Toolmark Reproducibility on Fired Bullets and Expended Cartridge Cases

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ABSTRACT

The reproducibility of landmarks, breechface marks and firing pin marks on one hundred successively fired bullets and cartridge cases was examined. Three types of Speer brand, one of Remington brand and one of DFA brand frangible cartridges were fired in a semi-automatic pistol. Remarkable differences were observed in the general appearance of the landmarks, breechface marks and firing pin marks which were impressed on the different brands of cartridges, even when consecutively fired. Identification of the landmarks between bullets from different brands of cartridges was difficult because their general appearance differed greatly. Difference in bullet diameters was found to be a major cause of changes in landmarks among different manufacturer's bullets. Although the depth and number of striations decreased gradually, reproducibility of breechface marks on the primers of cartridges was rather good. The diameter of firing pin indentations also differed among different brands of cartridges. Although the reproducibility of the diameter of circular lines on firing pin indentations was good, the detail in these circular lines fluctuated a great deal. Quantitative CMS was used as a means of critically evaluating and communicating the extent of striated pattern agreement among the rifling impressions on the fired bullets in this study.

Introduction

The discipline of firearm and toolmark identification is based on two empirical hypotheses. The first hypothesis is the consistency/reproducibility of markings which originates from the same firearm or tool. The second hypothesis is the existence of differences between markings originating from two different firearms or tools [1-5]. However, in reality, markings will change rather rapidly in the process of successive firing. On the other hand, markings from two different tools or firearms of the same make and type are sometimes similar because of high quality control during the production process [6].

Marking reproducibility is crucial to firearm and/or toolmark identification. Identification criteria are essential when marking reproducibility is lower than usually expected [7-12]. There have been some experiments in which marking reproducibility was examined in the course of successive firing of ammunition from a firearm. The results of those experiments indicated that consistent markings were found through several hundred or several thousands rounds. Reproducibility of prominent markings was good, however the life of some accidental minute markings was found to be very short. The reproducibility of breech face marks was high, whereas that of ejector and extractor marks was low [13-15]. Another study showed that remarkable change occurred on breech face markings within three hundred rounds [16].

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The author was involved in the study of five thousand consecutively fired bullets and cartridge cases. The comparison microscope was the only tool used for examining how toolmarks changed when that study was performed. Current computer technology has provided new tools for examining striation matching and we can retrieve similar markings from many candidates [17-19]. We can also use low cost digital photography and we can easily retrieve those photos using the computer. The author developed a digital image retrieval system for firearm identification named the BIRI (Ballistic Image Retrieval and Identification) system [20]. We now have the ability to check a large number of photos quickly using this technology.

In preparation for the present study, the author examined marking reproducibility of these same five thousand consecutively fired bullets and cartridge cases using digital photos. As reported earlier, good reproducibility of these markings was confirmed [21]. Fig.1 shows the marking reproducibility of landmark 4 throughout five thousand firings. Fig. 2 shows the marking reproducibility of breechface marks throughout five thousand expended cartridge cases. In this five thousand round experiment, ball ammunition manufactured under the same lot number was fired. In Japan, criminals often use mixed brand

cartridges from different manufacturers in real shooting cases. When multiple shots of mixed cartridges are fired from guns having the same general rifling characteristics, it can be rather difficult to determine how many guns were used in a shooting case.

In this present study, the author consecutively fired one hundred rounds comprised of several brands of ammunition. Markings on one hundred fired bullets and expended cartridge cases were recorded using digital photos and marking reproducibility was examined using the BIRI system. The extent of agreement was critically evaluated and described using a quantitative CMS (consecutive matching striae) technique.

Materials and Methods

A Hi-Point brand, C9 model, 9 mm Luger caliber, semi-automatic pistol, serial number P222153 (Fig.3), was used in this experiment. This pistol was imported from the United States for this experiment. The general rifling characteristics of this pistol were nine lands and grooves with a left hand twist. The width of the landmarks measured on frangible bullets was 1.4 mm and the angle of twist was 4.7 degrees.

In this experiment, five brands of ammunition were fired in semi-automatic mode. Catalogued data of these five brands of ammunition is indicated in Table 1. Speer ammunition was received packed in 20-round boxes and other brands of ammunition were received packed in 50-round boxes. Four Federal cartridges with 124 grain, full metal cased bullets were also used.

Five cartridges were loaded into a magazine in reverse sequence of firing, such as Gold Dot with a 147 grain bullet, Remington, Gold Dot with a 124 grain bullet, Frangible and Gold Dot with a 115 grain bullet. These five types of ammunition were then fired in semi-automatic mode into a water recovery tank. As the cartridge cases of the three brands of Gold Dot ammunition were indistinguishable in appearance, the Gold Dot cases with 124 grain bullets were marked with black paint, the Gold Dot cases with 147 grain bullets were marked with red paint, and the Gold Dot cases with 115 grain bullets were left unpainted. After firing each group of five shots the bullets were recovered from the water tank and each bullet was packed into a separate card box with the corresponding expended cartridge case. A label with the description, shot sequence number, and headstamp was attached to each cartridge box. It took approximately one hour to fire and package one hundred shots in the manner described. To prevent mushrooming of Speer Gold Dot bullets, the hollowpoint cavities of the bullets were filled with araldite, an epoxy adhesive. Cartridges were loaded into the magazine with the headstamps in an upright position.

Digital photos of each landmark of the recovered 100 bullets were taken using a FUJI HC-2500 digital camera mounted on a LEICA DMC comparison macroscope with the magnification of the objective lens set to 20X. Bullets were obliquely illuminated using a KL1500LCD light source. Each landmark on the bullet of Gold Dot 115 grain, Gold Dot 124 grain, Remington and Federal bullets were recorded by two photos. Each landmark on the Gold Dot 147 grain bullet and the Frangible bullets was recorded with three photos. In total, 2,160 landmark photos were taken.

Digital photos of the heads of the expended cartridge cases were taken using a LEICA M420 macroscope under three lighting conditions. They were vertically illuminated, obliquely illuminated from the top, and obliquely illuminated from the left. The orientation of the cartridge cases in the photomicrographs was the same as when they were loaded in the chamber of the pistol (headstamp upright). Photos of the entire surface of each cartridge case head were taken using the 0.5X adapter lens and 8X magnification of the objective zoom lens. Photos of markings on the primers were taken using 12.5X magnification of the objective zoom lens. Photos of firing pin markings were taken using 20X magnification of the objective zoom lens. In total, 900 photos of cartridge case markings were taken. All the photos taken in this process were viewed on the computer display using the BIRI system. As the images can be sorted by various criteria, using BIRI, marking reproducibility can be evaluated easily.

Results

General Characteristics of Landmarks

Great difference was observed in the shapes of landmarks among different brands and types of ammunition. BIRI is capable of displaying up to nine landmarks of a fired bullet on the computer display in a tile mode. Landmarks 1, 2 and 3 are shown from left to right in the upper row, landmarks 4, 5 and 6 are shown from left to right in the middle row, and landmarks 7, 8 and 9 are shown from left to right in the lower row. Landmarks were numbered clockwise as viewed from the bullet base. Landmarks with the same number are in phase and their markings are expected to correspond. The degree of change in landmark shape was small on Frangible bullets. Fig. 4 shows each landmark on the second shot using Frangible bullets. Fig. 5 shows each landmark on the 97th shot with Frangible bullets. These photos are the display copy of the BIRI system illustrating all nine landmarks in one image.

