Advancing Forensic Firearm Examination Protocol: Shotgun Firing Pin Impressions

Highlights

- Firing pin material properties effect extent of topographic change during test firing
- Current examination protocols do not image firing pin before test firing
- Firing pin surface morphology was insufficiently documented to evidence change
- Future practice should include routine imaging of firing pin surfaces prior to test firing

Novelty Statement

The novelty of this study lies in the exploration of the impact that material composition of a firing pin could have on forensic firearm examination process in the context of a real case study. Both forensic comparison and elemental analysis were conducted on firing pins from shotguns, which are frequently recovered and used in criminal discharges across Europe, but are often overlooked in published research literature. Thus, this work suggests changes to the current process of firearm examination and aims to address the current gap of knowledge and initiate future research in this area.

Abstract

The theory of forensic firearm examination relies on the assumption that of the two contacting surfaces, the harder surface leaves marks on the softer one. The class and individual characteristics left by firearm parts undergo change due to several key variables, including the ammunition, and the firearm themselves. Notably, the characteristics are subject to distinct or permanent change during the first few fires immediately after manufacturing. In contrast, alterations arising from the many other factors associated with the shooting process tend to develop with slight variations. Using four different shotgun, this study examined the distinct changes observed in the individual characteristics formed by firing pins on fired shotshell cases. Understanding the manufacturing processes and conducting elemental analysis on the

firing pins was necessary during this examination. The choice of material used to construct the shotgun firing pin appears to be the main reason for the inconsistent and changing marks observed on the fired shotshell cases. Although the changing individual characteristics within firing pin impressions could hinder the forensic comparison and examination of the shotgun, this study demonstrates how an integrated, holistic approach can overcome this challenge through the comparison and analysis of other firearm parts' marks. This study contributes to the scientific understanding of forensic firearm examination by evidencing the contribution and importance of the firearm part's material composition and the need to document the part's surface prior to test firing.

Keywords:

Cartridge case, Forensic science, Imaging, Microscopy, Surface topography, Shotshell**.**

1. Introduction

Shotguns and shotgun ammunition are widely used in hunting, game shooting and sports [1-3]. As a part of sporting culture, the legal availability to access shotguns compared to other types of firearms in Turkey and other European countries makes them subject of crimes including homicide and intentional bodily harm, or suicide [4-10] (Figure 1). Designed as shoulder-fired weapons, shotguns typically propel shot (also referred to as pellets), or a slug from their associated ammunition [11]. As fired shots and slugs typically contain limited characteristic features for comparison to try to establish which firearm discharged it (referred to as forensic firearm examination) due to the smooth bore [12-13], fired shotshell cases are the primary means of performing forensic firearm examination for shotguns [14]. However, fired cartridge cases from shotguns (shotshells) are not as prevalent in the databases of automated forensic comparison systems (referred to as ballistic identification systems, or BIS) compared to cartridge cases fired from other types of firearms [15]. This means one-to-one examinations are a more frequently encountered practice in the forensic comparison of fired shotshell cases in some laboratory's daily practices.

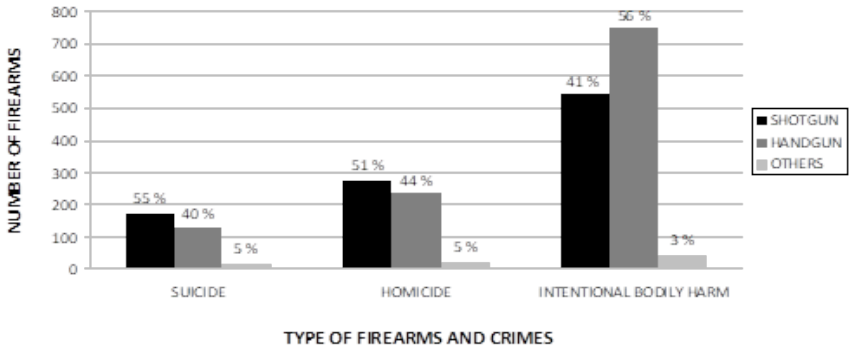

Figure 1: The types of firearms according to the specific crimes examined at the Gendarmerie Forensic Laboratories (Turkey) between the years 2018 and 2022.

Examination of a fired cartridge case is conducted using the specific class and individual characteristics formed on the cases during ignition of the cartridge [16]. A large amount of

pressure is generated during firing, which facilitates the formation of marks left by firearm parts such as the firing pin and breech face, which contact with the case surface [17]. To examine the physical evidence accurately, all the marks produced by firearm parts should be evaluated as a whole [18]. Among these parts, the firing pins form proportionally distinguishable marks on fired shotshell cases even under low-pressure build-up in the chamber [19].

Firing pins are manufactured using CNC (computer numerical controlled) lathes, metal injection moulding, and stamping for example, depending on the manufacturer's factory processes [17]. These primary production processes are often followed by finishing methods, such as abrasive blasting, tumbling, chrome plating, parkerisation to reduce surface roughness and are the sources of class, subclass, and individual characteristics. The class characteristics of the firing pin impression relate to the geometric shape (form) and dimension of the firing pin that produces this mark and is therefore a common feature that is present across different guns of the same make and model. Firing pins and their impressions may be elliptical, hemispherical, rectangular, or have a flat base [18]. Subclass characteristics can potentially be produced by features present on the surface of multiple consecutively manufactured firing pins, for example firing pins formed in the same mould or manufactured by the same tool [20], and therefore cannot be used to differentiate one specific firing pin as being the source of an impression from another. It is only the presence of sufficient individual characteristics that make forensic firearm examination possible, which at this time, is typically established through examiners' personal experience [21,22]. Individual characteristics are primarily produced in the firing pin impression from random defects and irregularities occurring incidentally during the firing pin's production or through changes to the firing pin surface caused by corrosion or damage during use [21,23]. Therefore, the reproducibility of the

impressions formed on fired shotshell cases depends on several factors such as the amount of pressure applied to the surface during cartridge ignition, the malleability of the primer, and the durability of the production material of the firing pin and breech face [24]. Furthermore, the procedures involved in the installation and extraction of primer caps during cartridge manufacture and/or reloading have a significant influence on the topography of tool marks on the primer after the firing process [25,26].

