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TECHNICAL NOTE

Gui-Hua L. Lang,[1] *Ph.D. and Gregory S. Klees,*[1] *B.A.*

The Study and Forensic Significance of Drill Bit Use Indicators

ABSTRACT: A case study involving an improvised pipe bomb with a drilled fuse hole is presented. This case study and its accompanying research details drill bit use and/or nonuse indicators. These indicators are then further classified to develop relevant conclusion criteria. These criteria are: (1) trace deposits in the form of particulate and/or smears on the drill bit, especially inside the flute and the tip area, (2) physical damage including chipping, abrasion, and fissuring on the drill bit which mostly occurred on the flute edge bevels and lip edges, and (3) thermal damage. One or any combination of these indicators could be used as effective criteria for concluding drill bit usage. This study also determined that a drill bit produces well-defined toolmarks on swarf shavings that could be identified back to that particular tool, and there is no mechanical break-in period for obtaining reproducible toolmarks on newly manufactured or unused bits.

KEYWORDS: forensic science, toolmarks, improvised explosive device, pipe bomb, drill bit, swarf

Every piece of forensic evidence has the potential of supplying a valuable investigative lead, and even the tiniest pieces are examined thoroughly to assist investigators in solving crimes. Drill bits are one type of evidence that is sometimes overlooked during a bombing investigation, especially when drilled holes perforate a work piece. According to the data collected from 2002 to February 2007 by the ATF Bomb Data Center, most domestic improvised explosive devices (IEDs) in the United States are pipe bombs using metal or plastic containers filled with low explosive powders. Black steel and galvanized steel pipe with iron end caps are the most common metal containers among metal pipe bombs. Polyvinyl chloride (PVC) and chlorinated PVC are the most common plastic pipe bomb containers used in device making. The majority of these pipe devices are fabricated to be initiated with a length of pyrotechnic fuse through a fuse hole. A functional fuse would initiate the explosives inside these pipe devices. As electric drills (cord or cordless types) are common household tools, most of the fuse holes are made by using these types of drills with an attached drill bit. The drill bit used for drilling the fuse holes can provide important forensic information in bombing investigations as they not only could contain trace material from items they contact, but can also, in the case of partially drilled holes, impart toolmarks on items that could be individually associated back to that bit.

A recent case containing evidence collected from five postblast scenes and two residences of three suspects was submitted to the laboratory for examination. Three of the postblast scenes were carbon dioxide compressed gas cylinder devices in mailboxes, and two of the postblast scenes were steel pipe IEDs. Two search warrants were conducted separately in two suspects' residences at different locations. During one of the searches, a ¼-inch diameter drill bit was recovered. An intact steel pipe device (Fig. 1*a*) filled with Hodgdon® Pyrodex® powder was recovered from another suspect's residence. This intact steel pipe device was designed to be initiated using a length of green pyrotechnic fuse through a ¼-inch diameter drilled hole in the faceplate of a galvanized iron end cap. Two fragmented galvanized iron end caps recovered from two different postblast scenes also had ¼-inch diameter drilled holes in their faceplates (Figs. 1*b* and *c*). While processing the evidence, it was apparent that linking the ¼-inch diameter drill bit to all devices could be compelling information to support the investigation. Although the diameters of the holes on all devices were ¼-inch and consistent in diameter with the drill bit, the drill bit appeared to be unused with no visual wear or damage. However, the drill bit could not be totally excluded as having been used due to a lack of any established criteria for determining drill bit usage. What happens to a new drill bit once it is used? Are there any indicators that could be used to establish drill bit usage? This study was designed to answer these questions and more. Can a new drill bit be distinguished from a used bit even if used just once? If so, what would be these discriminating indicators? What is the potential evidentiary significance of drill bits in forensic science?

Background

Drilling is one type of machining operation that is designed to cut circular holes into a workpiece. Cutting by drilling is achieved by rotating the drill bit against the workpiece with enough pressure in the direction of the workpiece to allow the bit cutting blades to penetrate it by removing material. Besides drilling, other common machining cutting operations are lathing, milling, sawing, grinding, and broaching. With these operations, there are numerous methods and equipment that can be employed to obtain a desired machined end product. Factors that affect how a metal will be machined include the type of cut needed, the accuracy and finish of the cut, the scale of production, the time of production, and the costs associated with the machining equipment and its maintenance. In this study, only the drilling operation related to this study will be discussed. More detailed information on drilling as well as other types of machining operations can be found in Colvin and Stanley (1).

Drill bits can be classified by their design and usage. For example, spade bit, brad point bit, masonry bit, and twisted bit are

[1]Bureau of Alcohol, Tobacco, Firearms and Explosives, Forensic Science Laboratory-Washington, Ammendale, MD 20705-1250.