Every landmark on the Frangible bullets was well defined. Every driving edge of these landmarks had enough depth and almost all of the trailing edges of these landmarks also had enough depth. The widths of the landmarks were consistent in all twenty of the fired Frangible bullets. Whereas the shape of

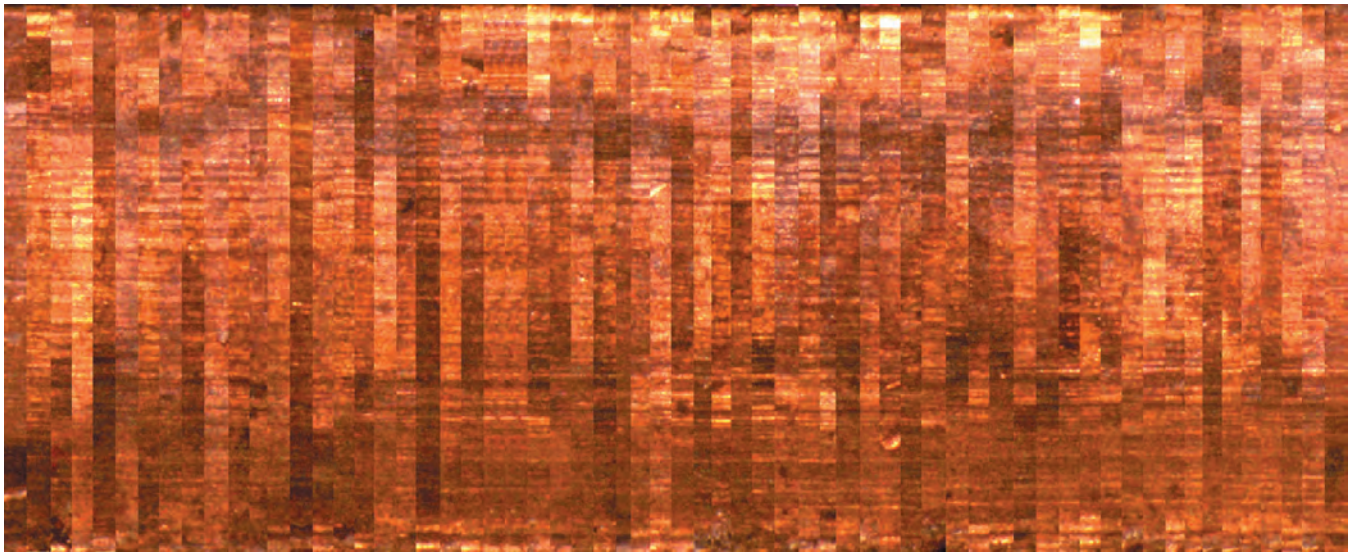

Fig. 1 This series of spliced digital photos demonstrates the change in the striated markings of 5,000 test fired bullets taken at the bullet base area on Landmark 4. This composite represents every 20th bullet fired between 1 and 100, every 50th bullet fired between 100 and 1,000, and every 100th bullet fired between 1,000 and 5,000. This comparison indicates that prominent striated markings are rather consistent throughout the 5,000 rounds fired.

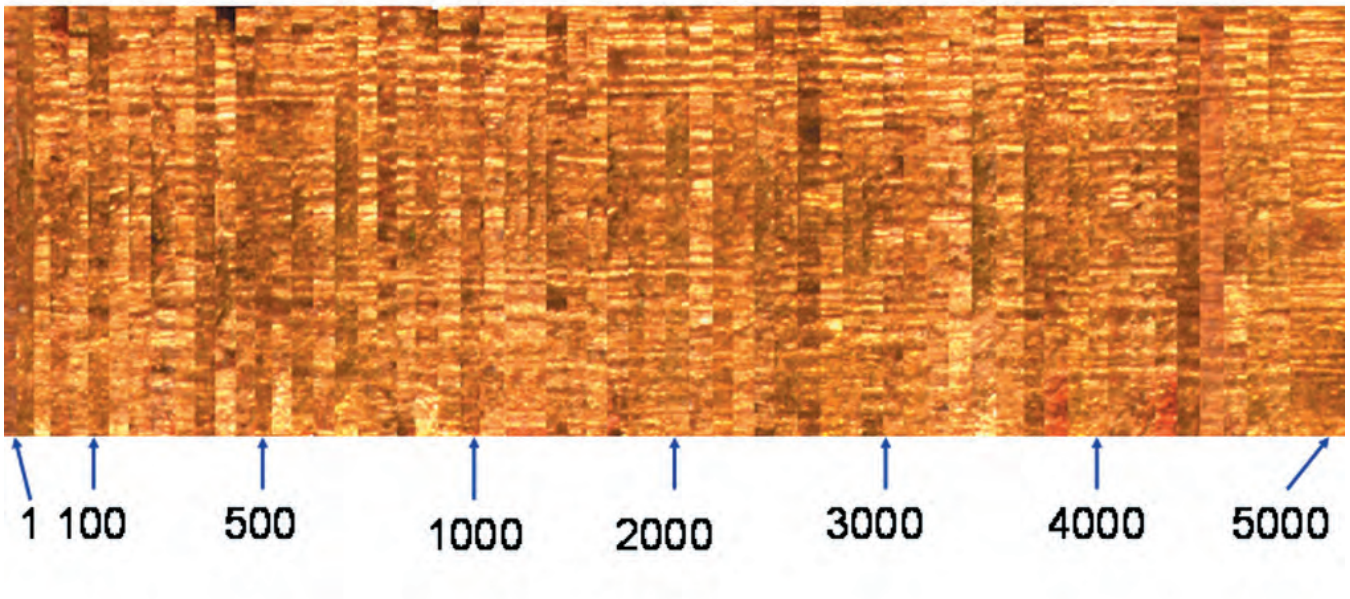

Fig. 2 This is a series of spliced digital photos that demonstrates the extent of change of the breechface markings of 5,000 test fired cartridge cases taken of the breechface impression. This composite represents every 20th cartridge case fired between 1 and 100, every 50th cartridge case fired between 100 and 1,000, and every 100th cartridge case fired between 1,000 and 5,000. This comparison indicates that prominent breechface markings are rather consistent throughout the 5,000 rounds fired.

the landmarks of Frangible bullets was consistent, many small pits or stipples were scattered on their surface. When these pits covered wide areas of the landmarks, it became difficult to examine minute striations (Fig. 6). However, these pits or small holes did not represent a major problem or difficulty for the identification of landmarks on Frangible bullets. There was no trend toward increasing numbers of these pits with successive shots (Fig.7). The landmark surface of Frangible bullets was light in color throughout this experiment. To the contrary, the surface of Speer and Remington bullets were rather smooth and dark in color. Some Remington bullets were especially dark in color.

The three types of Speer Gold Dot bullets had similarly shaped landmarks, and the driving edges of these landmarks were clear in the early stages of firing. The driving edges looked like they were doubly engraved in the bullets in later stages of firing. Many of the double-appearing edges engraved on the right side of the landmarks were the edges of skid marks. These skid marks originated near the breech end of the barrel. Trailing edges of landmarks on Speer bullets were shallow from the beginning, and the depth of the trailing edges became shallower with successive firing. Since the trailing edges of skid marks were deep, and the trailing edges of landmarks were obscure, the widths of the landmarks on the bullets in later stages of firing looked wider than the original widths. Fig. 8 shows each landmark of the first shot with a Speer 115 grain and Fig.9 shows those of the 100th shot with a Speer 147 grain bullet.