As firearms' parts are exposed to various external effects from production to end user, each moving or immobile component is produced using different raw materials to withstand these forces [25]. Steel is one of the raw materials used in the production of small firearms that contain mainly iron (Fe), 0.008-2.14 wt% carbon (C), and various alloying elements. Steel, a large family of ferrous alloys, is classified into different types according to their intended use, which depends on the methods applied in the production process, and combinations of elements to determine their characteristics [27]. Establishing the parameters of a material, for example, tensile strength, hardness, and wear resistance can enable the structure and properties of the alloy to be determined [28]. The fact that the firing pin is in frequent contact with the cartridge makes hardness an important property during the alloy production processes [17]. From discussions with shotgun manufacturers, DIN 17223 steel wire is used in the manufacture of firing pins [29]. This is a medium carbon steel containing 0.40-1.00% carbon (C), 0.35% silicon (Si), 0.30-1.50% manganese (Mn), <0.2% copper (Cu), <0.04% phosphorous (P) and <0.04% sulphur (S) [30]. However, "AISI 1040 complete steel" represents a widely utilised material within various sectors of the steel industry [31] and may be used in other firing pin manufacture [32]. The composition of AISI 1040 medium carbon steel includes a minimum of 98.6% iron, 0.40% carbon, and 0.75% manganese [33]. Furthermore, this type of steel may contain sulphur in the range of 0.10% to 0.40%, with a

maximum allowable level of 0.05% phosphorus [34]. This material is employed for fasteners and bolts in applications such as couplings and crankshafts [31]. In this study, deviational changes were observed in the individual characteristics of the firing pin impression produced when test firing a shotgun sent to the laboratory as part of casework. In light of the strength and variability in the marks left by the firing pin, this study investigated whether the pattern of individual characteristics within firing pin impressions changed after a certain number of shots. Elemental analysis was also conducted on the firing pin to non-destructively investigate whether its material composition may have affected the formation of firing pin impressions. Three other shotguns were test fired and analysed for comparison as part of this study.

2. Materials and Methods

As demonstrated in Figure 2, self-loading, semi-automatic shotguns constitute almost half of the shotguns examined at the Gendarmerie Forensic Laboratories. As a result, this study focused on the examination of a 12-gauge, Daglıoglu Arms, FD 63 Model self-loading, semi-automatic shotgun, serial number (SN) 34-G22YD-001292, year of production 2022 (Figure 3), which was sent to the laboratory together with 14 fired 12-gauge shotshell cases recovered from the crime scene. Observation by examiners determined that the weapon was not new, and had been used for a considerable amount of time after the production. The variability of individual characteristics of the firing pin in the first batch of test fires necessitated the proceeding steps to prevent irreparable damage to the evidence.

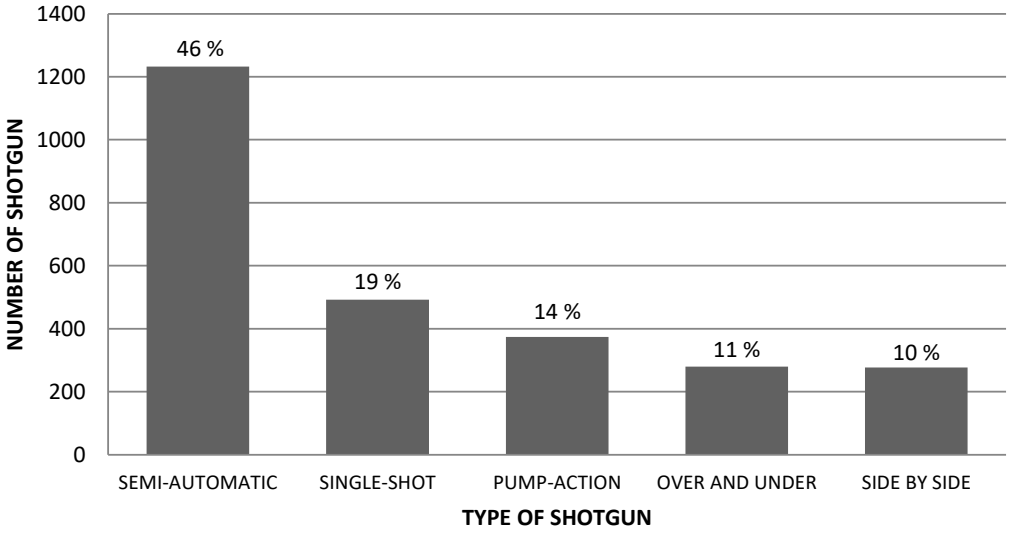

Figure 2: The types of shotgun examined at the Gendarmerie Forensic Laboratories between the years 2018 and 2022.

Figure 3: The 12-gauge shotgun (SHOTGUN-00) alleged in the case.

There is no standard rule on how many shotshells should be obtained for examination in a case of a recovered firearm with related evidence [23]. It practically depends on the examiner to determine the number and the best quality shotshell cases among them to be compared with the evidence. In this study, alteration in the individual characteristics began at the fourth discharge. Thereby, test fires were performed using the recovered shotgun (SHOTGUN-00) in three batches, each of which consisted of four shots to observe the changes in the individual characteristics intermittently. Each cartridge was also discharged at intermittent intervals, with a minimum delay of one minute, to facilitate adequate cooling of the firearm. Ultimately, it was resolved that more than twelve test fires (especially if using higher propellent loading cartridges, e.g. high performance magnum steel cartridge) would cause too much damage to the firing pin of an alleged crime firearm (i.e. evidence), rendering it unusable in the associated court case. A total of 12 test fired shotshell cases were therefore obtained and each was numbered in the order of discharge (1 to 12). Images of each test fired shotshell base were acquired using a Leica FSC comparison microscope (Leica Microsystems, Wetzlar, Germany) at 40X magnification after a one-to-one comparison with the fired shotshell cases found at the crime scene. The fired shotshell cases collected from the crime scene were compared with each other and imaged, as well.