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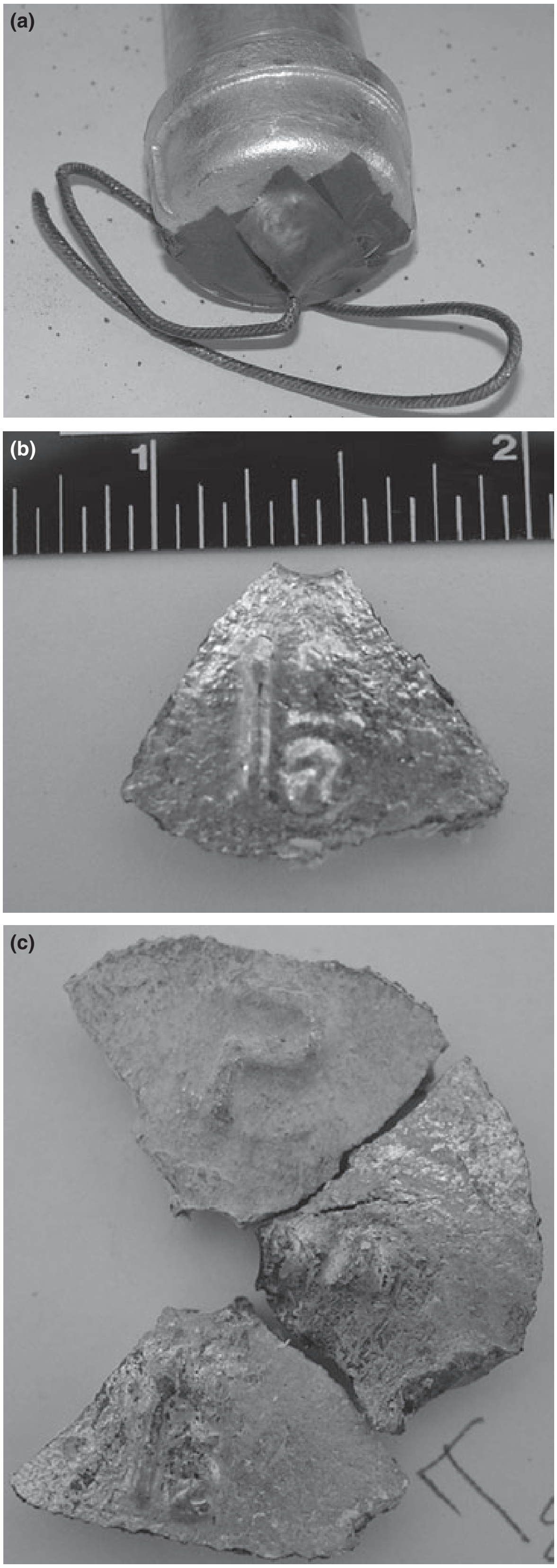

FIG. 1—*Evidence from a recent bombing case. (a) Intact steel pipe device filled with Hodgdon® Pyrodex® recovered from one suspect's residence. (b) Fragmented galvanized iron end cap recovered from first postblast scene with a partial ¼-inch diameter drilled hole in its faceplate. (c) Fragmented galvanized iron end cap recovered from second postblast scene with a partial ¼-inch diameter drilled hole in its faceplate.*

classified by their designs; center bit, spotting bit, core bit, and left-hand bit are classified by their usage. The drill bit can be further classified by the types of their shanks, such as straight or cylindrical shank bit, tapered shank bit, and square shank bit. Twisted with straight or cylindrical shank bits are the most common bits used today. The twist drill bit was invented by Steven A. Morse of East Bridgewater, MA in 1861. It was originally manufactured by cutting two grooves in opposite sides of a round bar, and then twisting the bar to produce the helical flutes, which give the name of the bit. Currently, a drill bit is made by rotating the bar while moving it past a grinding wheel to cut the flutes (2).

A twist drill bit is composed of three main parts: a point, body, and shank as illustrated in Fig. 2*a* (3). The point is the cone-shaped end of the bit that actually does the cutting, and it consists of the dead center and lips. The dead center is the sharp point at the tip of the bit and is the center of the drill bit's axis. The lips are the actual cutting blades or working surfaces of the bit. These lips are machined finished by a fine or precision grinding process to produce tapered, burr-free cutting edges so the cut material, called swarf, can easily travel through the flutes for efficient functioning (4,5). The body is the twisted portion of a twist drill bit and consists of flutes, the margin, and the web (Fig. 2*b*). The flutes are spiral grooves that run the length of the body. They have several functions including forming the cutting edge at the drill point, more tightly curling the shavings for easier material removal, providing space for the shaving's removal during the cutting process, and allowing coolant or lubricant to reach the cutting edge. The margin is the narrow strip on the edge of a flute extending its entire length, and is what is measured to determine the size of the drill because it represents the full diameter of the bit. The web is the metal column that separates the flutes, and its thickness toward the shank is gradually increased to provide the strength of a drill bit. The shank is the end portion of a bit that is mounted into a drill's chuck or spindle (6).

A cast iron end cap is one of the drilled materials chosen for this study because it is one of the most common components, where a fuse hole is often fabricated in a pipe bomb or IED. Cast iron is an extremely hard material and a common type of commercially

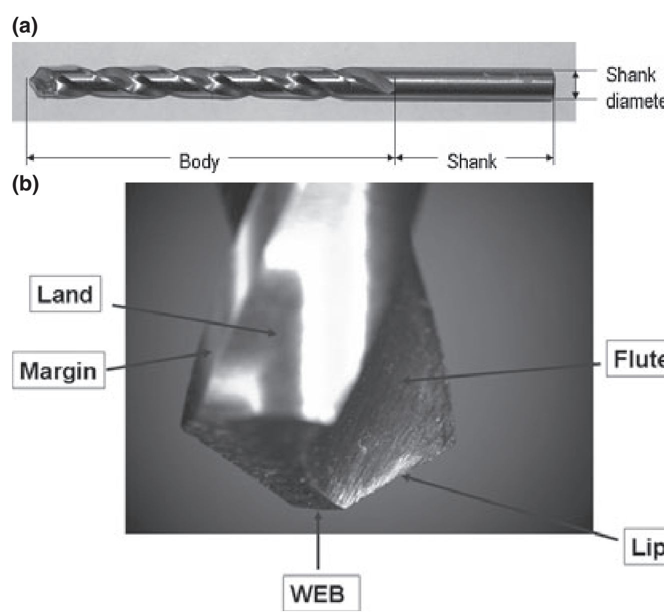

FIG. 2—*Nomenclature of a drill bit. (a) Schematic diagram of a drill bit with body and shank indicated. (b) Nomenclature of a drill bit: (1) margin, (2) web, (3) lip, (4) flute, and (5) land.*

manufactured ferrous metal. It contains relatively high carbon content, typically between 2.0% and 5.0%. Carbon steel is another ferrous metal that contains low carbon content, typically between 0.30% and 1.5%. Carbon steels with lower carbon content are not as strong as those with higher carbon content but are more flexible and ductile (6).