The shapes of the landmarks on the Remington bullets was somewhat similar to those of the Speer bullets. The trailing edges of Remington bullets were shallower than those on the Speer bullets. The surfaces of the Remington bullet landmarks were usually dark in color and the number of striations was small. Fig. 10 shows each landmark of the fourth shot with Remington 124 grain and Fig. 11 shows those of the 99th shot. The trailing edges were clear in the fourth shot but were all obscure on the 99th shot.

There were many landmarks with shallow trailing edges on Speer, Remington, and Federal bullets. The author subjectively classified these trailing edges into three categories. Trailing edges with enough depth to be clearly discerned were classified as rank 2. Shallow trailing edges and/or partly engraved trailing edges were classified as rank 1. Non-visible trailing edges were classified as rank 0. Table 2 shows the average rank of trailing edge depth of landmarks for each brand of ammunition.

Fig. 3 Hi-Point brand, model C9, caliber 9x19 mm semi-automatic pistol, serial number P222153 used in this experiment.

Table 1 Catalogue data of the cartridges used in this experiment

Ammunition	Caliber	Bullet Weight (gr)	Muzzle velocity (fps)	Muzzle energy (ft-lb)	Headstamp
Speer Gold Dot	9 mm Luger	115	1200	368	.SPEER. 9 mm LUGER
Speer Gold Dot	9 mm Luger	124	1150	364	.SPEER. 9 mm LUGER
Speer Gold Dot	9 mm Luger	147	985	317	.SPEER. 9 mm LUGER
DFA Frangible	9 mm CT	115	1153	340	WIN 9 mm LUGER
Remington	9 mm Luger	124	1110	339	R.P. 9 mm LUGER

Table 2 Edge Depth Rank of landmark trailing edges

Ammunition	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**Average**
Speer 115	*0.74*	*0.63*	*0.58*	*0.68*	*0.95*	*0.89*	*0.95*	*0.95*	*0.74*	*0.79*
Speer 124	*1.00*	*1.00*	*1.11*	*0.89*	*0.74*	*1.05*	*1.26*	*1.21*	*1.00*	*1.03*
Speer 147	*0.44*	*0.50*	*0.94*	*0.72*	*0.33*	*0.39*	*0.72*	*1.17*	*1.28*	*0.72*
Frangible	*2.00*	*1.75*	*1.95*	*1.80*	*1.95*	*1.95*	*1.65*	*1.85*	*2.00*	*1.88*
Remington	*1.40*	*1.45*	*1.55*	*0.75*	*0.15*	*0.15*	*0.30*	*0.95*	*1.20*	*0.88*
Federal	*0.75*	*0.50*	*0.50*	*0.50*	*1.25*	*0.75*	*0.25*	*0.25*	*1.25*	*0.67*
Average	***1.06***	***0.97***	***1.10***	***0.89***	***0.89***	***0.86***	***0.86***	***1.06***	***1.24***	***0.99***

L1 means landmark 1.

Frangible bullets had the highest average rank of trailing edge depth and Federal bullets the lowest. The average rank of the three types of Speer bullets was about half that of the Frangible bullets, with the Speer 124 grain bullets ranking highest. Fig. 10 shows the change in average rank of trailing edge depth of groups of five consecutively fired shots. It shows the trailing edges of landmarks to become remarkably shallow during the first thirty shots and the rate of change in depth to become moderate after thirty shots.

Prominent Striations on Landmarks

A deep and wide striation was observed on some of landmark 1 and some of landmark 4 of some of the fired bullets. Marking reproducibility of these prominent striations was not always high. Prominent striations were observed on every landmark 1 of the Frangible bullets; however the relative position of this striae to the driving edge was shifted toward the trailing edge with successive firing. This situation can be confirmed by comparing sequential photographs (Fig.13). Figure 13 was made by pasting together segments of photos which were cut from bullet base areas. No such prominent striations were observed on landmark 1 of Speer 115 grain bullets (Fig.14) but were observed on some of the Speer 124 grain and Speer 147 grain bullets. These prominent striations on Speer 124

and 147 grain bullets were wider and deeper than those observed on landmark 1 of the Frangible bullets; however, some of these bullets had no such prominent striations at all. The position shift of these striations on Speer bullets with successive shots was restricted compared to the shift on the Frangible bullets described above (Fig. 15, 16). There were no prominent striations on landmark 1 of the Remington bullets (Fig. 17). This type of prominent striae was also observed on landmark 4 of the Speer 124 grain bullets. Reproducibility of these striations on Speer 124 grain bullets was high, however, only a small number of other brands of bullets had such prominent markings on landmark 4.

Matching Striations on Landmarks

The reproducibility of striations was not high throughout these one hundred bullets. Some landmarks of the Frangible bullets had a lot of minute striations. Reproducibility of striations on landmark 1 of Frangible bullets was good despite the dislocation of the prominent striation already discussed (Fig.18). Numerous striations on landmark 2 of the Frangible bullets showed good reproducibility (Fig.19). The reproducibility of striations on landmarks 3, 4 and 9 was rather good. The reproducibility of striations on landmarks 5, 6, 7, and 8 was not very good.

It was easy to find matching striations on the Frangible bullet landmarks. To the contrary, there were less minute striations on the landmarks of other brands of bullets. It was difficult to find consecutive matching striations on landmarks which had only a small number of striations. The author searched for matching striations on all of these bullets using the BIRI system. Some matching striations were found toward the nose area of landmark 2 of Speer 115 grain bullets. Marking reproducibility in this area was rather good until the 51st shot. Some matching striations were found on the bullet base areas between the 21st shot and 71st shot of the Speer 115 grain bullets. It was a marginal match, and opinion may be divided over the significance of the existence of three CMS (consecutively matching striae).

Within the Speer 124 grain bullets compared, three CMS are easily found between the bullets whose firing order was separated by 10 rounds; however, it was difficult to find three CMS between the 3rd and 98th shot. Fig. 20 shows the reproducibility of markings on landmark 1 of the Speer 147 grain bullets. Markings were gradually changing and a deep striation was not aligned between the 10th and 35th shots. However, CMS runs greater than three were easily found between adjacent segments of photos compared. CMS runs greater than three were also found between the 10th and 95th shots. The 60th shot was a Federal bullet and marking on it is a little different from the others.

Remington bullets had the least striations on landmarks among the six brands of cartridges used in this experiment. There were some corresponding striations in the nose area of landmark 9 of the Remington bullets. In this area, CMS runs greater than three were observed between the 39th and the 44th shots and between the 44th and the 49th shots (Fig. 21). It was generally difficult to find matching striations between different brands of bullets. Fig. 22 shows an example of matching striations found between different brands of bullets whose firing order was far apart. This was a comparison between the 7th shot of a Frangible bullet and the 98th shot of a Speer 124 grain bullet. Some conspicuous striations are matched in this photo, however CMS runs greater than three were not found. The counting procedure used by this author was the same as the standard method proposed by Biasotti, Murdock and Moran[22] with the exception of counting the dark/gray valleys instead of the bright, reflected light areas represented by the tops of the striations. This is because tabulation of the valleys in this way is commonly used in Japan. Counting the valleys and not the brightly reflected light areas represented by the tops of the striations does not effect the tabulations of CMS.