As the 14 fired shotshell cases recovered from the crime scene (Figure 4) appeared to be from various brands (Table 1), different brands of 12 gauge/70mm shotgun shotshells were used in the test fires as seen in Table 2. Headstamps of test fired shotgun shells were mostly the same as the three headstamp types on the shotshell cases recovered from the crime scene to provide nearly the same material properties, such as hardness and malleability of the primer cap, and internal ballistic properties during ammunition discharge. This assumption was based on the technical specifications of cartridges released by the same ammunition manufacturer [26].

Minute differences in toolmarks are formed on cartridges produced by different brands. These differences include the amount of flowback, or changes in volume (primarily depth) of firing pin impressions [35]. Therefore cartridges with 12*12*12*12*, CLEVER 12 MIRAGE 12, STERLING 12 ITALY 12 headstamps, which are the same as crime shotshells, were test fired in the first three discharges. At this point, to achieve more apparent and pronounced marks on test cartridges under the microscope, "different brands and types of ammunition" were used as advised in the procedure of cartridge and shotshell examination [23]. As the experiment progressed, shotshells with dissimilar headstamps were tested to distinguish (non)reproducible individual characteristics. This experimental procedure was adopted to carry out cross-validation of different types of shotshells and thus increase the sensitivity of the forensic examination and comparison process. However, the number of test fires was restricted to 12 shots since a higher number of shots may have affected the morphology of the firing pin and damaged the physical evidence.

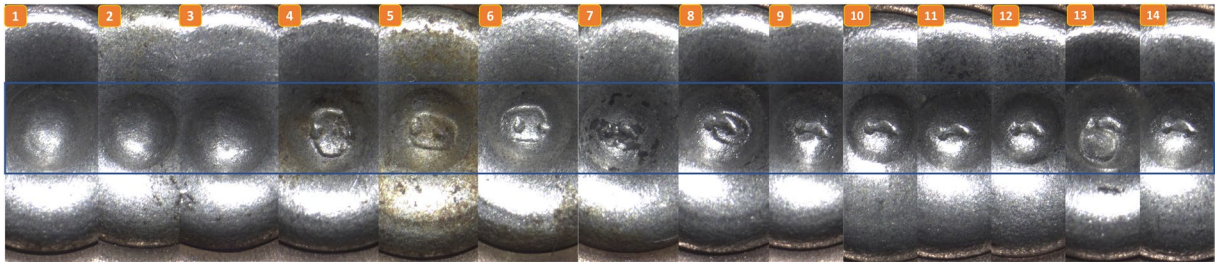

Figure 4: The firing pin impressions on 14 shotshell cases recovered from the crime scene. Note - the key to interpret the image numbers is provided in Table 2.

186 **Table 1:** Summary interpretations of fired 12-gauge shotshell cases recovered from the crime

187 scene.

Cartridge Case Headstamp	Number of Recovered Fired Shotshell Cases	Interpreted Brand of Shotgun Cartridge	Lead Shot Size	Assigned Number for the Firing Pin Impressions on Recovered Shotshell Cases in Figure 3
CLEVER 12 MIRAGE 12	3	Mirage	7	1-3
STERLING 12 ITALY 12	4	Sterling	Buckshot	4-7
12*12*12*12*	7	Jet	Buckshot	8-14

188

189 **Table 2:** The brands, models, and calibres of the 12-gauge/70mm-chamber shotgun shells

190 used in consecutive test fires.

Discharge Number	Brand	Headstamp	Lead Shot Size
1	SAGA	12*12*12*12*	6
2	PALIETTONI	CLEVER 12 MIRAGE 12	7
3	STERLING	STERLING 12 ITALY 12	Buckshot
4	YAF (YAVASCALAR)	CHEDDITE-12	1
5	YAF (YAVASCALAR)	CHEDDITE-12	3
6	OZKURSAN	OZKURSAN 12	8
7	RC2 CACCIA	RC 12 ITALY 12	1
8	JET	12*12*12*12*	5
9	YAF (YAVASCALAR)	CHEDDITE-12	4
10	STERLING	12*12*12*12*	Buckshot
11	STERLING	12*12*12*12*	Buckshot
12	STERLING	12*12*12*12*	Buckshot

191

192 To ensure the reliability of the forensic examination process, crime scene and test fired

193 shotshell cases were submitted to and examined by two further independent examiners in the

194 laboratory to perform a blind test. These examiners also observed the changing individual

195 characteristics on the fired shotshell cases and established these as an idiosyncratic situation.

To compare the reproducibility of firing pin impression's individual characteristics on the test fired shotshell cases and recovered exhibits with that of different samples, a comparable break-open (SHOTGUN-03; Huglu Firearms, cylinder barrel, SN: S.56410, year of production: 1980), a double barrel (SHOTGUN-02; Huglu Firearms, cylinder barrel, SN: 99.1646, year of production: 1999), and a self-loading, semi-automatic (SHOTGUN-01; Huglu Firearms, cylinder barrel, SN: 109400, year of production: 2000) 12-gauge shotgun were selected from the laboratory's reference collection of small arms. These three types of shotguns are the most examined ones in the laboratory. Twelve shotshells were fired from each of the three reference shotguns and a total of 36 test fired shotshell cases were obtained. Shotshell cases fired from the crime shotgun and three reference shotguns were examined under the same Leica comparison microscope and their bases were imaged at 40X magnification.