Materials and Methods

A SKIL® brand, Model 217, 3/8″, Heavy Duty double insulated, reversible electric drill with a keyed style chuck, manufactured by the Columbia Vise and Manufacturing Company (Cleveland, OH) was used in this study.

Drill bits used in this study were ¼-inch diameter DeWalt® (DeWalt Industrial Tool Company, Baltimore, MD) brand titanium nitride coated steel and ¼-inch diameter Ridgid® (Ridge Tool Company, Elyria, OH) brand cobalt coated steel bits. The drill bits and the testing material, which included 1¼-inch diameter SLK brand black cast iron end cap, SLK brand galvanized cast iron end cap, and Schedule 40 PVC end cap were purchased from a Home Depot® retail store (Beltsville, MD). One set of the high speed steel (HSS) bits was purchased from a local Lowe's® retail store (Beltsville, MD).

All test drillings were conducted with the drill and bit being stabilized by hand at approximately 90° to the end cap faceplate. The end cap test specimens were all stabilized by being placed in a Columbia brand #603 bench vise. The drill speed varied from low to medium speed. Each new drill bit was microscopically examined and photographed before its first drilling. After each of the three test drillings, the drill bits were microscopically examined and compared to the original conditions of each bit. After the first drilling and microscopic examination, the drill bit was cleaned with a dry two-ply type paper napkin by holding the napkin tightly against the shank and flutes' surfaces while wiping from the base of the shank to the point of the drill bit. The point of the bit was also rotated in the napkin to remove any loosely adhering debris. A dry new napkin was used for every cleaning. Shavings were also collected for microscopic examination after each drilling.

Results

Morphology of Swarf

Swarf is defined as the debris or waste resulting from the mechanical removal or cutting of a material (7). As Fig. 3 illustrates, swarf consists of either continuous chips, commonly known as shavings, or discontinuous chips, commonly known as particles (7). The elemental composition of swarf could be determined through various analytical techniques such as scanning electron microscopy coupled to an energy dispersive X-ray analyzer for quantitative or semi-quantitative analysis (8). Our study showed

