An Introduction to the Forensic Examination of Toolmarks

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ABSTRACT

As part of the curriculum at the Bureau of Alcohol, Tobacco and Firearms National Firearms Examiner Academy, the students receive basic training in the forensic examination of toolmarks. Although firearms examinations are a specialized area of toolmark examinations, the toolmark section is specifically devoted to tools and the marks that they produce. Information that the students receive include basic instruction in metals, metal deformation, chip formation, metal shaping processes, tools and tool actions, toolmark identification, and other related information. As one of the instructors for this section, I thought that it would be beneficial to other examiners in training and examiners who do not routinely examine toolmarks to have a basic introduction of this material available to them.

Introduction

In the forensic examination of toolmarks, it is necessary to understand the major factors that affect the production of the toolmark and subsequent examination. These factors include the surface material that the tool is working on; the material used to produce the tool; the relative hardness of each; the manufacturing process used to produce the tool and the tool working surface; the finishing process used to produce the tool working surface; the action of the tool; the result of the tool working surface on the material as it produces the toolmark; and the position and movement of the tool working surface relative to the surface being marked. To understand how these factors affect the forensic identification of toolmarks, the examiner must have a basic understanding of metals and engineering materials, the mechanical properties of these materials, metal deformation and fatigue, and the formation of chips resulting from a tool working on a surface. They must also have a basic understanding of the shaping process used to create the tool and toolmark, how it affects toolmarks, and how it affects tool wear.

Metals and Toolmarks

It is necessary to have a general understanding of metals and engineering materials in order to better understand what is occurring to metal during toolmark production. Materials engineering produces working materials consisting of specific properties which best suit a specific objective. These materials fall into several broad categories. *Ceramics* are compounds consisting of metals and nonmetals to produce materials that have high strength, but tend to be brittle, and include brick and glass. *Polymers*, such as rubber and plastic, are lightweight, and corrosive resistant. They can be made into a variety of shapes, but are not suitable for high temperatures, and are weak. *Semiconductor* material, like silicon, are used for solid-state electronics, but tend to be brittle. Two or more elements combined together to produce a new substance are classified as *intermetallics. They* are designed to strengthen the alloy and remain strong at high temperatures, but tend to be brittle at normal temperatures. *Composites* consist of materials which are combined to achieve properties that cannot be obtained by the original materials, and include concrete, plywood and fiberglass. The desired combination of stiffness, strength, weight, corrosion resistance, and other properties can be obtained (1).

In forensic toolmark examination, the primary material most examined is *metal*. Metals are classified as stiff, strong, having good electrical and thermal properties, good ductility, and shock resistance. Alloys are combinations of materials made to provide specific properties for a particular use. Examples of different types of metal include iron and steel, nickel alloy, copper, aluminum alloy, titanium, and tungsten. Iron is used primarily in casts due to it’s hardness. Iron can be produced so that it is easily machined (but brittle) or so that it is hard, but difficult to machine. Steels are classified as carbon steels, which have increased strength and hardness, or alloy steel, such as stainless steel, to achieve a higher corrosion resistance. Copper is soft and malleable, and brass and bronze are copper alloys. Aluminum alloys are one third less dense than steel, light weight and corrosion resistant, and easy to machine. Titanium is half as dense as steel, and titanium alloys are stronger than steel and corrosion resistant. Tungsten is very dense and best suited for extreme high temperatures (2). Depending upon the desired properties, use, manufacturing process, and strength requirements, all of the metals have advantages and disadvantages. These can be overcome by combining properties, hardening, and heat treating.

Mechanical Properties of Metal

The mechanical properties of metals describes the reaction of the grain structure of metal to an applied stress. Metal is made up of many irregularly shaped grains interlocked by grain boundaries. The size of the grains and grain boundaries can be controlled by regulating the cooling rate during solidification. This affects the mechanical properties of the metal, with the small grains resulting in greater strength and toughness in the metal, whereas the larger grains resulting in better plasticity or ductility (3).

When describing the properties of metal, the following terms are used: stress, strain, yield stress, tensile strength, ultimate strength, plastic deformation, and fatigue. The *tensile strength* is the response of a material to an applied load. It is the maximum stress applied causing the metal to be very deformed. *Stress* is a term used to describe the amount of load that is being applied to the metal, per unit area. The stress can be in the form of tension, torsion, shearing, or compression, and causes the individual grains of metal to deform. The *strain* describes the metals response to that stress in the amount of deformation per unit length. If a low stress is applied, then the strain (response to that stress) is elastic, and the metal grain structure will resume its original size. The *yield stress* is the amount of stress necessary to cause *plastic deformation*, where the elastic limit of the grain structure is exceeded. The metal grain structure will not return to its original size. The *ultimate strength* of the metal refers to the maximum amount of stress that the grain structures can withstand without fracturing. *Fatigue* occurs when a stress is applied at a level below yield stress, so that no plastic deformation occurs, but is continually applied many times, resulting in the material failing (4).

Metal Deformation and Fatigue

When a stress is applied to metal, the grains and grain boundaries become elastically strained. As the force continues, the elastic limit is exceeded, the yield stress has been reached, and plastic deformation begins to occur. Had the force ceased being applied prior to the yield stress limits, the elastic limit would not have been exceeded, and the grains and grain boundaries would have returned to their original size. Once the plastic deformation occurs, a permanent change of shape results.

The process of plastic deformation involves the movement of atoms within the crystalline structure of the metal, by the motion of line defects called *dislocations*. One part of a grain of metal moves relative to another part, producing a permanent shape change. The movement of the atoms within the crystals is known as *slip* and *twinning*. The force causes the top crystal to move, or slip, in one direction, referred to as a *slip plane*, while the bottom part of the crystal moves in the opposite direction. This causes one part of the crystal to connect with a different incomplete part of a crystal at the dislocation site, to form a complete crystal. An incomplete crystal is left at the original defect. When parallel planes of atoms slip consecutively over each other, it is referred to as *twinning* and the area where it occurred as a *twinning plane* (5). Plastic deformation describes the process that occurs to the crystalline structure of metal as a result of stress which exceeds the elastic limit of the metal resulting in a permanent change.

As stress is applied to a metal, it may require a significant amount to cause plastic deformation, and ultimately failure, under a single application of the force. This same metal may fail under less force, applied numerous times, through metal fatigue. The constant stretching and relaxing of the grain structure resulting from the alternating application and relaxation of the stress may cause cracks or fractures due to a change of the crystalline structure. The crack will continue with repeated application of the stress, until the strength of the metal fails.

To illustrate what occurs to metal during plastic deformation, examine what occurs to metal when a die is used to stamp a number. After stamping, the number is plainly visible, and no material was removed from the original metal. The metal that the die was in contact with was displaced, or plastically deformed. As the surface of the die impresses into the metal, it stretches the crystalline structure of the metal. As the elastic limit is exceeded, plastic deformation, or a permanent change to the structure of the metal, occurs. There will also be areas away from the actual die contact that were stretched, but in which the elastic limit was not exceeded. If this area were not held in place by the crystalline structure of the area that was deformed, then it would be free to return to it’s original condition. The amount of plastic deformation from the die will depend upon the pressure or force exerted, and the surface area contact of the die with the metal.