The firing pins of three reference shotguns were dismantled and that of the alleged crime shotgun were pushed through the housing due to the fact that it is integrated to the breechface part. They were subjected to a triplicated elemental analysis conducted using a Zeiss Evo LS15 Scanning Electron Microscope (SEM) (Zeiss Group, Oberkochen, Germany) and Oxford Instruments INCA 5.05 for data processing. The backscattered electron imaging was performed under 37X magnification and 20 kV. The main reason for opting for this non-destructive method is that the integrity of the evidence was not compromised. Before placing the firing pins on the sample mount, they were cleaned of residues that would affect the analysis. No coating was applied to the firing pins on the stage, left under vacuum conditions in the sample chamber. Energy dispersive x-ray (EDX) analysis was performed by emitting an electron beam to three different spots on the tips of the firing pins to consider the

reproducibility of results. The shape of a square whose side was at least two-thirds the thickness of the firing pins was drawn in the program interface and scanned (Figure 5). This consistent sampling size was chosen to represent the alloy structure of firing pins in the best possible way. Deducing results from data processing relies on atomic percentage in weight. Fundamentally, this process aimed to investigate whether the firing pin material composition may have affected the variability in firing pin impressions observed.

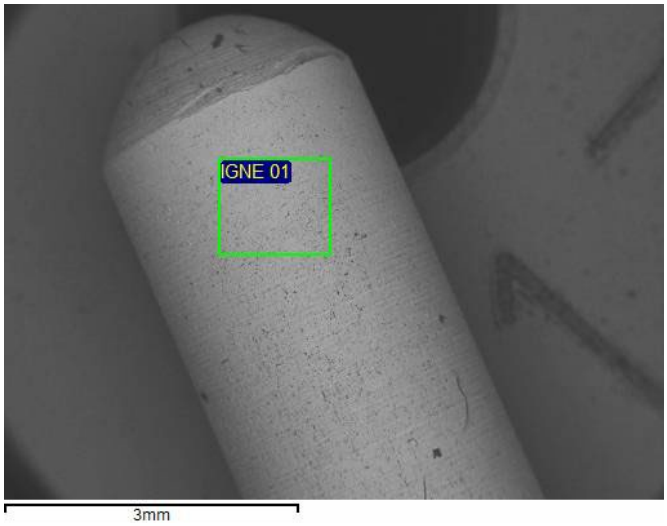

Figure 5: Scanning area for SEM-EDX analysis on the firing pin from SHOTGUN-01.

3. Results

Through the laboratory's ISO/IEC 17025 accredited forensic firearm examination process, 14 fired shotshell cases found at the crime scene were concluded to be fired from the shotgun under examination, SHOTGUN-00. While the firing pin impressions in the recovered shotshell cases may look different in Figure 3, the final decision was reached by means of corresponding marks on various parts, such as firing pin impression, ejector and extractor mark for example, as no robust breechface mark pattern was visible on the base of shotshell cases (Figure 6).

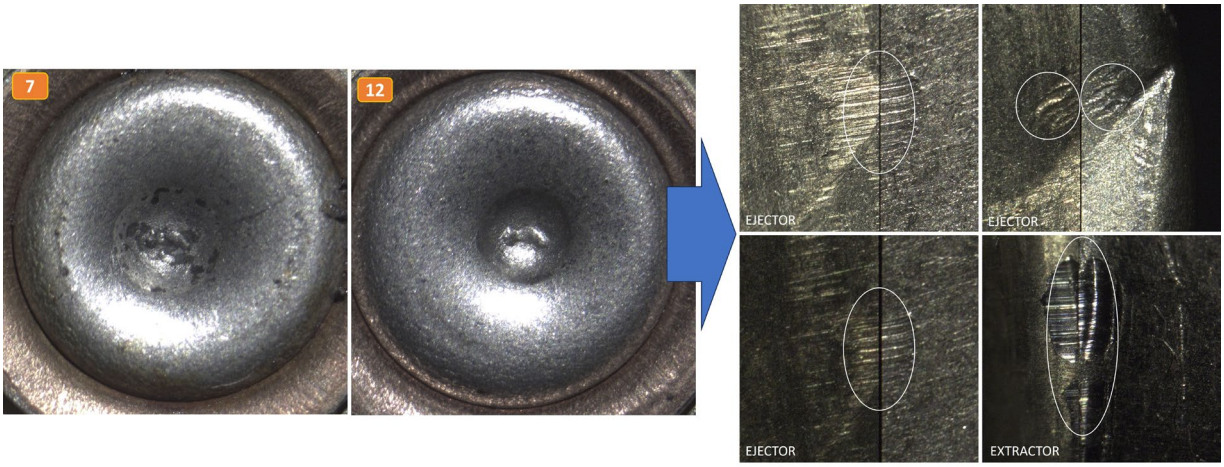

Figure 6: Ambiguous agreement of firing pin impressions (left). Corresponding individual characteristics within ejector and extractor marks (right) (shotshell cases numbers 7 and 12 recovered from the crime scene [key previously provided in Table 1]).

While the firing pin impressions on the crime scene shotshell cases were demonstrated in Figure 4, the appearance of the firing pin impressions on the 12 test fired shotshell cases discharged from the recovered shotgun (SHOTGUN-00) is given in Figure 7 and Figure 8. The two assigned examiners, who were unable to reach a definitive conclusion following the initial discharges from the alleged crime weapon, opted to conduct subsequent batches involving four shots. They established correspondence of individual characteristics within the ejector, extractor, and breechface marks easily; however, they noted discrepancies in the individual characteristics of the firing pin. As the test fires progressed, it was necessary to consult other examiners due to the resulting discrepancy. At this point, the assigned examiners and two additional examiners who were performing a blind test observed 'new', additional individual characteristics emerging within the firing pin impressions after 26 shots by means of subjective reasoning (Figure 9). This observation led the authors to examine the shotgun's firing pin in more detail.

