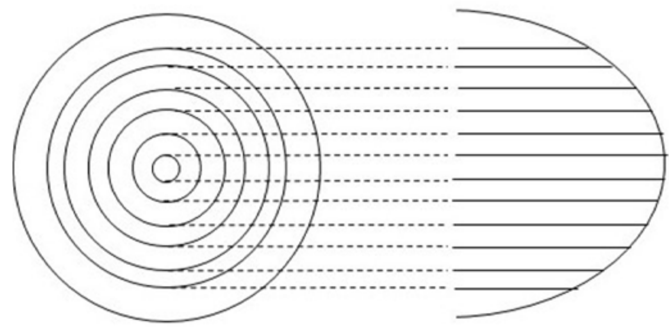

Figure 13: Firing pin drag with subclass from concentric circular marks

Bullets

In the absence of a firearm, the examiner has been strongly cautioned against making an identification based on correspondence in the groove engraved areas of bullets only. This is due to the possibility of subclass carry-over from a cut rifling process such as broaching. As discussed, regardless of the manner in which a barrel was rifled, it was believed that, at the very least, the land engraved areas of the bullet would be free of subclass influence. However, the assumption that land engraved areas on bullets will not be influenced by subclass characteristics cannot be fully relied upon without exception. This was discussed earlier but will be repeated in more detail.

There are two notable instances in which subclass characteristics have appeared on land engraved areas and the examiner is cautioned about each. The first involves hammer-forged barrels manufactured by Ruger [111]. It was observed that on adjacent land engraved areas of the same bullet, there was a significant amount of agreement of striations. As a result, if two bullets were being compared with another, one could be held stationary and the other rotated, allowing an examiner to potentially identify a number of land engraved areas on the rotated bullet as being made from the same land on the other bullet. As discussed, these barrels were hammer-forged and when one considers how the mandrel is manufactured (each groove on the mandrel being cut sequentially by a diamond cutter) one can understand how subclass characteristics would be produced on the adjacent lands in a hammer-forged barrel. The key to discerning this on questioned bullets without the responsible barrel is that the subclass characteristics will be reproduced on adjacent land engraved areas of the bullet. It is emphasized that not all hammer-forged barrels will exhibit this phenomenon.

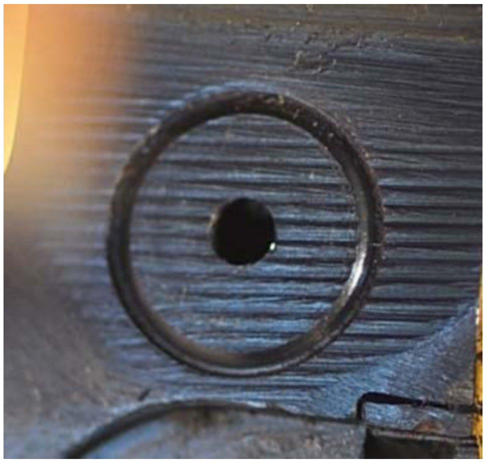

Figure 14: Colt Model Police Positive 32 Colt New Police Caliber (courtesy of J. Justine Kreso)

The second involves barrels that have been sized after drilling using a sizing broach rather than a boring or reaming operation. Typically, the barrel will be drilled and then sized using a sizing broach on the very same machine on which it will be rifled. This means that the sizing broach will have the same angle of twist as the rifling. In a recently reported study, consecutively manufactured Ruger barrels that had been drilled and sized with a broach showed significant subclass carry-over on the lands of the barrels [112]. Two things are noted regarding the appearance of these characteristics on fired bullets. The first is that the striations in the land engraved areas generally persist from the heel of the bullet to the ogive. The second is that the subclass characteristics tend to be offset from barrel to barrel such that they are not necessarily the same distance from the shoulders on consecutively manufactured barrels. Indeed, the researcher did suggest that one could distinguish bullets fired from each barrel to the exclusion of the other barrels provided if one had the entire set to examine. Much of this was based on the slight offset from the shoulders of the subclass characteristics. However, this condition cannot be met in most case situations.