Chip Formation

One of the variables that affects the examination of toolmarks is the action of the tool upon the surface it contacts, and the process by which the toolmark is left. In an impression type of action, plastic deformation has been shown to be an important factor. Another equally important factor to understand is what occurs when a tool acting on a surface creates chips, actually removing material. In any metal cutting operation, shapes are formed by removing small pieces from the workpiece in the form of chips.

As a cutting tool contacts metal, stress is applied to the grain structure. The crystalline structure is stretched, the elastic limit is exceeded, plastic deformation occurs, and fracturing begins internally along the shearing lines. The ultimate strength of the metal is exceeded, and material is removed, forming a chip.

The three basic types of chips include *continuous*, *discontinuous*, and *segmented*. The chip types are classified according to appearance and what occurs during removal. During the formation of continuous chips, plastic deformation occurs, but the metal does not fracture. Instead, it is forced to flow over the face of the tool, where it is hardened by the high pressure. Cutting a less ductile material prevents it from being able to flow causing it to fracture, and the chip breaks up into particles called a discontinuous chip. When a heavy feed rate is used in chip removal, the high stress creates internal fractures which move to the outside and cold weld together from the high pressure causing segmented chips (6).

If a ductile material is cut slowly, a built up edge of material begins to cold weld from the high pressure onto the surface of the cutting edge. As material builds up in this area, it soon fractures and breaks off, and a new built up area begins to replace it. When it breaks, it may take portions of the cutting surface with it, damaging and changing the cutting edge of the tool.

Chip formation and the quality of the cutting edge can be controlled with speed, angle of cutting edge, feed rate, and other variables. The nature of the cutting tool also affects the chips produced. As the tip or chisel edge of a twist drill, for example, it cuts by extruding metal to its sides, creating it's own form of chips. Once the drill begins to penetrate, the land edges of the drill begin to cut creating a second form of chip (7). The individual abrasive particles of a grinding wheel will remove chips that vary in size and shape by a cutting action, plowing, or rubbing (8).

Metal Shaping Processes

Metal working processes include *shaping*, which changes the physical geometry of the material, and *treating*, which changes the actual properties of the metal. If the mass of the workpiece is unchanged after it is processed, then it is called a *mass-conserving* process. If material was removed from the workpiece, then it is referred to as a *mass-reducing* process, and a *mass-increasing* process joins two or more work pieces permanently together. Methods of shaping metal include a mechanical process using plastic deformation and fracture, a thermal process using heating and melting, and a chemical process using solution and dissolution (9).

In the examination of toolmarks, the mechanical process in which metal cutting, shearing, and displacement is used is of primary concern. Metal cutting operations can be done with a variety of machine and hand tools, with some tools better suited for specific jobs of shaping metal. Toolmark examination is concerned with the tool working surface, movement of the tool relative to the workpiece, and the toolmark resulting from this contact. In general, machine tools hold the workpiece and cutting tool, imparts motion to the workpiece, tool, or both, and regulates the cutting speed and feed rate. The cutting tool is harder than the workpiece it is cutting, it is ridged and shaped to penetrate the work, and removes material from the workpiece in the form of chips (10).

Depending upon the machine and method used, chips are removed using *single-point cutters*, *multi-point cutters*, or *abrasives*. Single-point cutters have one cutting edge and are used in turning and boring operations. Multi-point cutters have two or more cutting edges and include drill bits, reamers, and saws. Abrasives have many particles with each acting as a cutting surface to remove chips, and include grinding and sand blasting (11).

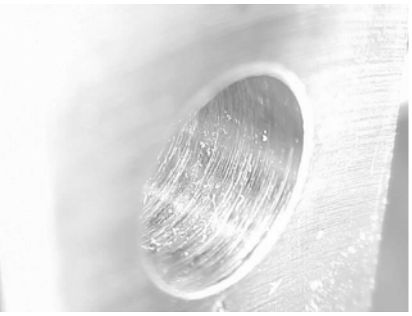
The three main variables that are controlled when cutting are: the cutting speed, feed rate, and the depth of the cut. By manipulating these factors, the operator affects the surface texture of the workpiece, the formation of chips, and tool wear. Various cutting processes and various materials require the adjustment of these variables in order to achieve the desired result (12).

Cutting machine tool operations can be grouped according to the operation, the most common being turning, milling, boring, planing and shaping, drilling and reaming, broaching, and grinding. Other machine tool operations include shearing, stamping, forging, and compacting processes, and are covered separately.

In a planing and shaping process, a parallel movement of the tool working surface with the workpiece removes material. It is a single-point cutting tool that produces parallel feed toolmarks. In the shaping process, the tool reciprocates against the workpiece, and in planing, the workpiece reciprocates against the tool (13).

Drilling is a cutting process in which the multi-point cutting edges are separated by flutes. Long chips are created which are moved along the flutes away from the workpiece. Helical feed marks are produced which may be fine or coarse depending upon speed and feed rate. Burrs will normally be seen at the hole exit, but may also occur at the hole entry (Photo 1) (14).

Photo 1: Drilling marks.



Reaming is a cutting process similar to a drilling process in which multi-point cutting edges are separated by flutes. Reamers are used in previously made holes to accurately size them and remove the roughness left by drilling. Very small amounts of material are removed in thin chips from the workpiece. Circular feed marks can be observed which are more consistently sized and spaced than what is observed with a twist drill bit. Their appearance also depends upon speed and feed rate (Photo 2)(15).

Photo 2: Reamer Toolmarks.

Milling uses multi-point cutting tools containing equally spaced teeth around its circumference. The cutting action is continuous, and many cuts are made for each revolution of the tool. The cutter is rotated, and the workpiece is fed into it. The cutting action produces discontinuous chips. For *conventional milling*, the cutter rotates in the opposite direction of the feed of the workpiece, while in *climb milling*, the cutter rotates in the direction of the workpiece. This process produces flat, contoured, or shaped surfaces. Toolmarks produced are generally similar in appearance and equally spaced (Photo 3)(16).

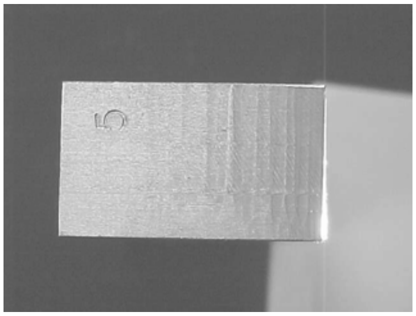
End milling uses a multi-point cutter separated by flutes which may appear similar to a reamer. It is used to make slots, angles, and curves, and produces discontinuous chips. The feed marks appear as evenly spaced and sized spirals, or half circles (Photo 4). If the sides of the cutting edges are used to face a surface, then the feed marks appear as widely separated relatively thick ridges (Photo 5)(17).

Photo 3: Milling toolmarks.

Photo 4: End milling toolmarks.

Turning and facing are single-point cutting processes done on a lathe. In facing, the chip removal process is accomplished with the tool at a right angle to the axis of rotation of the workpiece. In turning, the chip removal is accomplished with the tool parallel to the axis of rotation of the workpiece. Fine helical feed marks are produced (18).

Photo 5: Sides of end mill toolmarks.



Boring is a single-point cutting operation used to create or increase diameter or shape of an existing hole. As the workpiece rotates, the cutter feeds into the piece. In horizontal boring, the workpiece is stationary while the cutter rotates and feeds into the work producing internal helical toolmarks. In lathe boring, the workpiece rotates and the cutting tool feeds into it either parallel or at an angle to produce a taper. The chips that are formed can be continuous or segmented, depending upon material, speed of rotation, and feed rate. Internal helical toolmarks are produced (19).