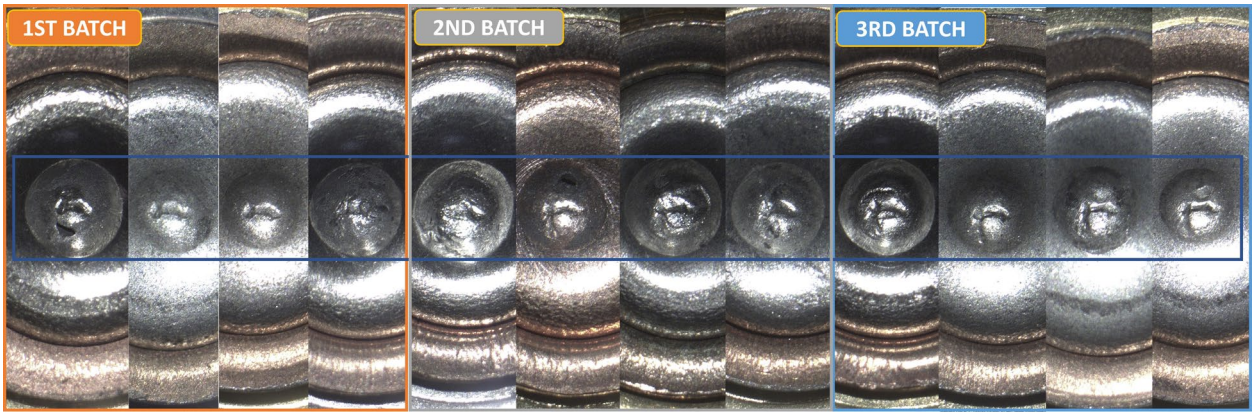

Figure 7: The firing pin impressions on the 12 test fired shotshell cases from the recovered shotgun SHOTGUN-00. Note - the test fires are presented left to right within this figure in the order of discharge.

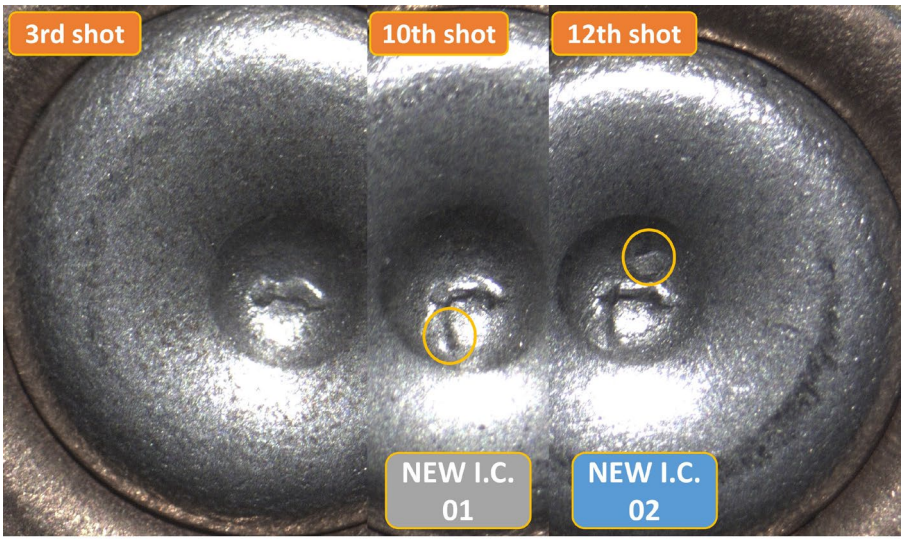

Figure 8: New individual characteristics created within the firing pin impressions observed as the number of test fires from SHOTGUN-00 increases from the first to third batch.

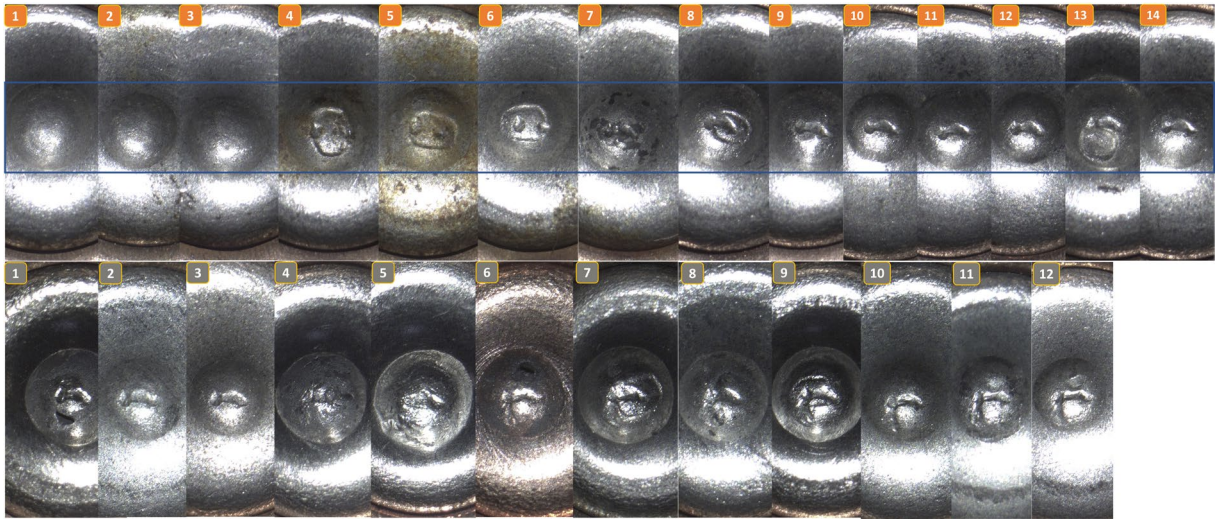

Figure 9: The firing pin impressions observed on the 14 recovered cases from the crime scene (top row) and the 12 test fired shotshell cases (bottom row).