As Remington bullets had less markings overall, it was difficult to find corresponding striations between the Remington and other different brands of bullets. Fig. 23 shows a rare example of matching striations between a Remington bullet and a Frangible bullet. On the Remington bullet there was no deep striation such as the one which appeared on the Frangible bullet. Although the firing interval between these shots was only two, the number of corresponding striations was small and CMS runs greater than three were not found.

General Characteristics of Breechface Marks on Primers

All the primers used in this experiment, except Federal, were nickel plated. The character “A” was found stamped on the Speer primers. There were no conspicuous non-firing markings on the Speer primers except for this “A” shaped mark. Marks on the primers of the first five shots are shown in Fig. 24. There are prominent parallel breech face marks on these primers. The diameters of the breechface marks on the primers and the diameters of the firing pin indentations were different for each brand of ammunition.

The diameter of the primer area which contacted the breech face was measured. In this measurement, the diameter was calculated from an enlarged image through the LEICA M420 using EZDOC imaging software from Mideo Systems. The result of these measurements is shown in Fig. 25. The diameter of the firing pin indentations was measured in the same way. Fig. 26 shows the diameters of firing pin indentations. Fig. 25 and Fig. 26 show a strong correlation between the size of the primer that contacted the breechface and the size of the firing pin indentation. The diameter of the contacted area of the primer and the diameter of the firing pin indentation of the

Frangible cartridges was largest while those of the Speer 115 grain and 124 grain cartridges were the smallest. Fig. 27 shows the area of the primer that contacted the breechface calculated from the results shown in Fig. 25 and Fig. 26. Basically, the number of parallel lines was large and the parallel lines were long on the primers with a widely contacted area. To the contrary, the number of striations in the breechface marks of Speer cartridges was small and striations were shorter than those of Frangible and Remington because the contacted area of the primer was narrower.

Marking Reproducibility of Breechface Marks

Prominent parallel striations were observed on the primers of Frangible and Remington cartridge cases. Fig. 28 shows the reproducibility of these markings. These figures were made by arranging segments of photos of successive firings of breechface marks from top to bottom. Each photo was cut from the middle area between the upper edge of the primer and the firing pin indentation. These rectangular areas are shown in Fig. 29. Fig. 28 indicates that the reproducibility of parallel striations was very good until around the 70th shot. Some striations became shallow in this area after the 72nd shot. This situation is confirmed in Fig. 29. Fig. 30~34 shows the reproducibility of the breechface marks impressed on the primers of each brand of ammunition. Each portion of a photo in these figures was cut from the area near the firing pin indentation. Although the reproducibility of breechface marks was fairly good throughout one hundred rounds, a trend of decreasing numbers of lines and decreasing depth of lines was observed.

To evaluate this trend of decreasing lines, the author applied a differential filter to the image. The obliquely lighted primer images were enhanced using a Sobel X filter. Fig. 35 shows two enhanced primer images of Frangible cartridge cases. The number of lines was large in the second shot and small in the 97th shot. The author counted lines on expended primers. Using the filtered primer images, the dark striations were counted in the upper half area on each primer. The line counts are shown in Fig. 36. The number of lines gradually decreased in each brand of cartridge.

General Characteristics of Firing Pin Indentations

Firing pin indentations of the first five shots fired for each cartridge brand, illuminated with oblique light, are shown in Fig. 37. The shape of the firing pin indentation was hemispherical in each brand of cartridge. Many of them had a firing pin skid mark from the center toward the nine o'clock direction (as viewed in the illustrations). These skid marks were shallow and narrow. There were several concentric circular lines in these indentations. As described earlier, the diameter of the firing pin indentation was large in Frangible and Remington cartridges. On the other hand, concentric circular lines in the firing pin indentations of Speer cartridges looked deeper than those of Frangible cartridges.

Marking Reproducibility of Firing Pin Marks

Concentric circular striations had some similarity among every brand of expended cartridge case. Similarity between those firing pin marks was easily observed using the BIRI system. It was confirmed that the similarity between cartridges from the same manufacturer was rather high. On the other hand, similarity between cartridges from different manufacturers was low, even between successively fired cartridge cases.

To examine marking reproducibility in two dimensions, the author applied the Sobel X differential filter to the images of firing pin marks using down light illumination. Two enhanced images of firing pin marks appearing on Speer 115 grain (bullet) cartridge cases, which were shot ten rounds apart, were compared in Fig. 38. Fig. 39 shows a comparison between Frangible cartridges ten shots apart. These photos show that the diameter of each concentric circular line was similar; however, details in the shape of the circular lines were different even among cartridge cases of the same brand.

To ascertain the reproducibility of the diameter of the concentric circular lines, the author measured their diameters using the three point method (Fig.40). It was rather difficult to determine the diameter of the circular lines because the lines were not exact circles. In this measurement, a firing pin image 256 by 256 pixels was used, and the interval of two adjacent pixels was about 10 micrometers.

Fig. 41 shows a number of circular lines counted on each firing pin indentation. The total number of circular lines ranged from six to twelve and the number of prominent circular lines ranged from one to four. There was no clear indication of decrease or increase of the number of lines along successive firings.

Fig. 42 shows the diameters of all of the circular lines. Some regularity was observed in the diameters which were less than a thousand micrometers; however, circular lines of a diameter greater than one thousand micrometers were less consistent. Fig. 43 shows the diameters of the prominent circular lines. The fluctuation band for the diameter is roughly fifty micrometers in the small prominent circular lines and one hundred micrometers in the large prominent circular lines. Fig. 44 shows an example of the prominent circular lines which were counted in this experiment. Four prominent circular lines are observed in Fig. 44.