Broaching is a multi-point cutting operation in which a series of teeth or cutters are arranged in line, each cutter increasing slightly in height or diameter from front to rear. Cutting action is distributed throughout the series of cutters, with each removing a small amount of material. It is used to size, shape, or finish a surface. As parallel toolmarks are created by the cutter on the workpiece, subsequent cutters over score the preceding toolmark, removing the material, so that any toolmarks observed are the result of the final cutter (20).

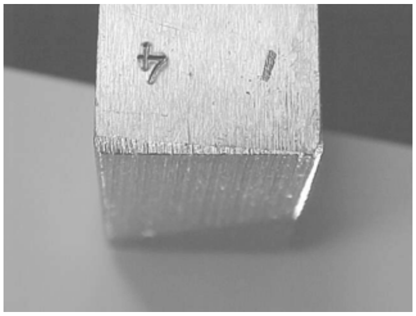


Photo 6: Grinding toolmarks.

Abrasive machining removes material by friction and erosion, and include *grinding*, *ultrasonic machining*, and *abrasive jet machining*. Grinding uses abrasives bonded into a ridged wheel. It is a multi-point cutting process in which several chips are cut from the workpiece simultaneously. As cutting edges dull, they may break off, producing new cutting surfaces, or remain unchanged depending upon how it is used. Grinding produces irregularly spaced and contoured toolmarks, and is used to produce flat or formed surfaces, and is primarily a finishing process (Photo 6)(21). The effect that the grinding wheel will have on the resulting toolmark will depend upon whether it is acting upon a soft or hard material. Ultrasonic machining carries abrasive particles in a liquid that is vibrated against the workpiece creating a hammering affect, cutting away small chips. Jet machining accomplishes the same result using abrasive particles in a high speed air stream to remove small chips from the workpiece. Abrasive particles include silicon carbide, aluminum oxide, boron carbide, and sand (22). Lapping is an abrasive process in which a loose abrasive slurry is moved at low speed and pressure across the workpiece to create very fine finishes. The points between the abrasive particles and the workpiece are always changing with the motion of the tool, which can be rotational or parallel (23).

Other processes used to shape metal that the forensic toolmark examiner should be familiar with are shearing, forging, drawing, blanking, cold heading, extrusion, swaging, sand casting, investment casting, injection molding, and compaction. Shearing is a mechanical process which controls the fracturing of metal to produce the desired shape. Pieces of the workpiece are separated by opposing forces which create a shearing zone and fracture the metal. Shearing, blanking, and perforation are all separation processes that use this principle. In shearing, the upper tool moves down onto the workpiece while the lower tool moves up, eventually passing each other. The workpiece begins to deform along the tool edge. When the elastic limit of the material is exceeded, the pieces separate. A fracture pattern can be seen and the edge will be slightly deformed, with burrs present (24) Blanking separates the workpiece by shearing producing burnished edges (25). Perforating punches holes or shapes in the workpiece using a shearing process producing burnishing in the sides of the holes, and burrs on the bottom surface (26). Although the processes may vary in how they separate the metal, a shearing force is still affecting the metal structure.

Metal forging processes include cold heading, forging and drop forging. Cold heading produces enlarged sections of wire held in a die by compressing it into the cavity and forcing it to conform to it's shape (27). In forging, the material is compressed to the desired shape under high impact pressure. Excess material that may squeeze out between dies is called flash, and occurs in closed die forging. The heavy impact on the metal during forging also improves the quality of the metallic structure (28). Drop forging follows the same basic process, but the workpiece is heated prior to being forged. Several operations may be performed to achieve the final result (29). In upset forging, a heated rod is placed into a die from one end, while a punch impacts the rod from the other end. This forces the material to assume the shape of the interior of the die.

Other forming processes include deep drawing, swaging, and impact extrusion. In deep drawing, a flat piece of steel is shaped by a punch pressing against the steel and forcing it into a die. The metal stretches to form the die shape, as in cartridge casing manufacture (30). In impact extrusion, a cold metal plug is forced around a punch in a single high speed impact which causes the metal to flow down through a die, or up around a punch, creating the desired shape (31). Swaging is a process in which the workpiece is reduced to a desired size or shape by repeated impacts from "hammers" in a rotating or stationary die. "The workpiece is slowly fed into a swaging die opening. As the spindle assembly rotates, dies and backers are forced outwards against rollers by centrifugal force. As backers ride over the rollers, they push against dies which deliver a blow to the workpiece. The dies continue rotating rapidly delivering powerful blows to form the workpiece quickly" (32). Wire drawing is a metal reducing process in which a wire rod is forced through a series of dies which force it to conform to the die shape and size, reducing the wire diameter. The quality of the metal properties improve, and the wire lengthens (33).

Extrusion and ejection molding are shaping processes in which molten plastic is shaped in a die or mold. In the extrusion molding process, heated material is fed into a barrel, which has a helical screw that forces the plastic through a die and around a mandrel to produce a hollow tube (shotgun shells) (34). In injection molding, the heated material is forced into a mold cavity until it hardens into the desired shape. Seam lines and sprue marks will be visible (35).

Casting processes include sand casting and investment casting. In the sand casting process, cores in the desired shape are placed into a two part frame, with sand compressed around the core. The frames are then separated and the core removed. The frames are put back together, and molten metal is poured through a sprue into the cavity in the sand. After hardening, the sand is removed and the cast is made (36). In investment casting, a ceramic slurry is applied to wax or plastic patterns. Once it hardens, the wax or plastic is melted away, leaving a mold with several cavities of desired shapes. Molten metal is then poured into these cavities. When it hardens, the slurry is broken away, leaving the desired casts (37). The compaction process uses metal and carbide powders to form desired shapes using high pressure. The pressure causes plastic deformation to occur to the particles forcing them to cold weld together, forming the desired shape, which can be machine worked and hardened (38). Some parts are made by *metal injection molding* (MIM). These are pieces made with a wax and metal powder that are compressed, and are 30% larger than the required piece. They then go through sintering, which causes the wax to vapor off. The metal fuses together and shrinks 30%, resulting in a finished piece. This can achieve the same metal properties as a steel piece.

Additional processes that the forensic toolmark examiner will encounter include *electrical discharge machining* (EDM), *electrical chemical machining* (ECM), and *electroplating*. EDM is a process in which repeated electrical sparks removes material. A dielectric fluid washes away particles, and a burr free surface results (39). ECM uses a negatively charged electrode and a conductive fluid that is advanced into a positively charged workpiece. Material is removed by the positively charged workpiece particles separating from the workpiece because of the attractive forces of the negatively charged electrode (reverse electroplating) (40). Electroplating deposits a thin metallic coating onto a workpiece by negatively charging the workpiece and positively charging the metal that is to be coated onto the workpiece. The negatively charged workpiece attracts the positively charged metal within an iodized electrolytic solution, causing the positively charged metal particles to adhere to the workpiece (41).

Two other processes used to shape metal include stretching and twisting. Drawing processes, such as in the production of cartridge cases, produces a stretching, or *tension* stress. Rolling or bending metal will produce compression stresses at the inside of the bend, while producing tension stresses at the outside of the bend. Twisting the metal so that the stressing forces work in opposite directions is called a *torsion* stress (42).