The elemental analyses of the firing pins from four different shotguns are provided in Table 3. Analysis was conducted at three different points on the tip of each firing pin (Figure 10) for evaluation. A 20 % difference was observed in the proportion of carbon in the firing pin composition of the alleged crime shotgun (SHOTGUN-00) compared to the three reference guns. The analysis also detected the presence of low levels of silicon and lead, warranting further investigation.

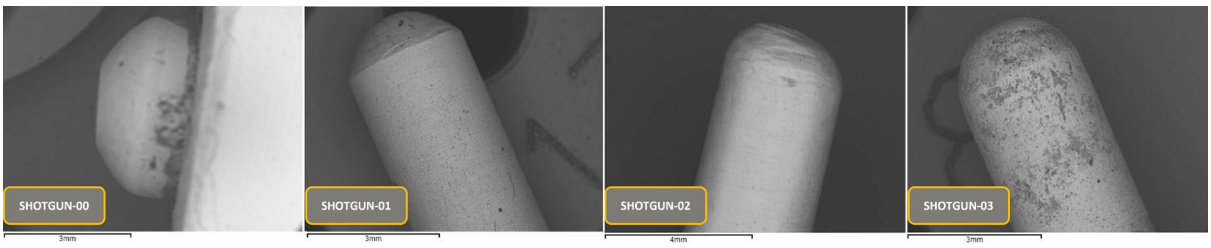

Figure 10: Backscattered electron micrographs of the four shotgun firing pins (key provided in Table 3).

Table 3: The elemental analysis of the tip area of the firing pins of four different shotguns using SEM-EDX.

SHOTGUN NUMBER	SHOTGUN MANUFACTURER	YEAR OF PRODUCTION	CYCLE OF OPERATION	Analysis Number	Mean Elemental Composition (%)					
					C	Al	Mn	Si	Pb	Fe
SHOTGUN-00	Daglıoglu Arms	2022	Semi-automatic	1	27.64	0.22	0.45	0.20	0.27	71.22
				2	26.95	0.39	0.39	0.24	0.25	71.78
				3	24.12	0.31	0.41	0.25	0.22	74.69
SHOTGUN-01	Huglu Firearms	2000	Semi-automatic	1	4.26	1.36	1.13	-	-	93.25
				2	5.19	0.96	1.34	-	-	92.51
				3	4.87	1.08	1.22	-	-	92.83
SHOTGUN-02	Huglu Firearms	1999	Manual over and under	1	6.12	1.27	0.49	-	-	92.12
				2	6.42	1.17	0.63	-	-	91.78
				3	6.35	1.22	0.54	-	-	91.89
SHOTGUN-03	Huglu Firearms	1980	Manual single-shot	1	4.25	1.27	1.18	-	-	93.30
				2	5.28	1.07	0.95	-	-	92.70
				3	4.92	1.38	0.89	-	-	92.81

Information regarding the production of the firing pins was acquired by engaging with the two shotgun manufacturing companies [29,32]. Both companies manufacture their own firing pins in-house and do not buy them from an external company. The firing pin of SHOTGUN-00 was stated to be manufactured from AISI 1040 complete steel, whereas the firing pins for SHOTGUN-01, SHOTGUN-02, and SHOTGUN-03 are produced using DIN 17223 B steel spring wire. The Daglıoglu Arms (SHOTGUN 00) firing pin is treated using hot caustic bluing after shaping using CNC machining to produce a protective and aesthetically pleasing finish to the surface with no further coatings or treatments. The Huglu Firearms shotguns (SHOTGUN 01, 02, and 03) have no caustic chemicals or coatings applied after CNC machining. Differences in the material properties of the firing pins examined may contribute to the increased rate of change of the individual characteristics produced by SHOTGUN-00's firing pin and the higher carbon and lead levels, further discussed in Section 4.

The firing pin impressions on the test fired shotshell cases obtained after the test fires from all four shotguns are provided in Figure 11. The images in Figure 11 were chosen as they were most representative of the firing pin impressions observed in each batch of test fires for the four shotguns. Figure 12 shows the firing pin surface of SHOTGUN-00 after the final discharge and Figure 13 compares the firing pin surface with its corresponding impression on the final test fire.