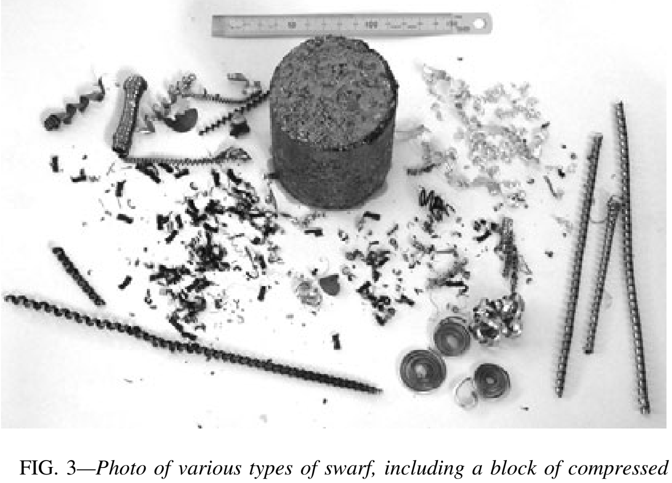

FIG. 3—*Photo of various types of swarf, including a block of compressed swarf.*

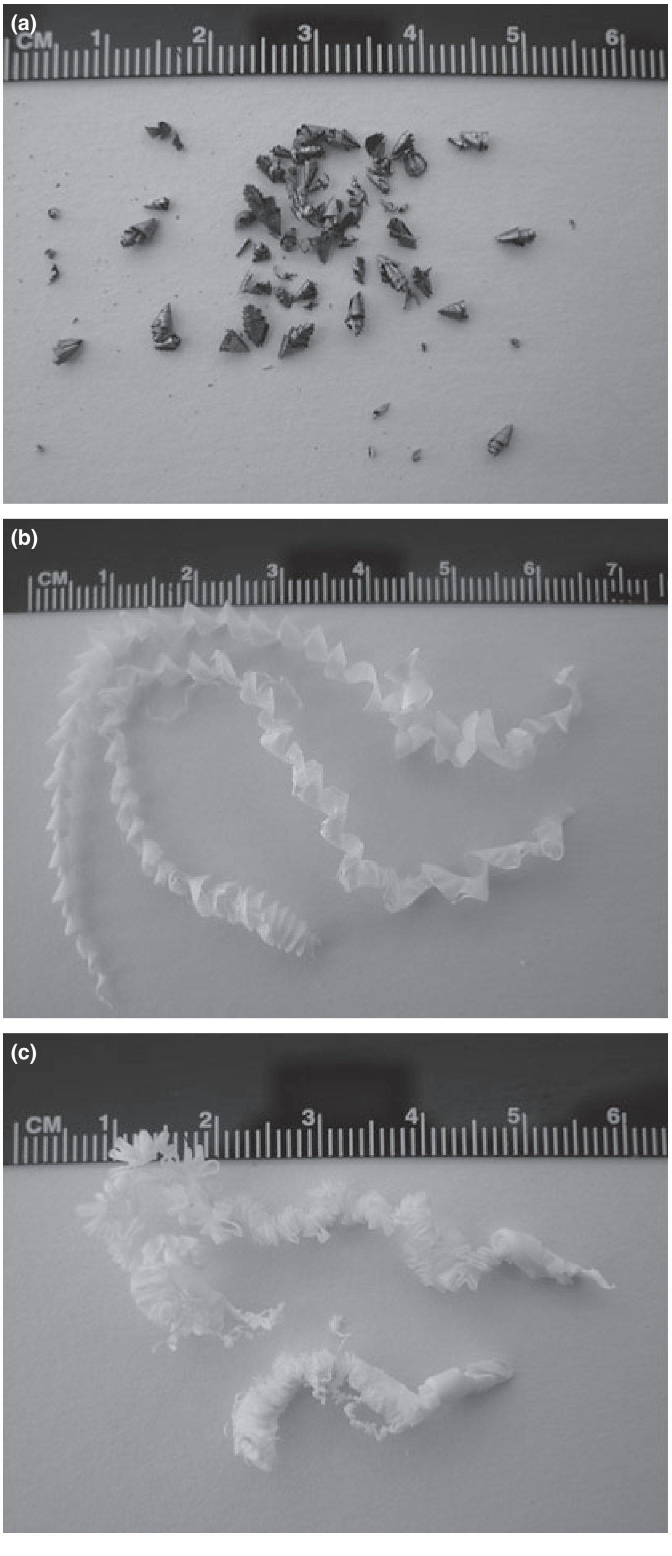

FIG. 4—*Morphology of swarf produced from drilling different material. (a) Cast iron end cap. (b) PVC end cap at lower drilling speed. (c) PVC end cap at higher drilling speed.*

that the swarf type and size vary for different drilled materials. For cast iron end caps, the swarf was smaller and more of a discontinuous chip (Fig. 4*a*) while PVC swarf was long ribbon-like continuous shavings (Fig. 4*b*). The cast iron swarf could be differentiated from galvanized cast iron swarf due to the lack of zinc coating. The PVC swarf had different formations like folded ribbon or coiled ribbon depending on the speed of drilling process. The faster the drilling speed, the more folded ribbon formation swarf was seen due to the larger amount of heat generated at the drill bit, which partially melted the PVC material (Figs. 4*b* and *c*).

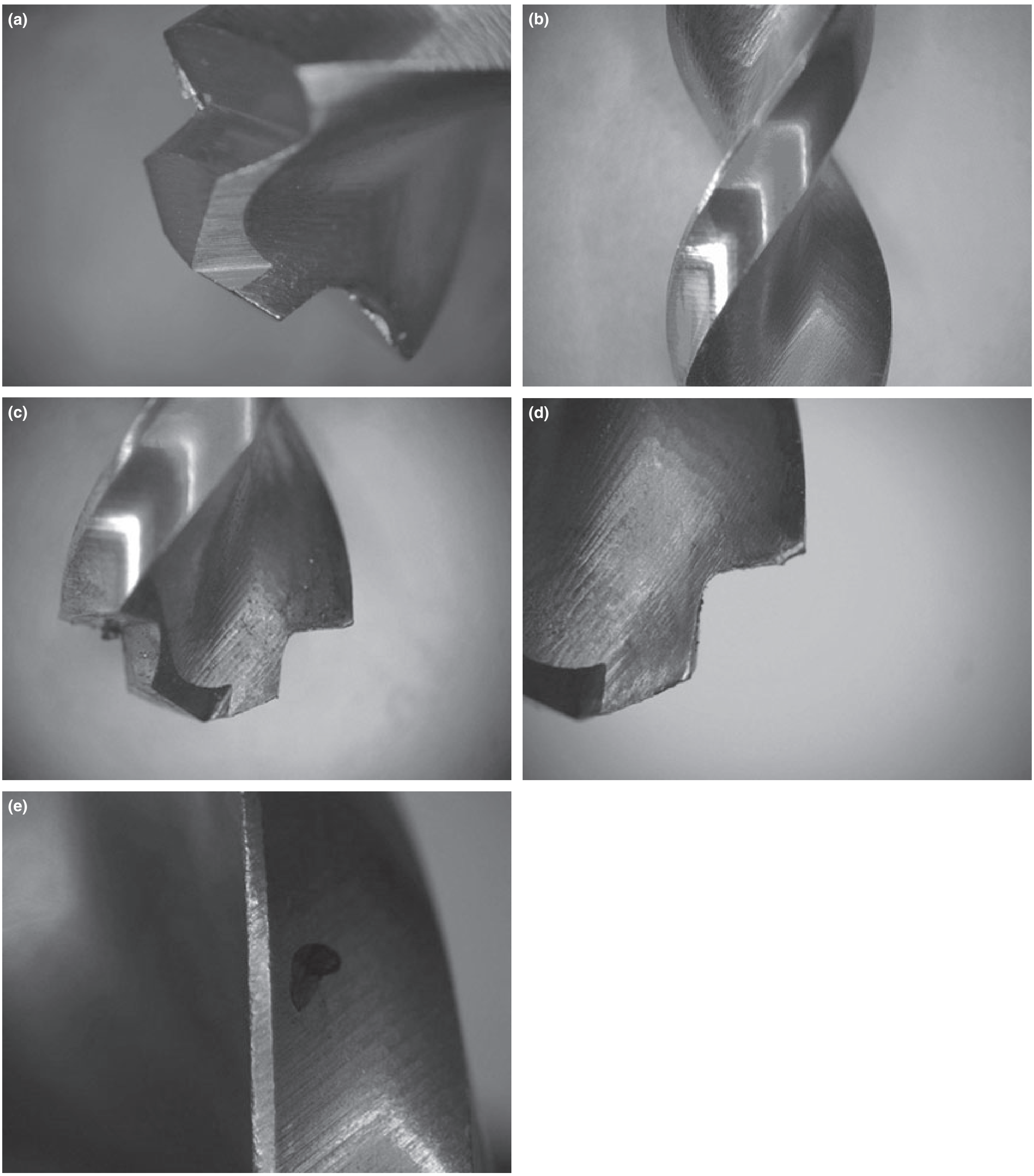

FIG. 5—*Titanium nitride coated drill bit. (a) Close-up view at the tip area of the new bit. (b) Photo of the smooth flute edges of the new bit. (c) Trace deposits of swarf in the flute and the tip area. (d) The corner of the right lip edge was chipped off. (e) Erosion observed on one of the flute edges' bevel.*

Titanium Nitride Coated Drill Bit with Black Iron End Cap

The manufacturing finish of a Dewalt® brand titanium nitride coated bit was smooth overall as given in Figs. 5*a* and *b*. After its first drilling, the drill bit was examined under a stereomicroscope, and it was noticed that large and small swarf removed by the drilling process was deposited on the bit as seen in Fig. 5*c*. Much of the deposits were concentrated in the flutes and on the tip area with visual physical damage also present in these areas (see Figs. 5*d* and *e*). Additionally, a dark blue colored tip was observed that was indicative of thermal damage. After the initial microscopic examination was completed, the used drill bit was cleaned using a paper tissue by wiping the drill bit up and down two times. The microscopic examination showed that the finer swarf was still on the drill bit, especially inside the flutes.