Metal Hardening Processes

The chemical and mechanical nature of metal can be changed to obtain specific properties of hardness or ductility. It may be desirable to have a metal “soft” and ductile for machining, but “hard” for it’s final use. Heat treating and cold working metal are processes that achieve desired properties of metal. There are two classes of heat treating metal, *quenching* and *annealing*. In quenching, the metal is heated to a point above where the properties of the metal change, called a transition point. It is then quickly cooled in oil or water, to solidify those properties. This process can be used to harden the surface of the metal, or the entire metal, and produces brittleness. In annealing, the metal is heated to a point above the transition point and slowly cooled, which softens the metal, and provides ductility and machineability to the metal. Metal hardening process that fall into these classes include, sintering, induction hardening, stress relieving, case hardening, and tempering (43).

Induction hardening involves heating the workpiece using an electromagnetic field which is then quenched to harden the surface, although it can be used for complete hardening (44). Stress relieving uses lower temperatures and is done to eliminate the stresses from cold working metal, machining, welding, drawing, heading, and similar processes (45). Sintering is a heat treating process that is used for compaction processes, which can be done in a liquid or solid phase, to create the strongest final product possible (46). Case hardening uses chemicals to change the surface of the metal and heat treating to increase hardness, while the core remains ductile (47). Tempering improves a metal’s toughness and ductility by heating the workpiece to a point below the transition point, to reduce cracking, improve machineability, and increase impact resistance (48).

Hardness is one measure of a metal’s properties and is determined by its resistance to penetration. The impression made in metal by the impact of a steel ball is measured and compared to a hardness scale. A *Brinell Hardness* S*cale* and a *Rockwell Hardness Scale* are most common, with the higher number designating a harder metal (49).

Tools

The AFTE Glossary defines a tool as, "an object used to gain mechanical advantage. Also thought of as the harder of two objects which when brought into contact with each other, results in the softer one being marked" (50). Toolmark examinations include machine tools like lathes, mills, drills, etc., and non-power hand tools like screwdrivers, pry bars, vise grips, pliers, bolt cutters, etc. In machine tool operations the tool is actually the device that cuts or shapes the workpiece, and a machine provides the power. In both categories, toolmark examination is concerned with how the tool was manufactured, and specifically how the tool working surface was manufactured and finished. The tool working surface is the part of the tool that actually produces the toolmark that is subsequently examined.

All of the processes previously discussed in the section concerning metal shaping processes are used to produce part or all of a tool. It would be an impossible task to list all tools produced by all manufacturers, and include the method used to produce the tools. An examiner should become familiar with common methods used for tools that are normally seen in casework, and be familiar with characteristics that can be attributed to specific operations as discussed in the section about metal shaping processes. For example, recognizing irregularly shaped and contoured toolmarks, and determining that a grinding surface was used to generate those toolmarks.

The shape of a hatchet head is manufactured using a drop forge method, with the cutting surface finished, or sharpened, using a grinding operation. A careful examination of the perimeter of the head will reveal the results of flash from having been squeezed out from between the dies. Not all hatchet manufacturers will use this method, but the characteristics are present that will allow the examiner to make that determination.

The most common tool that an examiner will see is the slotted screwdriver that has been used as a prying tool at a crime scene. Several methods of production have been used to manufacture these tools. Several of the metal shaping and hardening processes previously discussed are used in the manufacture of screwdrivers, and include shearing, forging, grinding, polishing, upsetting, heat treating, annealing, and plating. The screwdriver grips can be made from a number of materials using various methods, but the toolmark examiner is primarily concerned with the blade, or tool working surface. For example, the Stanley Tool Company shears a bar stock to length, uses a forging process to flatten the tip, and trims to shape. It is then shot blasted, heat treated, ground, and polished. The grinding may be done on all the surfaces of the blade, or just the tip (51). Rosco Tools forges the ends while hot using a progressive die operation on a punch press to form the shape of the blade and trim the edges. The workpiece is then heat treated and the face and sides ground. The tip may or may not be ground (52). Other manufacturers use different methods, or a variation of the same method. An examination of the blades, faces, and sides of the screwdriver can show a ground surface, flash from forging, striations and fracture from shearing, or other clues that can be used to determine the method of manufacture. Burd and Gilmore illustrate these types of marks found on a screwdriver blade (53).

Another tool that examiners will likely see in casework are bolt cutters. Since the examination of bolt cutters involves toolmarks produced by the cutting jaws, the concern is with the manufacturing and finishing processes of the tool working surfaces. The jaws produced by H.K. Porter are forged. They then go through a process of annealing, trimming to remove flash, shot blasting, grinding, bevel milling, and heat treating. There are other steps, but those are the main processes that affect the cutting surfaces (54). Butcher and Pugh discuss the manufacturing of Record™ bolt cutters, in which they give a detailed explanation of the toolmarks observed on the cutting jaws after each manufacturing process (55). The bevel on the leading edge and cutting face are shaped with a multipoint cutter and ground. This produces coarse oblique striations on the beveled face. Additional grinding produces shallow oblique striations. The cutting edges are ground, producing striae, without completely removing the striations produced during the initial cutting of the bevel and face.

An additional example of how tools are manufactured that the toolmark examiner will examine are pliers, or specifically, tongue and groove pliers. These are the wide opening type that are commonly referred to as "channel locks", from the proper name of a company that manufactures them. The tool working surface that concerns the firearms examiner are the teeth. Cassidy reported on the manufacturing of Craftsman brand tongue and groove pliers, and specifically the teeth (56). The teeth are broach cut, with a different broach used for the upper and lower jaws. They are then hardened, tempered, de-scaled by tumbling, and plated. Any subclass characteristics that may be present from the manufacturing process are oriented 90 degrees to how the toolmarks are produced, eliminating their influence.

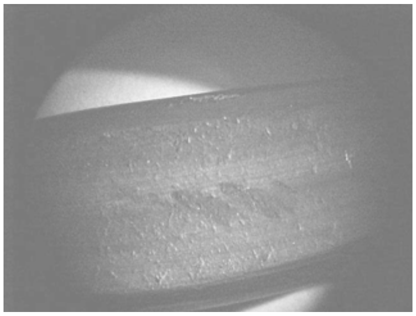
Additional examples of tool manufacturing would be cumbersome, and not possible to include everything. The pages of the *AFTE Journal* are an excellent source for other research concerning the manufacturing of specific tools. It is important for the toolmark examiner to determine the methods of production of the tool working surfaces that are suspected of producing the toolmark in question, by an examination of these surfaces, and when possible, by contacting the manufacturer. It is when determining the potential individuality of these surfaces that this knowledge is essential.

Actions of Tools

For the purpose of toolmark examinations, tools are classified according to the type of action the tool is designed for. These actions include, *compression*; *crimping*; *flat action*; *gripping*; *shearing*; and *slicing*. A compression tool, such as a hammer or die stamp is designed to compress by pressure or impact. A crimping die tool has opposing jaws that are designed to press together, bend, or crease the material, and include wire crimps and bank seal presses. A slotted screw screwdriver, pry bar and tire iron bladed end, are examples of tools that employ a flat action to the workpiece. A gripping action imparts a squeeze or hold on an object by using opposing jaws that abut each other and include vise grips, pipe wrench, and tongue and groove pliers. They are also called serrated jaw gripping tools. Bolt cutters and diagonal cutters have opposing jaws that use a pinching action and are designed to cut. They are also called opposed blade cutting tools. A shearing action uses two blades on adjacent planes that pass by each other and are designed to cut, and include scissors, sheet metal snips, and pruning shears. A knife, razor, or hand held plane are examples of tools designed to impart a slicing action, in which the blade or cutting surface cuts by moving in the direction of the cut (57).