Discussion

Differences in General Characteristics of Landmarks

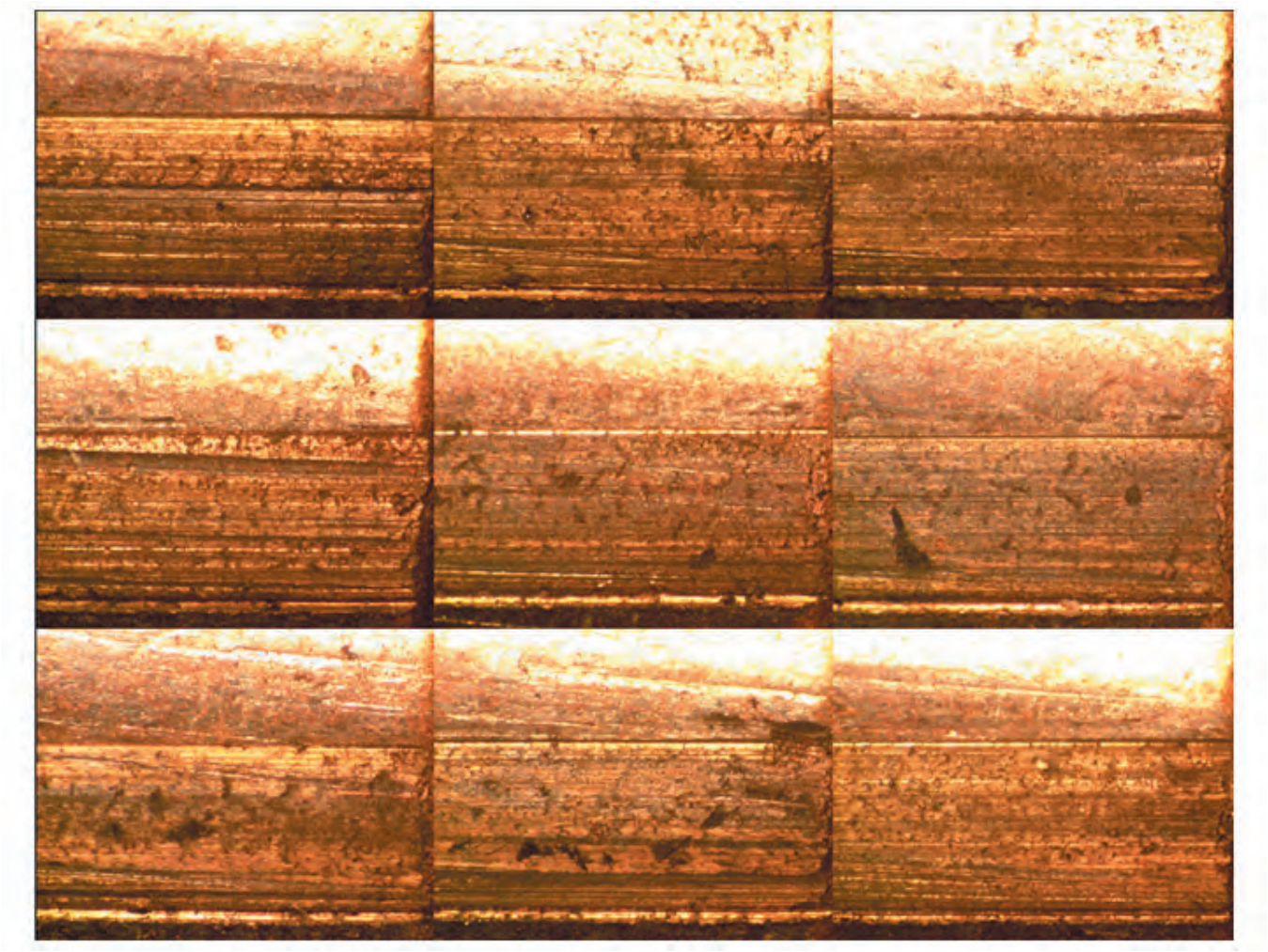

Fig. 4 Landmarks of second shot using Frangible 115 grain bullets.
From left to right, landmark 1, 2, and 3 in the upper row; Landmark 4, 5 and 6 in the middle row; Landmark 7, 8 and 9 in the lower row

The shape of the landmarks varied greatly among the different brands of ammunition. The surface of the landmarks of Frangible bullets was light in color. On the other hand, the surface of the landmarks of Remington bullets was dark. This color change is caused by smoke from burned powder. The author measured the diameter of all of the fired bullets. Each bullet was examined using a LEICA M420 macroscope with digital camera and a Chuo Seiki digital stage. The diameter was measured using Mideo EZDOC software. The diameter of each bullet was measured six times by rotating every sixty degrees using a digital stage.

Fig. 45 shows the average diameter of each fired bullet. The average diameter of twenty Frangible bullets was 9.03mm and that of the Remington bullets was 8.93mm with the diameter of the Speer Gold Dot 124 grain bullets between these two.

A strong correlation was observed between bullet diameter and rank of trailing edges. This is shown in Table 2. Bullet diameter and the appearance of prominent marking on landmark 1 also had strong correlation.

Position Shift of the Prominent Mark on Landmark 1
A prominent striation was observed on landmark 1 of each Frangible bullet and many of the Speer 124 grain and 147 grain bullets. The position of this prominent striation shifted from left to right with successive firing. This phenomenon indicates two things; firstly, this prominent marking may be originating from the breech end area of the barrel, secondly, the land in the breech end area was eroded by successive firing

in this experiment. The degree of shift in Speer 147 grain bullets was small compared with that of the Frangible bullets. This difference in degree of line shift may be caused by the difference in bullet velocity. The velocity of bullets when forced into the breech end area of the bore is considered slow in heavy bullets and fast in light bullets. Frangible light weight bullets moved into the breech end area with high velocity and the bullets slipped a lot. To the contrary, the velocity of Speer 147 grain bullets was low and they started their rotational movement after a short slippage movement.

Change in Surface Contour of the Land

The reproducibility of striations on the Frangible bullets was rather high. This indicates that the surface contour of the bore changed only a little throughout this experiment. Low reproducibility of marking on other brands of ammunition might be caused by insufficient contact with the bore.

Identifiability of Landmarks of Frangible Bullets

There has been an assertion that the markings of frangible bullets are impossible to identify with the firearm from which they were fired [23]. Although the surface of Frangible bullets often had many pits or small holes, the landmarks of DFA Frangible bullets were the easiest to identify in this experiment. Continued firing of Frangible bullets is said to deteriorate the rifling of the firearm used, and early replacement of the service firearm due to rifling wear was also asserted. In this experiment, erosion near the breech end of the bore causes a shift of location in prominent striations on landmark 1. The author agrees that firing Frangible bullets could cause early erosion of the bore because the diameter of Frangible bullets in this caliber is large and they have limited compressibility in diameter.

It was rather easy to identify Frangible bullets up to fifty-two shots because the corresponding phase of landmarks was easily found using the prominent mark on landmark 1. Reproducibility of striations on landmark 1 and landmark 2 was also good. However, it is the author's opinion that identification between fired Frangible bullets separated by more than fifty rounds was difficult without prior knowledge.

Identifiability of Landmarks Between Different Brands of Ammunition

Since the general shape of landmarks is very different among different brands of ammunition, examiners may potentially eliminate bullets from different brands of ammunition in the early stage of comparison if he/she has no prior knowledge of this variability.

Deep Striations vs. Shallow Striations

Reproducibility of the deepest striations was rather good compared with shallow striations. However, reproducibility of the widest deep striations was not always good. It will be noted that the relative position of two striations will change when they originate from different areas of the bore. Deep striations may strongly affect an examiner's impression regarding identification. On the other hand, minute striations may affect CMS counts. We must examine both of them carefully.

Striations on Primers

The general appearance of primers is very different between each brand of ammunition. The "A" shape character on Speer primers interferes with the imprinting of striations and the number of striations on primers decreased somehow in the presence of this character. The number of striations on primers decreased after around seventy rounds. Disappearance of fine striations was the reason for this decrease of lines. In the case where minute striations between prominent striations disappeared, CMS runs will decrease considerably.

Circular Striations in Firing Pin Indentations

Circular striations were analyzed using images illuminated by down light. The striations in the center area of firing pin indentations look prominent under down light illumination. Some circular lines located in the surrounding area of the firing pin indentation looked prominent under oblique lighting, especially on the Frangible and Remington cartridge cases.

The Size of the Primer's Areas of Contact with the Breech Face and Firing Pin

When the size of the primer's area of contact with the breech face was large, the number of lines on the primer was also large. The shape of expended primers of the Frangible bullets indicated that high pressure was developed inside the chamber. This high pressure may be caused by the large diameter and incompressibility of the Frangible bullets. The size of the Remington primers' areas of contact were larger than those of the Speer, even though Remington's bullet diameter was the smallest. This phenomenon may be caused by primer hardness differing between each brand of ammunition.