The damage from the second and third drillings was not noticeably different from that of the first drilling.

Cobalt Coated Drill Bit with Black Iron End Cap

The finish of a Ridgid® brand cobalt coated bit was as smooth as the DeWalt® titanium nitride coated bit used in this study as shown in Fig. 6*a*. After the first drilling, small and large swarf deposits were noted in the flutes and point areas with large shavings attached to the lip edge (Fig. 6*b*). Black smears were also observed at the point area of the bit. Not until the second drilling was physical damage on the flute edge and lip edge observed (Fig. 6*c*). The third drilling did not produce additional noticeable damage on the bit.

HSS Drill Bit with Black Iron End Cap

The finish of the new HSS bit was rough with pits and minute irregular manufacturing marks on the flute edges and point areas. After the first and second drillings, the physical damage to the bit was more pronounced than the original manufacturing imperfections. For example, parts of the lip edge and flute edge were smashed and rolled up. The lip edge was damaged after the first drilling, and the flute edge damage was observed after the second drilling. No significant additional physical damage was seen for the third drilling. Again, the swarf deposits were significant after the first and second drillings, even after the cleaning process.

HSS Drill Bit with Galvanized Iron End Cap

The first drilling produced substantial wear marks in the form of drill bit tip chipping and erosion on the flute and the tip corner edges. Substantial amounts of particulate deposits were present all over the drill bit. After cleaning, the drill bit still had much finer swarf attached, especially in the flutes. No thermal damage was observed.

HSS Drill Bit with Schedule 40 PVC End Cap

The first drilling of the PVC end cap produced a large amount of long, folded, ribbon-like swarf and finer swarf than subsequent drillings. The long, folded, ribbon swarf was easily removed with a paper napkin, but small swarf tended to adhere to the flute edges of the drill bit. No physical degradation, such as erosion or thermal damage was observed following the first drilling. Since the PVC swarf holds static charge, they tend to cling to the drill bit and, thus, are more difficult to remove. A more thorough cleaning is needed to remove this type of static swarf.

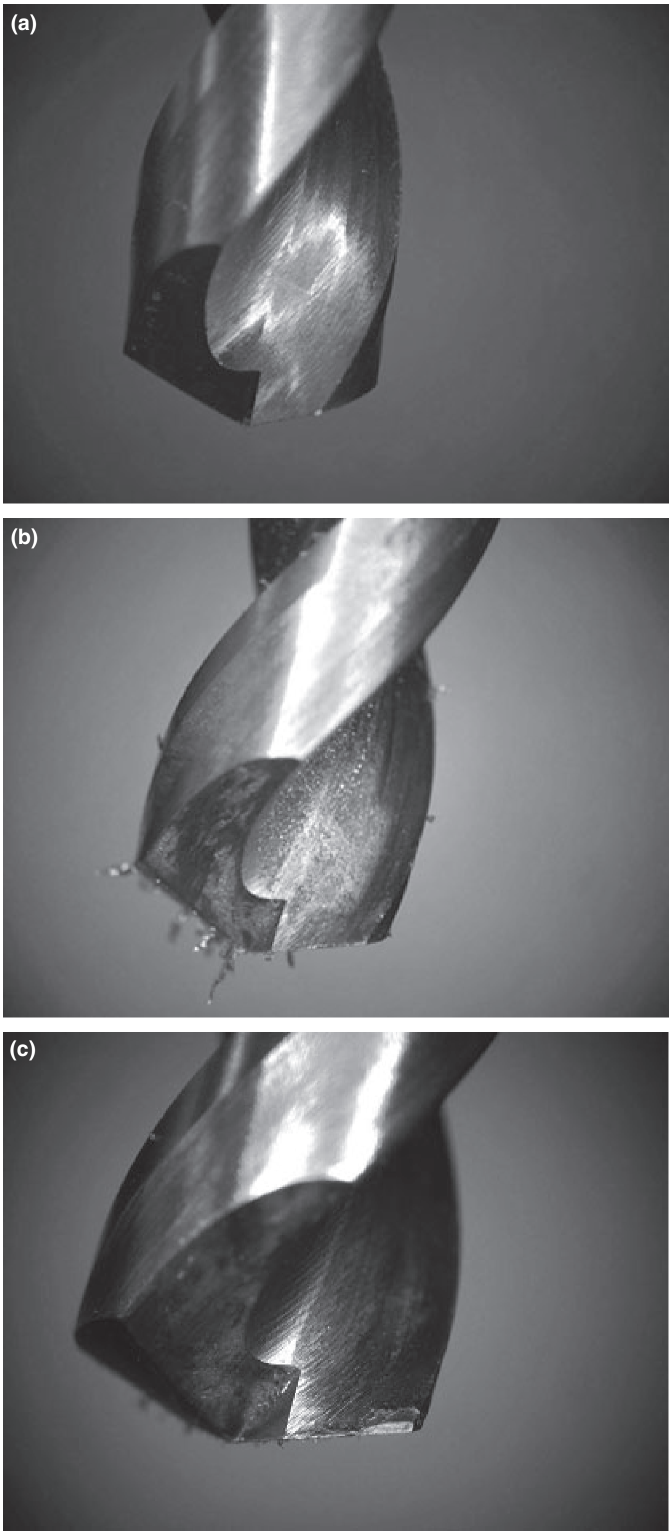

FIG. 6—*Cobalt coated drill bit. (a) Photo of a new cobalt coated drill bit. (b) Swarf deposits in the flute and the tip area of the drill bit. (c) Physical damage observed on the lip edge.*