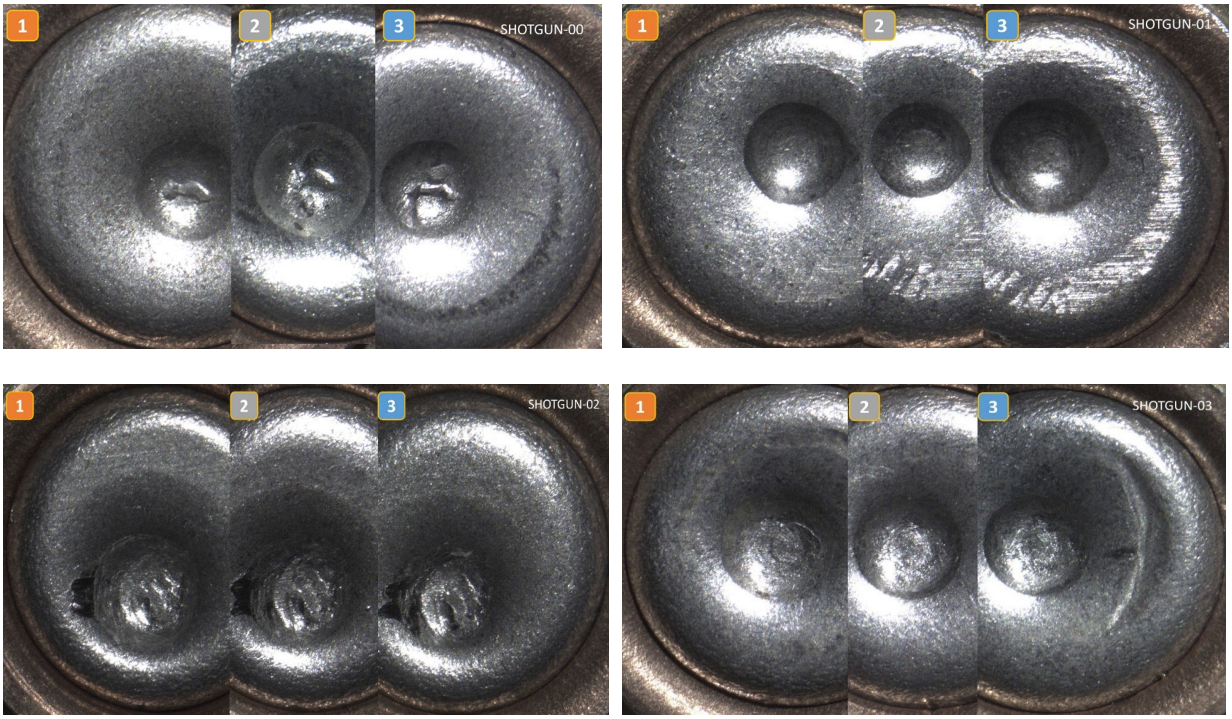

Figure 11: The firing pin impressions on test fired shotshell cases obtained with SHOTGUN-00, SHOTGUN-01, SHOTGUN-02, and SHOTGUN-03 in three batches of test fires.

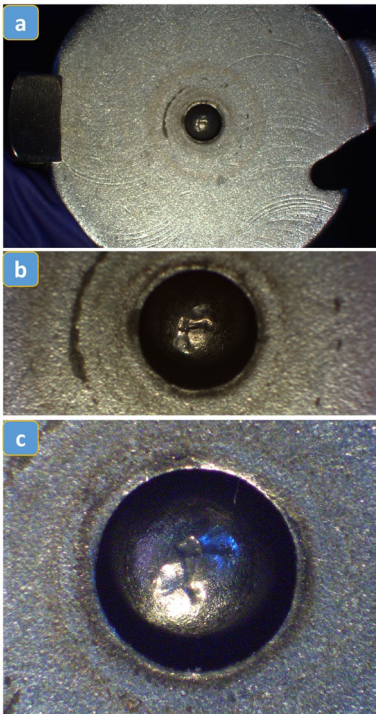

Figure 12: The images of the a) breechface, b) breechface around the firing pin, and c) firing pin tip surfaces in recovered shotgun SHOTGUN-00 after the final discharge.

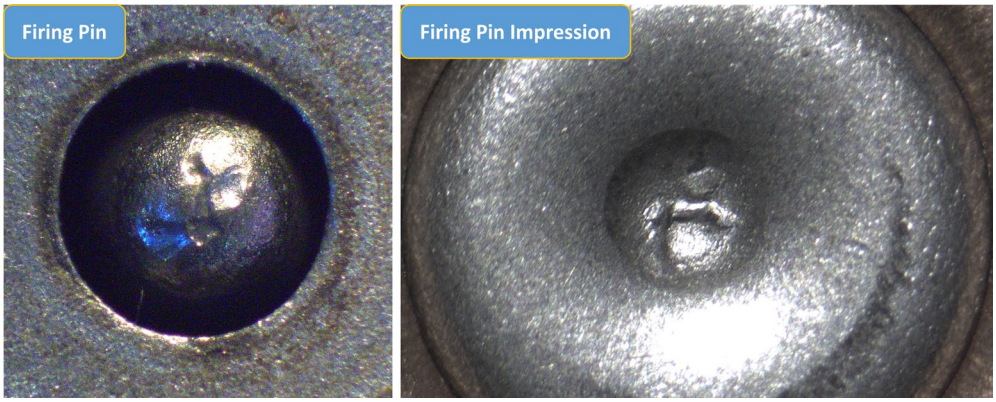

Figure 13: The comparison between the morphology of the firing pin surface and the marks created in the firing pin impression of the final test fired cartridge case for SHOTGUN-00.

4. Discussion

The theory of forensic firearm examination postulates that two toolmarks can be regarded as being from the same source once their impressions and/or striations (individual characteristics) are in sufficient agreement [36-38]. However, the firing pin impressions on the fired shotshell cases cannot be expected to be the same after thousands of shots [39-41]. The impressions should also be reproducible on different fired shotshell cases to establish the reporting conclusion for the forensic comparison [39]. As noted in the introduction, the reproducibility of the impressions formed on fired shotshell cases can be affected by the amount of pressure applied to the surface during cartridge ignition, the malleability of the primer, and the durability of the production material of the firing pin and breech face. In this study, it was unambiguously observed that the individual characteristics of the impressions formed by the firing pin of SHOTGUN-00 were not reproducible. The deformations, which occurred on the tip of the SHOTGUN-00's firing pin, are thought to be the reason for the formation of new individual characteristics (Figure 8).

The characteristic marks of firearm parts are transferred onto shotshell cases and the marks produced can be affected by various interior ballistic factors and the production materials [18]. It is known that the prominence of the marks on fired cartridge cases undergoes slight changes after consecutive fires, however, this does not typically hinder an examiner's ability to conduct a forensic examination and conclude that multiple cartridge cases have been fired from the same source [39-42]. In fact, these studies include examinations made after thousands of consecutive test fires from a single firearm for each. This study, however, in which different brands of shotshells were fired in a limited number of test fires, revealed the formation of new individual characteristics on the firing pin marks after only 12 shots (Figure 7). The formation of new individual characteristics in impressed toolmarks is generally attributed to accidental damage, rusting, and so on, which occur to the firearm part during the service life of firearms, rather than incidental manufacture marks [43,44]. The firing pins can be affected by these semi-manageable service life conditions due to the weakness of materials, thereby bearing new individual characteristics even after a number of consecutive fires and the possibility of forensic firearm examiners reaching an incorrect reporting conclusion [45].