Conclusion

Markings on one hundred successively fired bullets and expended cartridge cases were examined. Markings among different manufacturers of ammunition differed significantly even between consecutively fired bullets. Identification between bullets from different manufacturers was generally difficult. Since the reproducibility of striations on frangible bullets was rather good, the change in the bore surface was considered rather small. From an analysis of skid marks on landmarks, the surfaces of the bore near the breech end area were eroded within one hundred fired rounds. Diameter, weight and/or velocity of bullets will affect the reproducibility of striations on landmarks. A smaller number of striations were

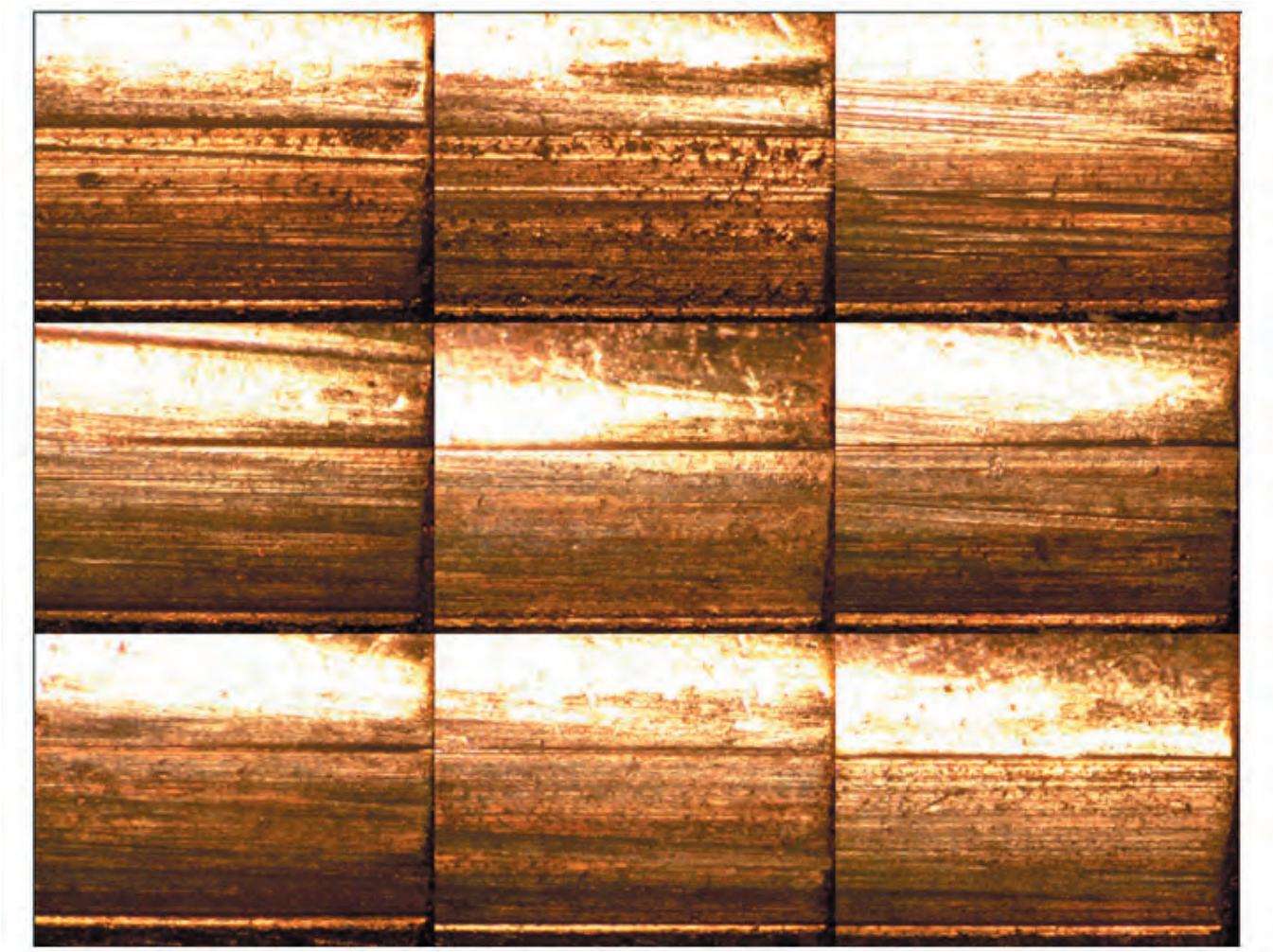

Fig. 5 Landmarks of 97th shot using Frangible 115 grain bullets.

observed on the small diameter bullets. There were prominent parallel breech face markings on the primers of expended cartridge cases. The size of the primer's areas of contact with the breech face and firing pin was different among each brand of ammunition but they were consistent within the same make of ammunition. The number of parallel striations on primers decreased with successive firing. There were concentric circular lines on hemispherical firing pin indentations. These circular lines were not exactly circular. The similarity of these circular lines between the same make of cartridge was rather high. On the other hand, the similarity of these circles between different makes of cartridges was low, even between successively fired cartridge cases. The reproducibility of the diameter of these circular lines was rather high. However, detail in these circular lines changed from firing to firing and therefore could not be used as individual characteristics for identification purposes.

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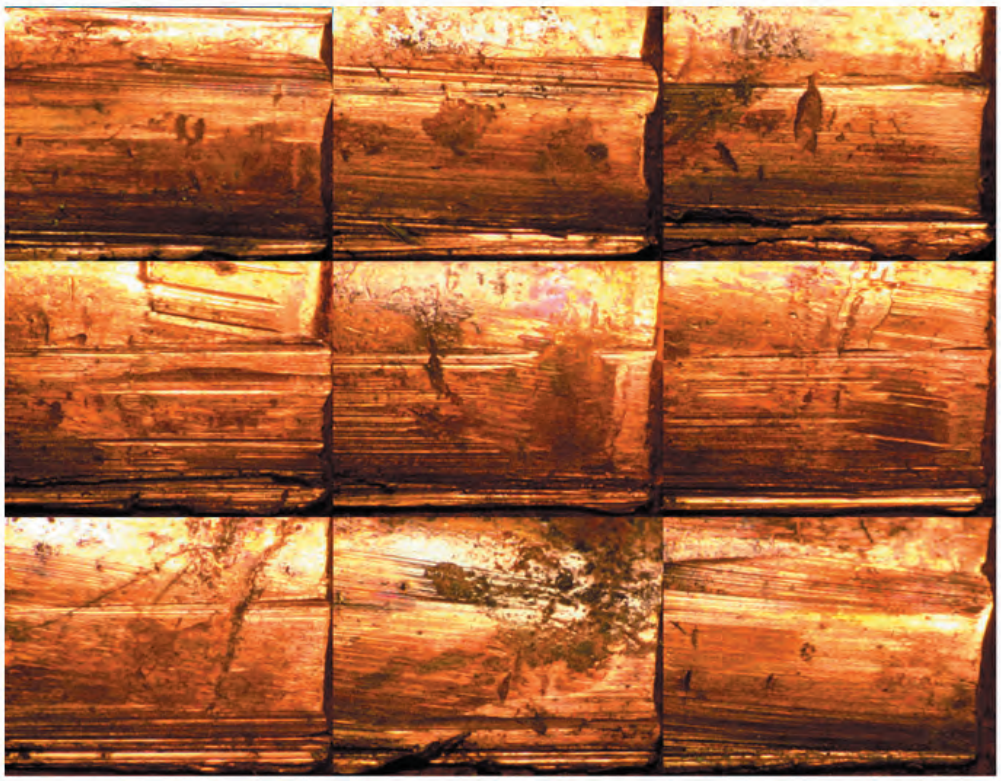

Fig. 6 Landmarks of first shot using Speer Gold Dot 115 grain bullets.