Discussion

Drill Bit Use Indicators

The results of this study show that drill bit use or nonuse can be determined by examining three indicators: (1) trace deposits in the form of particles and/or smears, (2) physical damage, and (3) thermal damage. A discussion of each indicator follows:

Deposits—The swarf deposits on the drill bit were observed for all drill bits studied. It made no difference if the test medium was a galvanized iron end cap, a black iron end cap, or a PVC end cap. A substantial amount of swarf was left on the drill bit after the initial drilling, even after minimal dry cleaning with a napkin. The PVC end cap showed large ribbon-like swarf that was folded as it was dislodged while drilling. This study demonstrated that a used drill bit accumulated swarf that could not be casually cleaned, especially when the drilled specimen was metal. Finer swarf tends to adhere to the flute surfaces and requires greater effort to remove all swarf from the drill bits. However, the bit used to drill the PVC end cap could be cleaned to look like a brand new one with some effort.

Physical Damage—All the experiments in this study showed that the majority of erosion occurred on flute edges and tip edges in the first two drillings. No dramatic additional physical damage was observed for the third drilling from the second drilling. This finding indicates that the weak areas of the bits were mostly affected during their initial use. After the three initial drillings, it is assumed that only regular wear, such as erosion on edges and tips will occur. It is expected bits would continue to dull until they were not sharp enough to be useful, but this was not confirmed. However, there was no physical damage observed when a HSS drill bit was used to drill a PVC end cap in this study.

Thermal Damage—Thermal damage was not consistently observed on the drill bits in this research. Only the titanium nitride coated bit exhibited thermal damage at the tip point, which was observed as a dark bluish color after the first drilling. Occurrence of thermal damage may depend on the work material, the composition of the drill bit, and drill bit speed. A logical conclusion could be made that when a strong drill bit (e.g., titanium) is used on a relatively harder work material (e.g., cast iron), thermal effects are more likely to occur. Conversely, when a weaker drill bit is used on a relatively harder material, the bit will have a higher tendency to break before showing any thermal effects if the drill speed is excessive. If a strong bit (e.g., titanium or steel) is used on a relatively softer material (e.g., PVC), no significant thermal or physical damage on the bit should be expected.

Toolmarks

The potential individuality of marks left by the contact of a tool on a work piece has long been established in forensic science. Seminal microscopic studies conducted by May, as early as 1912, of assorted tools that contained individual characteristics randomly