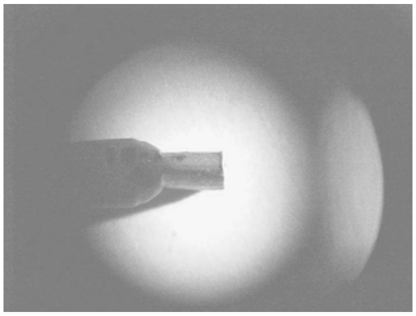
The type of action imparted by the tool is a class characteristic and can be determined from an examination of the toolmark or area containing the toolmark. This is helpful in no-tool cases when attempting to inform investigators about what tool to look for, and in the initial examination or elimination of the tool as a source of the evidence toolmark. The information is also of use in determining how the tool was used, the direction of tool movement, and being able to reproduce toolmarks for comparison to what is observed about the evidence toolmark. If the action imparted by the suspect tool is inconsistent with what is observed in the evidence toolmark, then this tool can be eliminated. The class characteristics of the basic tool actions outlined above can aid in these determinations. It may be necessary to produce tests with the suspect tool and observe this tools action before a determination can be made.

Photo 7: Compression toolmark.



Photograph 7 illustrates the type of toolmark imparted using a compression action. This was done using a 5lb sledge hammer onto ½” diameter lead wire. The workpiece may register the surface characteristics of the impacting tool, depending upon relative hardness and pressure, and the workpiece shape may change.

Photo 8: Crimping toolmark.



Photograph 8 shows an electrical wire connector crimped at the end. The class characteristics show both sides of the workpiece being compressed relatively equally. Depending upon the material and pressure, a replica of the surface of the crimping tool may be impressed.

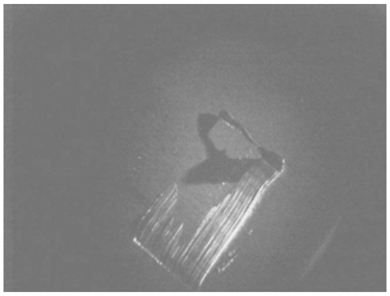


Photo 9: Striated scape toolmark.

Photograph 9 shows a typical striated scrape mark made from a flat blade, done in lead using a slotted screw screwdriver. The entire width of the tools blade may register, and the direction of tool movement can be determined from a build up of material at the stopping point of tool movement.

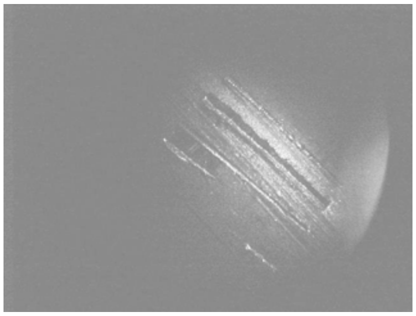
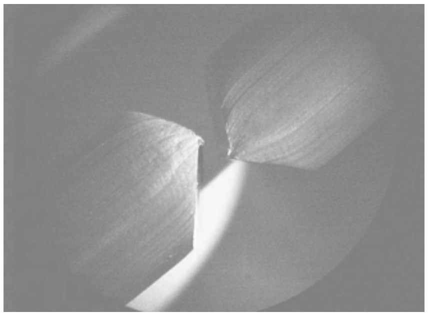


Photo 10: Gripping toolmark.

A gripping action tool, such as vise grips, will leave an impression of the teeth of part of the jaws and if the tool slips, will leave striated toolmarks in which the direction of movement can be determined. Photograph 10 shows vise grip toolmarks on galvanized pipe material.

Bolt cutters are tools with opposing jaws that are designed to cut using a pinching action. The characteristic shape of this type of cutting action of a bolt cutter shows one side of the angled cut at a slightly shallower angle than the opposite side, and a small lip or projection at the apex over the side that is at a more acute angle. This is illustrated in photograph 11. When cutting a hard material, there will also be a fracturing at the area of the apex of the cut, and the fracture pattern will be obvious.

Photo 11: Pinching toolmark.



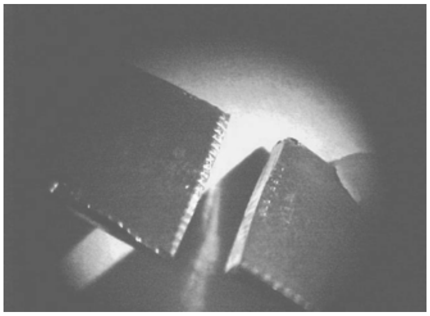
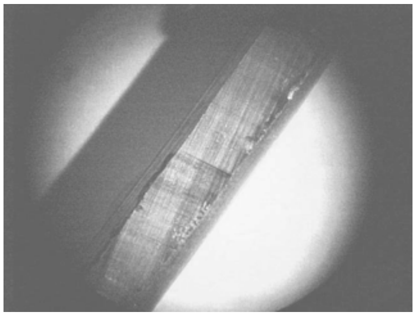


Photo 12: Shearing toolmark.

A shearing action will be a relatively smooth cut in soft material and may be at a slight angle depending upon how the tool was held. Striations from the cutting surface will be seen, and in hard material a fracture pattern will occur at the point where the material breaks instead of cuts. Photograph 12 shows a shearing cut in lead using metal snips.

Photo 13: Slicing toolmark.



Photograph 13 shows the result of a razor blade that was used to illustrate a slicing action in lead wire. The fine striae from the cutting surface can be seen as well as "creases" adjacent to the striae where the tool stopped as more pressure was needed to continue the slice.

These are only a few examples of some of the class characteristics resulting from specific tool actions. These can be used to determine possible tool type, how a tool was used, and to eliminate a tool from having been used. This information also provides a basic understanding of how a tool's action is used, and how that affects a toolmark and subsequent forensic examination.

Tool Working Surfaces and Toolmarks

The examination of toolmarks is primarily concerned with the actual portion of the tool that contacts a surface and produces the toolmark. This area of the tool is called the tool working surface. To conclude that a specific tool working surface is the source of a toolmark, the individuality of that tool working surface must be determined. The basis for this determination lies in the manufacturing process used to produce that tool working surface, what has occurred to that surface since manufacturing, and how that surface interacted with the material when the toolmark was produced.

The first concern is to examine the manufacturing methods used to produce the tool working surface. The other parts of the tool are not considered, unless they are causing a toolmark that is under examination for a toolmark identification. What is the potential for individuality of the tool working surface? What is the potential for having many more tools with a similar working surface that produces toolmarks that can be attributed to a group of tool working surfaces, or *subclass*?