In this study, the firing pins from each of SHOTGUN-01, 02 and 03 were established to be made of DIN 17223 B steel spring wire and that of SHOTGUN-00 AISI 1040 complete steel. The formation of alloy components at a compatible level with each other directly affects the hardness by means of mechanical properties [28]. Due to the destructive nature of hardness testing, this type of analysis could not be performed on the firing pins. Generally, it is known that the properties of AISI 1040 steel are as follows: hardness: 201-255 Brinell, max stress: 700-850 n/mm^2, yield stress: 465 n/ mm^2 min., impact KCV: 28 joules min [34]. DIN 17223 B steel; hardness: 51 Rockwell C, ultimate tensile strength: 2350 n/ mm^2 , yield stress : 2200

n/ mm^2 [46]. The properties of DIN 17223 are much more favourable to the firing circulation conditions than those of AISI 1040. Furthermore, although AISI 1040 steel is suitable for machinability, it is prone to exhibit poor characteristics and a build up edge at low cutting speeds [47].

Evaluating these conditions, it appears that the firing pin of the alleged crime gun (SHOTGUN-00, Table 3) is likely to have a reduced hardness and wear resistance in comparison to the other three firing pins manufactured by Huglu Firearms and examined in this study. The firing pins in SHOTGUN-01, 02, and 03 therefore appear to produce more consistent firing pin impressions. In contrast, the firing pin in SHOTGUN-00 was inclined to produce new individual characteristics after each discharge. Since these results were observed after only 12 test fires, additional test fires were not needed. Thus, it can be inferred that the differences in material properties used for firearm parts manufacturing have had an impact on the characteristic marks observed. The use of a comparably 'softer' steel could also provide an opportunity for ignited primer and/or propellant particles to become embedded into the surface of the firing pin over time, thus resulting in the increased levels of carbon and lead detected during SEM-EDX analysis. Alternatively, as the SHOTGUN-00's firing pin was integrated into the breechface (Figure 10), the entire part was mounted on the stage of the SEM and may have limited the viewing angle and resulted in discrepancies in elemental composition. Further destructive analysis of the firing pins would be required to confirm or refute these hypotheses; as SHOTGUN-00 was a casework gun, such testing was not possible. However, this could be an area of future study.

According to traditional shotshell examination, minor differences, such as small variations in the depth or morphology of the firing pin, may prevent an examiner from reporting that two

379 fired cartridge cases had been fired from the same source, if it is not supported by other
380 evidence. Therefore, the marks of various firearm parts on shotshell cases, such as extractor
381 and ejector marks, should be analysed using a holistic approach and considering all of the
382 available evidence [18,48]. During the comparative examination between the fired shotshell
383 cases recovered from the crime scene (Figure 4) and the test fired shotshell cases from
384 SHOTGUN-00 (Figure 7), it was noted there was some disagreement in the marks within the
385 firing pin impressions. Hence, a conclusive conclusion could only be achieved by considering
386 the extractor and ejector marks together with the firing pin impressions (Figure 6). To
387 minimise the potential for cognitive bias in this particular case and subsequent study, two
388 further qualified firearm examiners were asked to conduct blind, independent examinations
389 and also concluded that SHOTGUN-00 discharged the shotshells recovered from the scene
390 through their holistic examination.
391
392 Current practice in the authors' laboratory does not include taking images of component part
393 surfaces, such as the firing pin, or elemental analysis prior to test firing. This study therefore
394 highlights the need for forensic examiners to consider making changes to their standard
395 operating procedures by routinely examining and imaging through photography, the external
396 surfaces of accessible firearm components, in particular the firing pin, to document their
397 condition upon arrival in the laboratory, if they do not already. Casting of the component
398 surface using silicone compounds, such as those produced by Isomark or Mikrosil, could also
399 be considered prior to test firing. Adopting such practice(s) would have provided more robust
400 evidence of the change in the firing pin surface in the case of the recovered SHOTGUN-00
401 over time, which is currently a limitation of this study. Non-destructive elemental analysis,
402 such as SEM-EDX, may then be performed if needed to understand and potentially explain in
403 court why such surface deformations may have occurred, and thus the individual

characteristics may have changed more rapidly than may have previously been observed by examiners in a particular case.

5. Conclusion

Shotshell cases occupy little space in the databases of automatic ballistic identification systems compared to cartridge cases fired from other types of firearms [15]. This fact necessitates improvement of the one-to-one comparison technique and laboratory procedures for fired shotshell examination. According to the basic principles of this technique, firing pins do not typically undergo drastic morphological changes in a short time period unless they incur physical damage. Due to the durability of firing pins, any deviations in the firing pin impressions can be detected by the firearm examiners to assess the level of agreement between observed individual characteristics. Thus, the reproducibility of the individual characteristics should be able to be assessed with a small number of test fires. However, where a firearm part's material properties may produce fast surface deformation, more test fires are required for proper analysis and interpretation. As it is not possible to establish the material properties of the components without destructive testing, routine procedures should be revised to incorporate image-based documentation of major firearm parts, such as the firing pin, before test firing commences.

As current examination practices involve the cross-validation of the firing pin, breech face, ejector, and extractor marks in a holistic approach, it was possible to conclude that the shotshells from the crime scene were produced by the recovered shotgun, SHOTGUN-00, despite differences in the firing pin impressions. However, incorporating image-based documentation of the firing pin prior to test firing would have further enhanced the

examiner's ability to assess toolmark reproducibility and extent of change between the time of firearm recovery, arrival at the laboratory, and subsequent use.

Overall, this study suggests that further documentation, discussion with firearm manufacturers and elemental analysis of the firearm part would enhance the holistic approach to forensic firearm examination to strengthen reporting conclusions and prevent wrongful convictions, particularly in cases where individual characteristics change in a short time period. Future studies may contribute to forensic firearm examination literature by focusing on the impact that the material composition of component parts has on various cartridges, their marks and impressions.

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