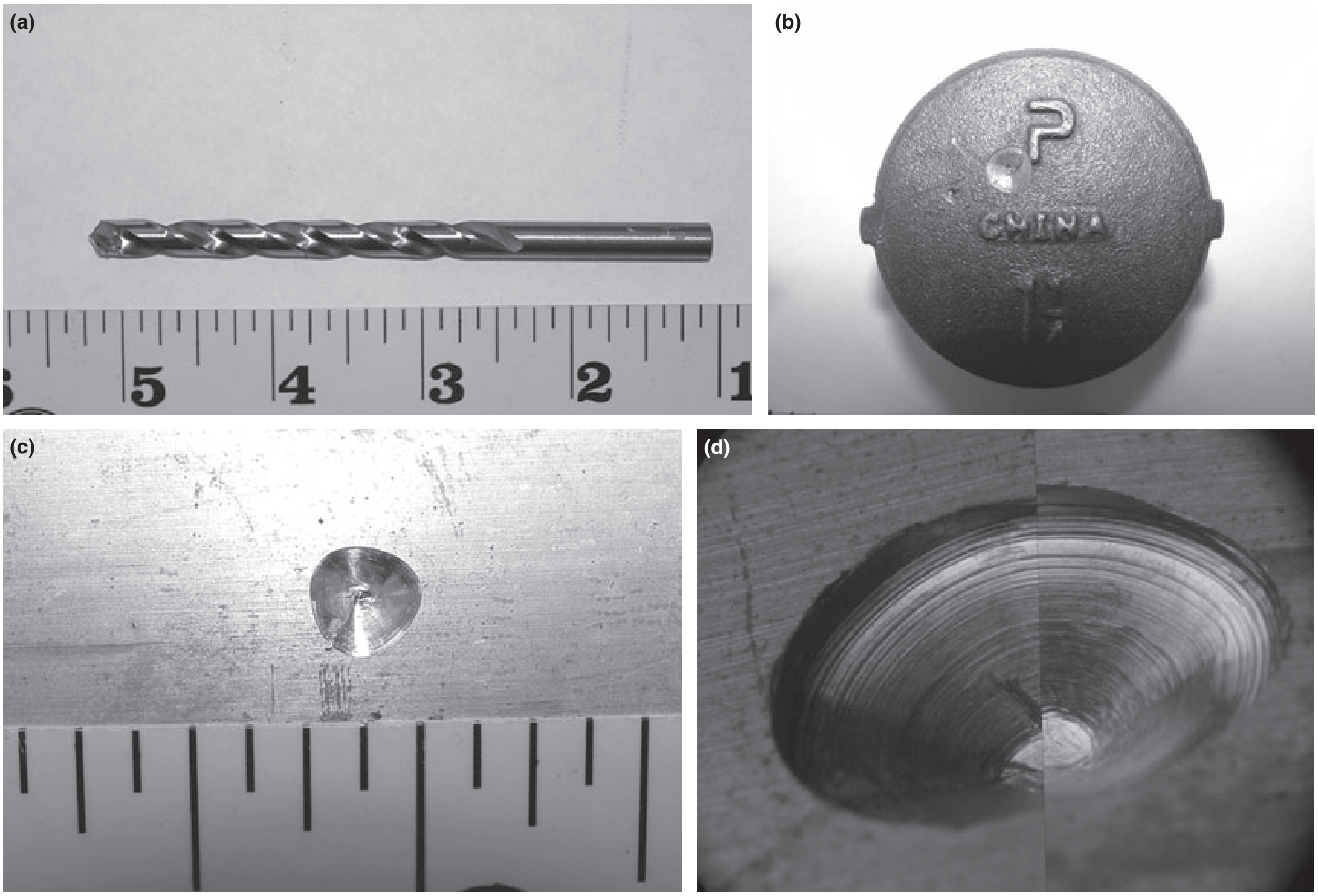

FIG. 7—*Traditional toolmark examination on partially drilled hole. (a) HSS drill bit. (b) Partially drilled hole impression on a IED black iron end cap (questioned item). (c) Drill hole test impression by recovered drill bit (known item). (d) Photomicrograph of toolmark association with device impression on left and drill bit test impression on right.*

produced by common machine finishing processes conclusively proved that practically every tool used in his shop could be positively identified (9). During these studies, toolmarks produced by tools containing blades which were finely ground and honed to a "razor-like edge" could be identified back to a particular tool (9). Gunther and Gunther (10) soon provided foundational support for May's empirical toolmark findings by explaining how individual characteristics can originate on a tool surface from the manufacturing processes of that tool and imparted onto a work piece. This latter point also conforms to Locard's exchange principle. Davis (11) later noted that tools containing ground machine finishes consistently produced toolmarks with individual characteristics that could be consistently identified back to the tool that produced them. Recently, Miller (12) discussed extensively how knowledge of various processes in tool manufacture is important in determining a tool's individual characteristics and avoiding misidentification by subclass characteristics. Nichols (13–15) provided a compendium of empirical toolmark studies that consistently associated tools with ground, lapped, tumbled, and filed finished working edges to a mark that it produced even when that mark was also compared to consecutively produced tools. Salmon (16) provides a supporting view from outside forensic science of these findings by discussing how surface roughness features, produced by modern grinding processes leave noticeable individual characteristics in the form of random surface contours and metallurgical imperfections. These studies illustrate that the manufacturing finish of a tool's working surface, and not the general design, type, and configuration of a tool, is the critical factor in determining individuality when comparing it to a questioned mark.

Studies directly addressing the individuality of twist drill bits, which are basically double-edged rotating cutting tools, were first reported by Reitz (17) in his examination of consecutively produced drill bits. In 1998, Jones et al. (18) reported on the reproducibility and individuality of toolmarks when compared with consecutively manufactured drill bits. In 2004, Lewis et al. (8) reported that a suspect was placed at the crime scene by the matching toolmarks on the copper swarf recovered from the suspect's boots to the toolmarks of a copper swarf recovered from the crime scene. In these instances the results regarding the ability to individualize toolmarks back to the drill bit that produced them were consistent with the earlier findings cited by May, Davis, Miller, and Nichols. This potential to individualize marks back to a particular tool source makes the forensic comparative discipline of Toolmark Identification very valuable in the examination of IEDs.

The conventional or most well-known method for examining toolmarks produced by a drill bit occurs when a partial or nonperforating hole is produced on a work piece, such as IED component end caps or pipes (Fig. 7*b*). The toolmarks present in this partially drilled hole are compared with the toolmarks from a test cut or specimen produced by a suspect's bit cutting blades (Fig. 7*c*). These two sets of toolmarks are then microscopically compared side-by-side to determine if the known toolmarks of the bit match the questioned toolmarks on the IED (Fig. 7*d*). However, this study also determined that drill bits produce well-defined toolmarks on swarf as reported by Lewis et al. (8) and Reitz (17), which could be identified by an experienced toolmark examiner, even from a perforated hole (Figs. 8*a*, *b*, and *c*). The matched toolmarks could be used to individually associate a specific drill bit to a specific fabricated device. If the toolmarks on swarf from a drilled hole on a device are matched to those found on swarf recovered from a suspect location, this would directly link a drill bit to a device. In a case where no swarf was recovered from the device, toolmarks on test cut swarf could be used to indirectly link those found on swarf recovered at a third location only if the third location could be linked to the device by other forensic evidence. In this situation, the toolmark match would be probative and compelling information.