Non-Firearm-Produced Tool Marks

The key to understanding the potential for subclass characteristics lies in the determination of the type of tool that made the tool marks. Following that is an understanding of the tool-substrate interaction. While the number of tool manufacturing processes is relatively small compared to the number of different tools that could be represented in a crime scene, the variety of tools, the manner in which they can be used, and the type and size of the tool mark that is left can make the determination of subclass characteristics quite difficult.

For example, there are a number of different tool surfaces that are ground, including knife blades, the cutting edges of axe heads, chisels, and blades from various cutters including scissors and side cutters, both single-edge and double-edged. They can be used to cut, pry, stab, or pierce, or a combination of more than one. For example, a blade from scissors can be used to pierce a rubber hose and then turned to enlarge the hole. While a knife blade can be used to cut a piece of wire, so too can a single blade from scissors. A cut tool mark can be relatively small with respect to a tool cutting blade, which could have a potential impact on the interpretation of the potential for subclass characteristics in the tool mark.

For these reasons, tool marks associated with things other than cartridge cases and bullets can be more difficult to assess and need to be addressed on a case-by-case basis using the principles and cautions discussed in this paper. For example, one of the repeated concerns throughout this discussion is that an examiner should approach impressed striated marks with caution because of the potential for cutting methods to result in subclass characteristics along with no significant tool-substrate interaction. Other potential clues as to the potential of subclass characteristics include repeating patterns of striae spacing. Although **Figure 14** shows a tool mark related to a firearm (breech face), it serves to illustrate this concept.

Given the variety of potential combinations of tools and tool-substrate interactions that could be responsible for some tool marks, examiners are cautioned to be critical in the interpretation of these tool marks and seek to have a full appreciation for the type of tool involved in their formation. See page 684 of reference 4 for proposed wording that could be used for these types of conclusions."

Conclusions

Subclass characteristics are of concern to a firearm and tool mark examiner because they can potentially mimic individual characteristics. If present and not adequately addressed, subclass characteristics can result in the incorrect association of tool marks as having been produced by the same tool.

Subclass characteristics are directly related to the manufacturing process by which a tool was created and finished. Not all tool manufacturing processes result in subclass characteristics being present on a tool working surface. Furthermore, even though a process has the potential to result in subclass characteristics being present on a tool working surface, this does not mean that it will.

In addition to the manufacturing process by which a tool working surface was finished, the interaction of the tool with the substrate will impact whether any subclass characteristics that are present on the tool working surface will be imparted to the tool mark. When there is movement at any angle (other than parallel) to subclass characteristics that are present on the tool working surface, then that subclass influence will not be transferred to the resulting tool mark.

Given the importance of subclass characteristics, it is important to make a purposeful and deliberate examination of the tool working surface of any tools submitted in casework so that it can be determined whether or not subclass characteristics are actually present and, if so, how they might impact the examination. Proper evaluation of the tool working surface includes a determination of how the tool was made, whether or not subclass characteristics are actually present, and what marks exist on the tool surface unrelated to any subclass characteristics that may be present. In addition, it is important to assess how the tool marks to be compared were made to determine if the interaction between the tool and substrate would have negated any potential subclass influence on the tool working surface.

The evaluation of a tool mark absent a tool is more challenging. However, based on the same principles, it is possible to make a determination whether or not a tool mark would have subclass characteristics in it. It is important to have an appreciation for the type of tool that made the mark and this is not always possible. However, when it is, much is to be gained from understanding the potential ways in which that tool could have been manufactured and how the subclass characteristics, if present, would appear in the resultant tool mark.

It is important for the examiner to make a record in their case notes of the basis for any determinations they develop regarding the potential presence or absence of subclass characteristics on firearm or tool mark-related evidence. It is insufficient to place a brief statement such as "no subclass influences observed" in examination notes without describing the observations that led to the stated conclusion. These observations can be briefly summarized.

Subclass characteristics are a legitimate concern. At the same time, even if the specific manufacturing process used to produce a tool's working surface is known to lend itself to the possibility of subclass characteristics, numerous studies have demonstrated that this is not always true in practical application. Furthermore, trained examiners can detect and account for subclass characteristics even when subclass is present in the midst of individual characteristics. Therefore, though examiners must vigilantly consider the potential presence and impact of subclass characteristics in firearm and tool mark identification casework, when this work is properly done, it is possible to correctly associate questioned tool marks to the tools that made them.

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