AFTE defines subclass characteristics as, "discernable surface features of an object which are more restrictive than class characteristics in that they are produced incidental to manufacture; are significant in that they relate to a smaller group source (a subset of the class to which they belong); and can arise from a source which changes over time"(58). To understand subclass characteristics, examine toolmarks on an object produced from a mold. The same mold will produce many objects which display those same toolmarks from the mold itself, different from other molds. If no other mold exists, than all can be identified back to this one mold. If one master is used to make many molds, then each mold will have the surface irregularities or toolmarks of the master. Objects made in these molds will have these toolmarks imparted to them, and be indistinguishable from the molds that produced them, so that it would not be possible to determine what mold made what object, because they would all exhibit the identifying characteristics transferred to each by the master.

Photograph 14 shows an area of two gun barrels that were produced using investment casting. Each barrel was made from it's own separate mold, however, since all of the molds were produced by a single master model for the barrel, all of the resulting barrels would display the same mold toolmarks. Photograph 15 shows an identification of these mold toolmarks, which are subclass characteristics. In this case, the subclass influence has no effect on an identification, because finishing processes will remove these toolmarks.

Photo 14: Mold toolmarks.

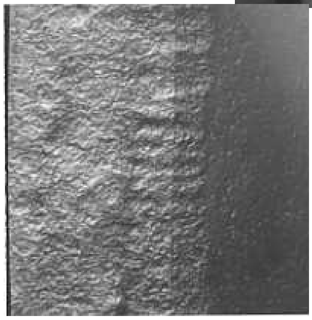


Photo 15: Mold toolmark identification.

Additional subclass characteristics can be seen in photograph 16, where a gripping action imparted impressed toolmarks to the wire during nail manufacturing. The photograph depicts an identification of these toolmarks from two different nails. These gripper subclass toolmarks will change during the life of the gripper, causing the toolmarks to change between relatively small groups within the overall production of nails.

Photo 16: Gripping toolmarks.

Photo 17: Impression toolmark.

Photograph 17 illustrates an identification of a toolmark created on a metal disc that was punched from a metal sheet to create a hole during a perforating process. As the surface of the tool changes over the course of punching these discs, the toolmarks that will be observed on them will change, thus being a subclass toolmark produced during the overall life of the tool.

These examples are of a nature that do not have a major affect on a toolmark examination between an evidence toolmark and a suspect tool, because their subclass influence is primarily concerned with batches of manufactured items. A bunter identification on a group of cartridge casings would be an example of this type of subclass identification. If the working surface of a suspect tool can be found to be sufficiently reproduced on another similar tool, then the toolmarks generated by these tool working surfaces may display subclass characteristics that could be erroneously identified.

Photograph 18 shows the serrated edge of the tool working surface of the edge of one of the blades on a pair of metal snips. This area of the blade was manufactured by broach cutting. If this area is part of the suspect tool, and a test toolmark is made and compared with an evidence toolmark, then let photograph 19 represent a microscopic comparison which exhibits a significant amount of agreement However, photograph 19 depicts toolmarks generated using the serrated edge of two different tool working surfaces. An identification based on this portion of the tool is a subclass identification, not individual to the tool, but to a group of tools that share these same subclass characteristics (59).

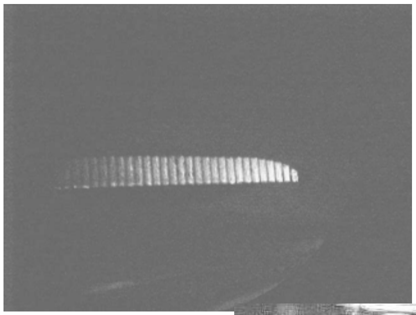


Photo 18: Serrated edge of blade.

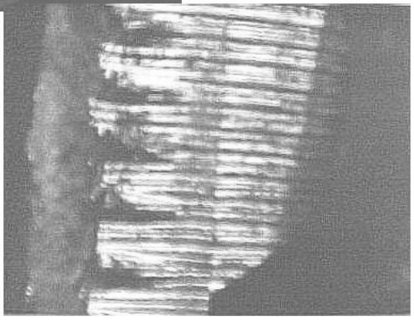


Photo 19: Two different blades.

The research conducted by Burd and Gilmore concerning screwdrivers showed many areas of subclass characteristics on newly manufactured screwdrivers. They showed the similarities from the die used on the flats of the blades, and shear toolmarks on the edge of the blades. They illustrated significant similarities in toolmarks produced by two different tools using the edges (60).

Since a subclass characteristic deals with a small group, one is more likely to find them in tool working surfaces that are closely manufactured. The *AFTE Journal* has many articles dealing with the study of subclass characteristics and toolmarks produced by consecutively manufactured tools. In Cassidy's research, he looked at consecutively manufactured tongue and groove pliers. The tool working surface that an examiner is concerned with in these pliers are broach cut. He concluded that consecutively made pliers could be distinguished from each other by the toolmarks that they produce (61).

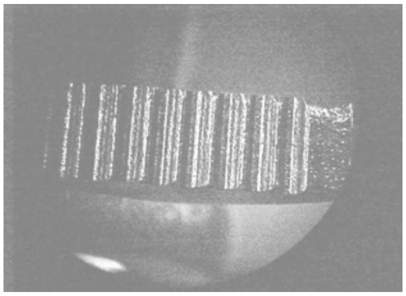


Photo 20: Jaw of pliers.

Subclass characteristics can be expected when using a broach to cut a surface, yet Cassidy had no difficulties in identifying separate jaws. The reason that the tool working surfaces of the pliers did not reproduce subclass characteristics in the toolmarks is not because of an absence of these characteristics, but because of the method employed in the use of the tool. Photograph 20 shows a jaw of tongue and groove pliers. The parallel striae from the broach cut can be seen, parallel with the teeth. Photograph 21 shows a comparison identification of the toolmarks produced by one jaw, in which the movement of the tool was parallel with the teeth. Photograph 22 shows a comparison of the toolmarks produced by two separate jaws, in which the tool movement was parallel to the teeth. Random striae can be observed, and the agreement would require additional examination before a conclusion could be reached. Photograph 23 shows a comparison identification of toolmarks made using the same jaw, in which the motion of the tool was 90 degrees across the teeth, as the tool was designed to move. It can be easily observed that there is a more significant reproducibility of the toolmarks than what was observed in Photograph 21. Photograph 24 shows a comparison of toolmarks made using two different jaws in which the motion of the tool was across the teeth, as the tool was designed to move. As can be seen, although both jaws reproduced well, there is much less agreement of striae. It can be easily determined that these two toolmarks were produced by different tool working surfaces. In this example, it can be seen that although subclass characteristics may exist, the method in which the tool is used can negate any subclass influence on the toolmarks produced, and the ability to make a toolmark identification.

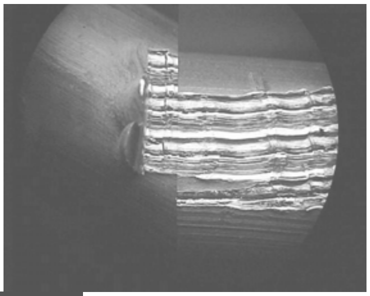


Photo 21: Tool motion to teeth (same jaw).

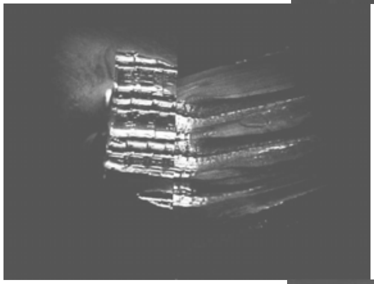


Photo 22: Tool motion parallel to teeth (different jaws).