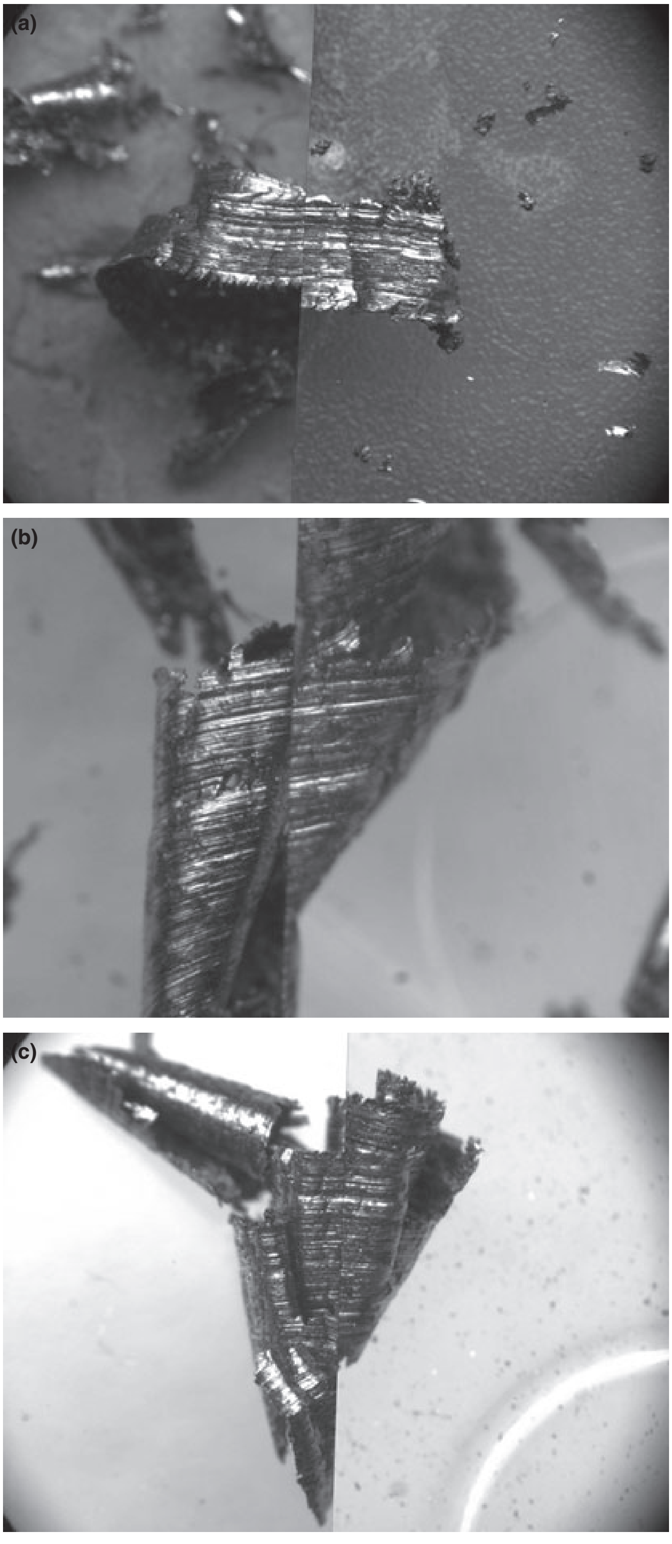

FIG. 8—*Swarf toolmark association photomicrographs with first test drilling on left and third test drilling on right. (a) Titanium nitride coated drill bit at 20× magnification. (b) Cobalt coated drill bit at 50×. (c) HSS at 50×.*

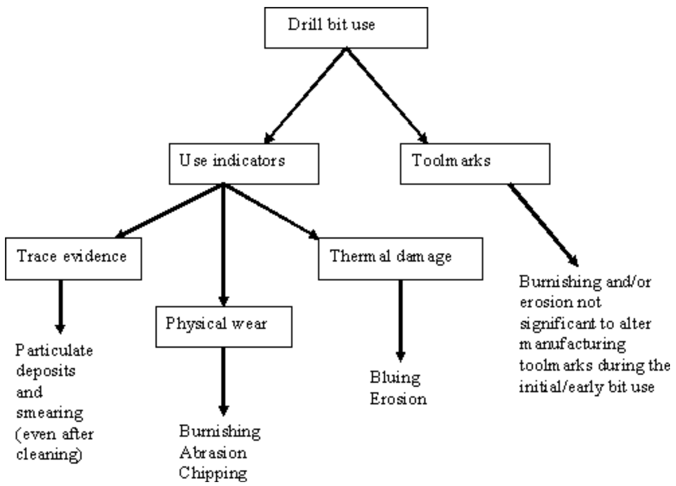

FIG. 9—*Summary of drill bit use study.*

The well-defined toolmarks on the first drilled shaving and the third drilled shaving (Fig. 8) (shaving from the second drilling was not examined) also confirmed that no initial mechanical break-in period is necessary for new drill bits to leave consistently reproducible toolmarks. In many instances, a machined or mechanical item such as an automobile engine or firearm barrel requires an initial break-in or surface burnishing period of use before it imparts consistently reproducible toolmarks (19). This study demonstrated that, unlike those mechanical items, a drill bit produces readily identifiable toolmarks on its initial use and that the toolmarks are reproducible even after three subsequent uses of the tool.

The reproducibility of toolmarks on swarf is important for forensic scientists in attempting to provide investigative leads. When conducting search warrants, drill bits and drills should be included on the search list if a device that contained a drilled hole(s) was recovered from either a postblast scene or from a device seized during a search. It is also important to collect swarf of potential value based on similar morphology from a search site if a device with a drilled hole is involved in the case. Collecting the right type of swarf is important due to the possible large and varied amount of swarf available on a workbench. Because most swarf could not easily be differentiated by their physical appearance, collecting any swarf of interest should be a recommended practice.

Conclusions

This study noted the presence of distinct indicators that can enable differentiation of a used drill bit from a new or unused bit. Additionally, these indicators can be classified and characterized to establish criteria for determining drill bit use. The three indicators of drill bit use are: (1) the presence of trace deposits in the form of particulates and smears on the drill bit, especially inside the flute and the tip area; (2) physical damage including chipping, abrasion, and fissuring on the drill bit, which mostly occurred on the flute edge bevels and lip edges; and (3) thermal damage. One or any combination of all three indicators could be used as effective criteria for drill bit use evaluation as summarized in Fig. 9.

Physical damage is the most prominent indicator for any drill bit used on metal. Trace deposits are the second most prominent indicator and they remain even after the cleaning process. The third indicator of thermal effect was only observed for selected drill bits and selected drilling materials. One should expect possible thermal damage from a strong drill bit drilling a hard material, and no thermal or physical damage when a drill bit is used to drill a softer material like PVC. Indications of thermal damage are a definite indicator of prior use; however, no conclusions regarding prior use should be drawn from a lack of thermal damage.

During this study, the forensic value of toolmarks from drill bits was also evaluated. The study concluded that no mechanical break-in period was needed for obtaining reproducible toolmarks from newly manufactured or unused drill bits. Toolmarks imparted on swarf were well defined and can be individually associated either with recovered swarf or test cut swarf.

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Additional information and reprint requests:
Gui-Hua L. Lang, Ph.D.
ATF National Laboratory Center
6000 Ammendale Road
Ammendale, MD 20705-1250
E-mail: Gui-hua.L.Lang@usdoj.gov