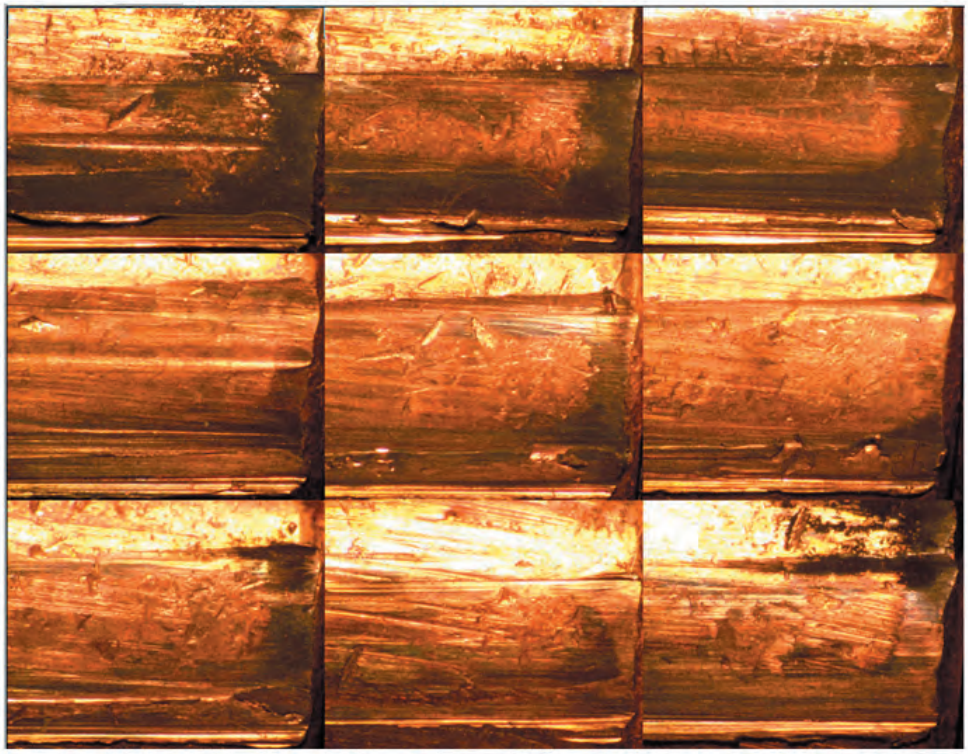

Fig. 7 Landmarks of 100th shot using Speer Gold Dot 147 grain bullets.

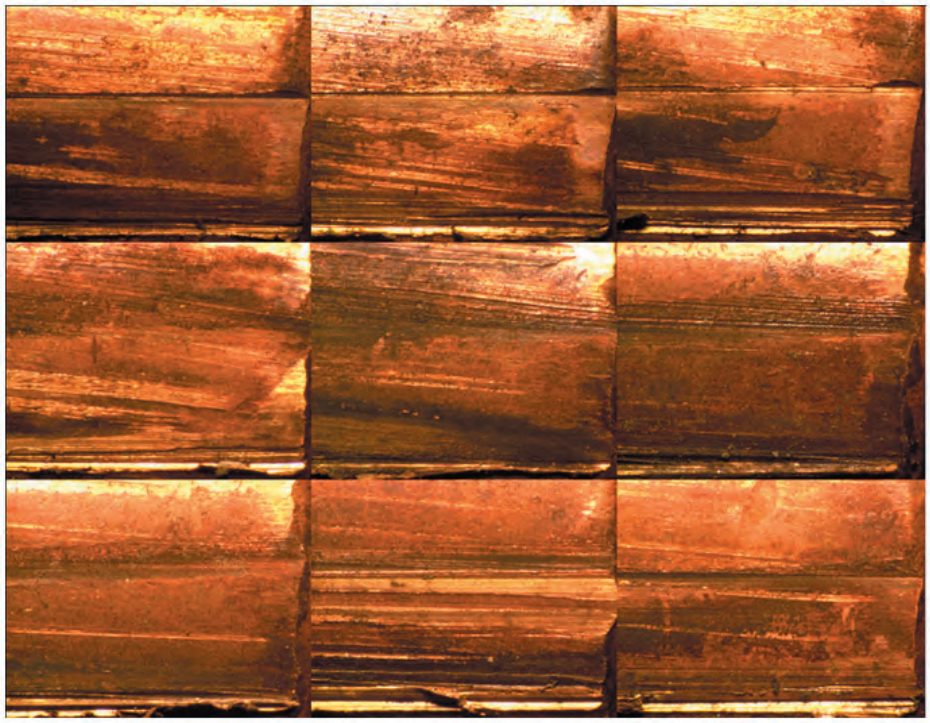

Fig. 8 Landmarks of fourth shot using Remington 124 grain bullets.

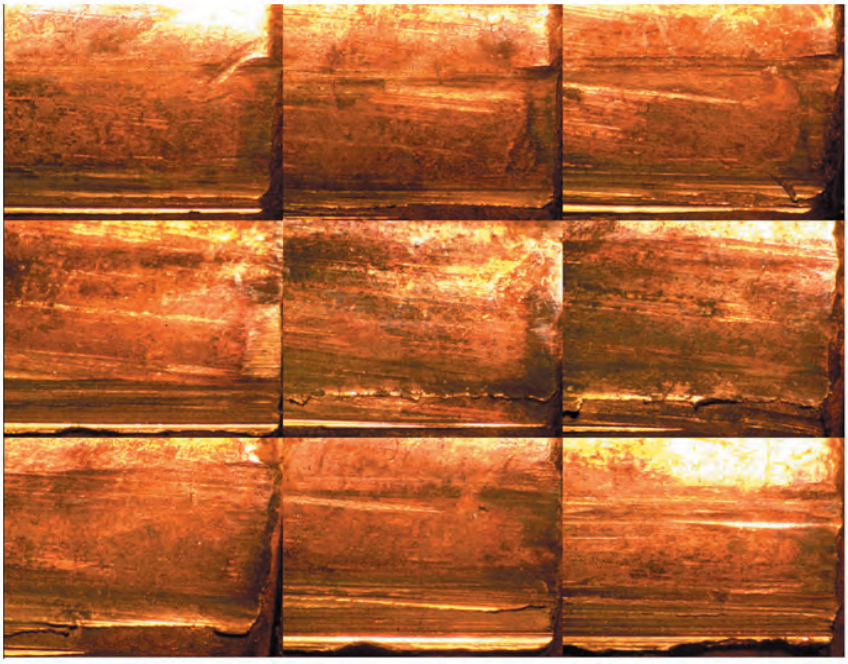

Fig. 9 Landmarks of 99th shot using Remington 124 grain bullets.