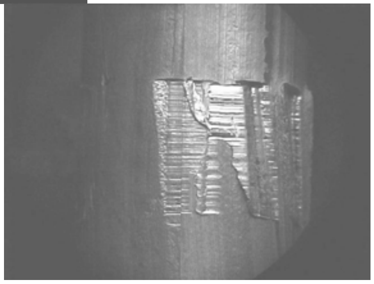


Photo 23: Tool motion across teeth (same jaw).

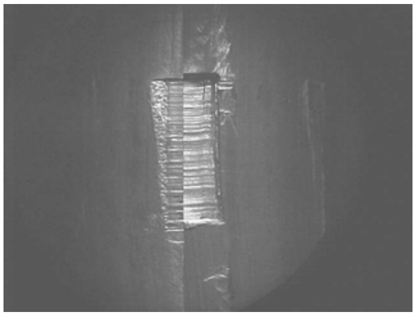


Photo 24: Tool motion across teeth (different jaws).

Tool Wear

Tool wear from normal use, abuse, and misuse actually aid in producing tool working surfaces that possess individuality. It is also a factor that can change the tool working surface sufficiently to preclude an identification with an evidence toolmark that was produced before the tool changed. As soon as a tool working surface begins to do what it was designed to do, it is subjected to the factors that create change. A new tool working surface will change rapidly initially, until the initial break in has occurred. Then the wear becomes slower and more uniform through normal use. This was demonstrated in the shearing process of producing cut nails. A significant change in the toolmarks observed on the sheared surface of the tool was demonstrated on the nails produced during the first 15,000 of production, while the next significant change was not observed until 65,000 nails were produced (62).

For machine tools such as lathes, mills, drill bits, etc., the rate of normal wear depends upon the cutting speed, feed rate, and depth of cut. As the tool contacts the workpiece, it creates friction and heat. The metal deforms, chips are removed, and the process continues as long as the tool working surface is in contact with the workpiece. While material is removed, the tool itself heats to a point where the tool metal becomes soft and cannot cut. At this point, the tool must be sharpened or replaced. To increase the life of the tool during normal use, the cutting speed and feed rate are reduced, the depth of cut is shallower, and a cutting fluid is used to cool down the workpiece and remove chips (63).

Tool wear from normal use consists of several types. A built up edge of material that occurs on the cutting surface of the tool during chip formation can cause a projection that will affect how the tool is cutting, as well as produce a toolmark on the workpiece. If this built up area breaks off, it leaves a depression and rough surface to the cutting edge that will also affect cutting and create a toolmark on the workpiece. The tool edge can erode at the cutting edge and create a crater. A notch in the cutting surface can form at the depth of cut. Chips can weld to the face of the tool and break off also removing part of the tool material, called pullouts. The tool material can crack from rapid heating and cooling, called thermal cracking. The edge of the tool may be heated sufficiently to soften and deform, or the cutting edge may chip. All of these types of wear result in a change to the tool working surface, and ultimately the toolmarks produced by these surfaces (64).

Tools can be abused any number of ways. Abuse is caused by simply not using the tool in the way that it was originally designed or intended by the manufacturer. A screwdriver has always been improperly used as a prying tool or gouge and chisel. Hammers are used to break things. Axe and hatchet blades hit rocks. Bolt cutters and diagonal cutters cut stock harder and larger than intended. The greater the abuse, the more the tool working surface will change. These changes individualize the tool working surface, and may be sufficient to preclude any subclass influence that may be present.

Forensic Toolmark Identification

Forensic toolmark identification is a scientific discipline that is concerned with the identification of toolmarks to the tool that generated that toolmark. This includes firearms identification, which is a specialized area of toolmark identification concerned with identifying the firearm or parts of a firearm that generated the toolmarks observed on a fired ammunition component. This area of toolmark identification is described elsewhere in the *AFTE Journal*, and is not included as part of this paper. Toolmark identification also includes fracture match or physical fit in which two separate pieces of material are shown to have once been part of, and broken from, a whole, like a puzzle piece fit.

Toolmarks are classified as either striations or impressions, based upon the action of the tool when the toolmark was generated. A striation is defined by AFTE as contour variations on the surface of an object caused by a combination of force and motion when the motion is approximately parallel to the plane being marked. An impression is defined as contour variations on the surface of an object caused by a combination of force and motion where the motion is approximately perpendicular to the plane being marked (65). A hammer impact is an example of an impressed toolmark, and a pry bar scrape is an example of a striated toolmark.

Tools can be identified to the toolmarks that they produce because they usually have random microscopic surface irregularities that are present on the working surfaces. These surfaces, if they are unique, leave their unique "signature" in the form of toolmarks that can be microscopically compared and identified because of the nature and reproducibility of these features. The tool working surfaces are usually unique microscopically as a result of the manufacturing processes and subsequent use and misuse of the tool. It is therefore, important to know the manufacturing process of the tool working surface and it's potential for subclass characteristics and individuality because, it is only by ruling out subclass toolmark influence that a tool working surface, and hence a toolmark produced by that surface, can be established as being unique. This can be accomplished by a familiarization of manufacturing processes, and examination of the tool working surface, as well as an examination of the test toolmarks produced using that tool.

The objective of a toolmark examination is to determine if a suspect tool was used to generate an evidence toolmark. This is accomplished by examining the evidence toolmark to determine the class characteristics and if sufficient individual characteristics are present for a possible identification to a suspect tool. If the evidence toolmark is of value for a comparison, the examination continues. If the evidence toolmark exhibits insufficient individual characteristics, it is unsuitable or has no value for an identification. The suspect tool is then examined to determine if the class characteristics are such that the tool is capable of having made a toolmark similar to the class characteristics observed in the evidence toolmark. If so, the tool working surface is then examined for trace evidence left from the surface exhibiting the evidence toolmark, as well as any trace evidence from the tool working surface that may be present in the evidence toolmark. Paint and metal transfers are examples. The tool working surface must also be examined for it's potential for subclass influence and individuality. The tool action is then examined along with the evidence toolmark to determine how the tool may have been used to produce the evidence toolmark. The *angle of tilt* of the tool working surface in relation to the surface that it is acting upon, and the *angle of progression* of the tool as the toolmark is produced are important factors to examine.

Davis gives a good introduction to the effects of angle of tilt and angle of progression (66). The angle of tilt refers to the angle at which the tool working surface contacts the surface receiving the toolmark. As the angle changes, so does the surface area of the tool contacting the surface receiving the toolmark. This affects the resulting toolmark and reproducing test toolmarks that were as close to the same conditions as when the evidence toolmark was generated. The angle of progression refers to the progressive movement of the tool working surface as the toolmark is generated, and can affect the appearance of the contours of striae.

Pressure is another factor that can affect the appearance of a toolmark, and subsequent reproducibility of the toolmark. As the pressure increases, the irregularities on the tool working surface will have more of an influence on the resulting toolmark. This can result in some areas of the tool working surface making contact and leaving toolmarks that could not be produced under less pressure. It can also over-score toolmarks that would be produced using less pressure. Significant differences in pressure between the generation of test toolmarks as compared with the evidence toolmark can lead to a conclusion of elimination of the tool, or an inconclusive. It could not however, result in an erroneous identification.

In the *Theory of Identification as it Relates to Toolmarks*, AFTE defines four possible conclusions of a toolmark examination. The four conclusions and definitions are (67):

> **1. IDENTIFICATION**: Agreement of a combination of individual characteristics and all discernable class characteristics where the extent of agreement exceeds that which can occur in the comparison of toolmarks made by different tools and is consistent with the agreement demonstrated by toolmarks known to have been produced by the same tool.
>
> **2. INCONCLUSIVE**:
>
> A. Some agreement of individual characteristics and all discernable class characteristics, but insufficient for an identification.
> B. Agreement of all discernable class characteristics without agreement or disagreement of individual characteristics due to an absence, insufficiency, or lack of reproducibility.
> C. Agreement of all discernable class characteristics and disagreement of individual characteristics, but insufficient for an elimination.
>
> **3. ELIMINATION**: Significant disagreement of discernable class characteristics and/or individual characteristics.
>
> **4. UNSUITABLE**: Unsuitable for microscopic examination.

The comparison of test toolmarks made using the working surface of the suspect tool with the evidence toolmark must result in sufficient agreement of individual characteristics for a conclusion of identity. This agreement must be consistent with the agreement observed when inter-comparing the test toolmarks, and exceed the best agreement observed in toolmarks known to have been produced by different tool working surfaces, before a conclusion of identification can be made. The toolmarks observed must be the result of a tool working surface that is individual, without any subclass influence. Then the agreement observed can form the basis for the identification of the suspect tool working surface having generated the evidence toolmark.

In order to examine the toolmarks produced by the suspect tool, test toolmarks are made. It is important to generate test toolmarks attempting to reproduce the same circumstances as when the evidence toolmark was produced, accounting for pressure, angle of tilt and progression, and other discernable factors. The material used for receiving the test toolmarks should be the same as that which displays the evidence toolmark, or softer. It is better to use a soft material, such as lead, first, to avoid any potential for change to the tool working surface from producing test toolmarks in a harder material. Only test toolmarks used for an identification are necessary to retain, unless a harder material was used, then all test toolmarks should be retained as "laboratory generated evidence".

Once test toolmarks are generated, they should be compared to each other to observe the characteristics and reproducibility of the toolmarks, and then compared with the evidence toolmark. A comparison microscope is used, with the evidence toolmark placed on the left stage, and the test toolmarks made using the suspect tool placed on the right stage. It is sometimes difficult to be able to position the object displaying the evidence toolmark on a microscope stage, and it may be necessary to cast the evidence toolmark and test toolmark using Mikrosil™ or a similar casting material. In this way, the casts can be compared more easily on the microscope stages.

As with all toolmark examinations, the examiner is evaluating the character of the toolmark on one side of the prism line, as exhibited by the height and width of the ridges or raised portions of the toolmark contour, and the depth and width of the spaces or furrows between the ridges. If sufficient agreement is observed, and subclass influence has been ruled out, then a conclusion of identity can result. If significant differences are present then an elimination could be justified. If a sufficient amount of agreement cannot be observed, than an inconclusive may be all that can be determined. Remember, the suspect tool is being examined subsequent to the generation of the evidence toolmark. The longer that this time is, the greater the potential for change to the tool working surface from normal use and abuse.

The *AFTE Journal* is the best source of information for technical reports and case reports of specific types of toolmark examinations. These reports and other articles detailing research into a specialized area of toolmarks is full of information that will assist examiners in case work. Photograph 25 illustrates an example of an impressed toolmark identification in which electrical wire crimpers were used to crimp a wire connector. Photograph 26 shows an example of a striated toolmark identification made using a slotted screwdriver. These only represent an example of the two types of toolmark identifications as a broad category. Any hard object contacting a softer object and leaving reproducible identifying characteristics can be categorized as a toolmark examination.

Photo 25: Impression toolmark.

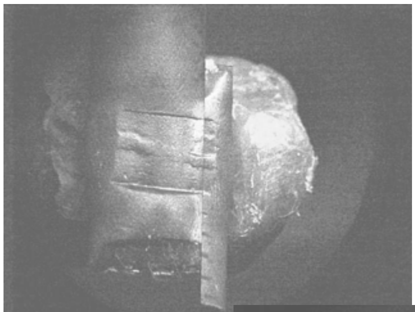
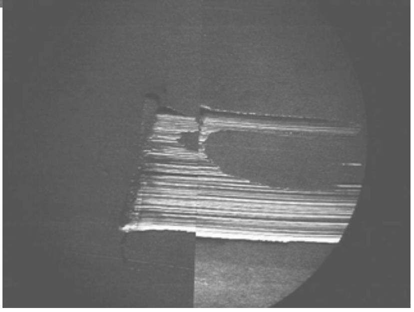


Photo 26: Striated toolmark.



Some of the research into this area has already been mentioned. Additional examples include hatchet, or slicing, cuts in wire (68); the identification of multi-strand wire (69); stab toolmarks in tires (70); knife cuts (71); the identification of torn electrical tape (72); and fracture matches (73). Research into toolmark identification has been going on for 100 years. Springer reported on the research published in the area of toolmarks (74), and Nichols reported on the research done in the area of criteria for an identification of toolmarks (75), but no one work is all inclusive.

Summary

It should be clear that the science of toolmark identification requires a basic understanding of machine processes and the effect that these have on metal. The examiner should be familiar with the mechanical properties of metal, metal deformation, and chip formation. Knowledge of the various manufacturing processes used to produce tool working surfaces can assist the examiner in determining the potential for subclass influence and individuality of a tool working surface. By gaining an understanding of how tool action affects the toolmark, an examiner can better determine if a specific tool is capable of generating the evidence toolmark, and can account for some of the variables necessary for reproducing test toolmarks. The examiner should have an understanding of tool wear and how that affects the individuality of the tool working surface. The examiner must also gain an understanding of what constitutes an identification of a toolmark with a tool, and be able to articulate the basis for that opinion.

Acknowledgement
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Dangerous Walking Stick

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Key Words: weapon alteration, homemade weapon, walking stick, cane, concealed firearm, "zip-gun"

ABSTRACT

This article describes an improvised firearm in the shape of a walking stick. This firearm fires 5.56 x 45mm caliber (.223 Rem) ammunition, and was found to be both accurate and lethal. Muzzle velocities were found to be consistent, at approximately 256 m/sec (~830 ft./sec.).

Case history

A walking stick held by a suspect dressed as an old man was confiscated based upon intelligence information suggesting that he was probably on his way to commit a homicide. The suspect also possessed 5.56 x 45mm ammunition when he was apprehended.

The walking stick was forwarded to the Forensic Firearms Laboratory for examination and test fire. A written report was furnished to investigators stating that the walking stick was, in fact, a self made weapon capable of firing 5.56 x 45mm caliber ammunition. Test fired cartridge cases were compared with the laboratory=s collection of cartridges from open cases, but no match was found.

According to Israeli law, this walking stick is defined as a weapon, due to its lethal energy. The walking stick in question was defined as a weapon due to its measured lethal energy of 459 Joules per cm^2. The suspect was accused of possessing an unlicensed illegal weapon and was sentenced to three years in jail.

Description

The walking stick was made from two major metal parts, both covered with wooden colored wallpaper (photos # 1,2,3).

Photo #1: A general look at the walking stick. The scope was found in the suspect's house.