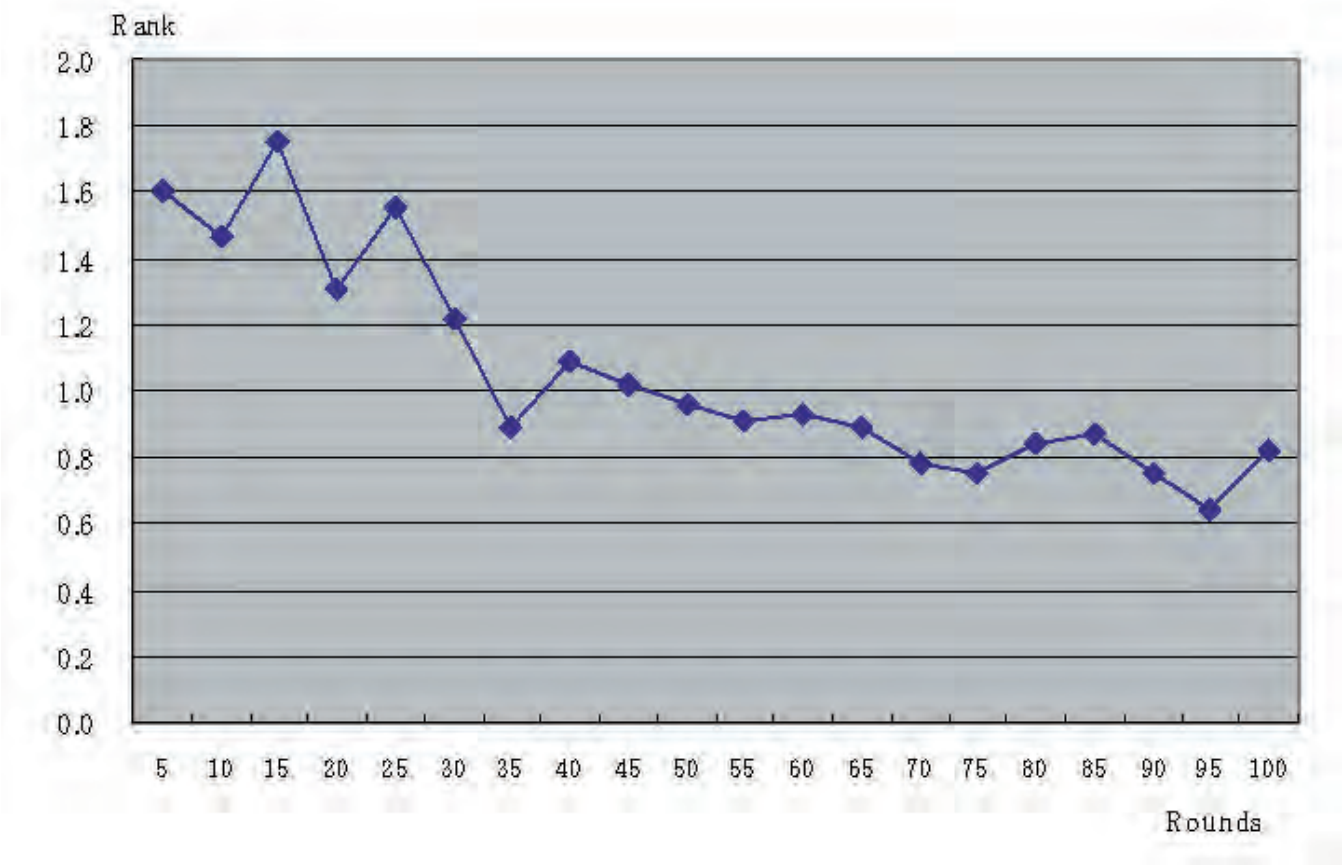

Fig. 10 Change in the rank of trailing edge depth (each group of five consecutively fired shots averaged).

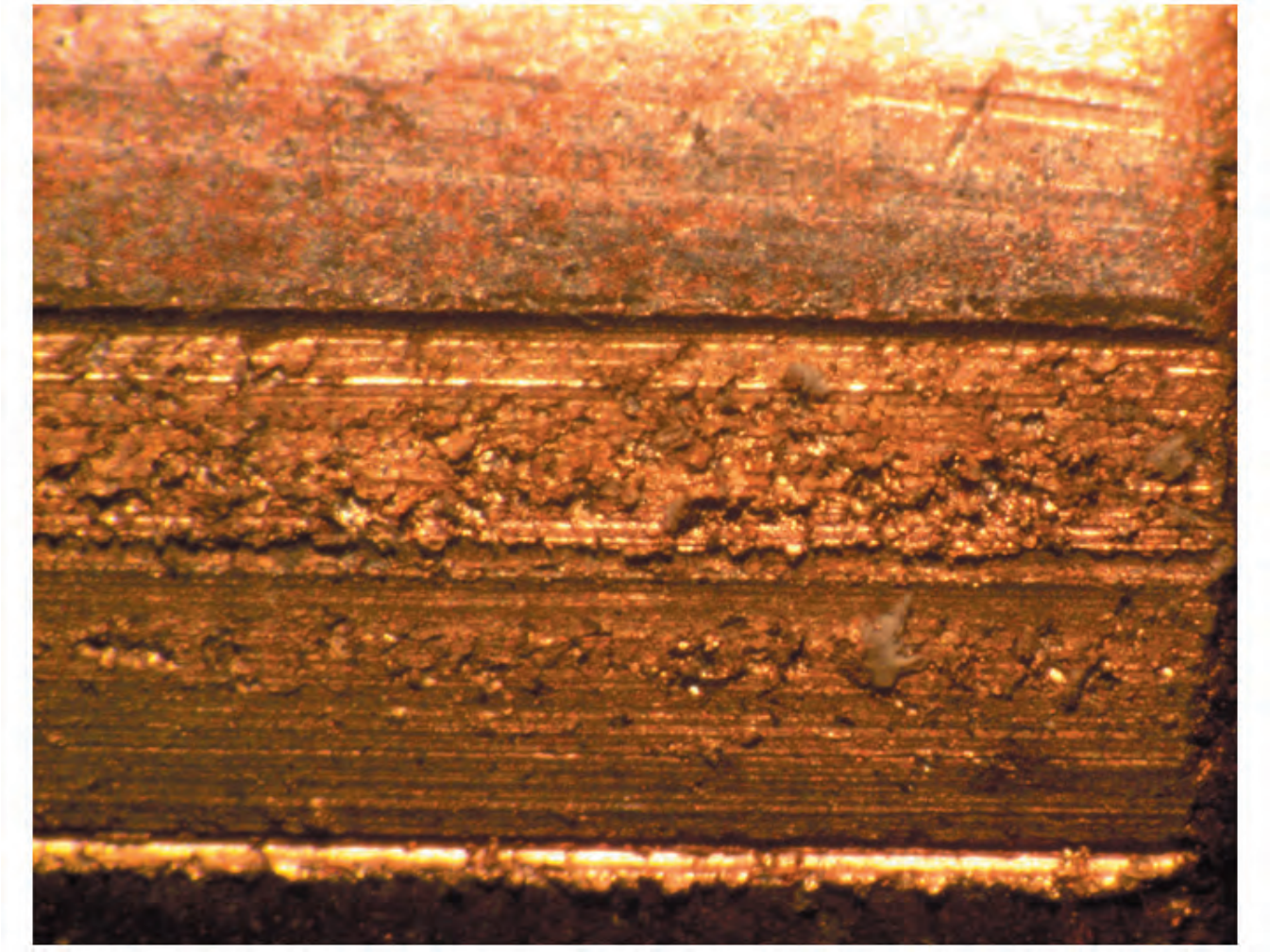

Fig. 11 Landmark 1 of 7th shot on a Frangible 115 grain bullet. Note: Pits covering striae.

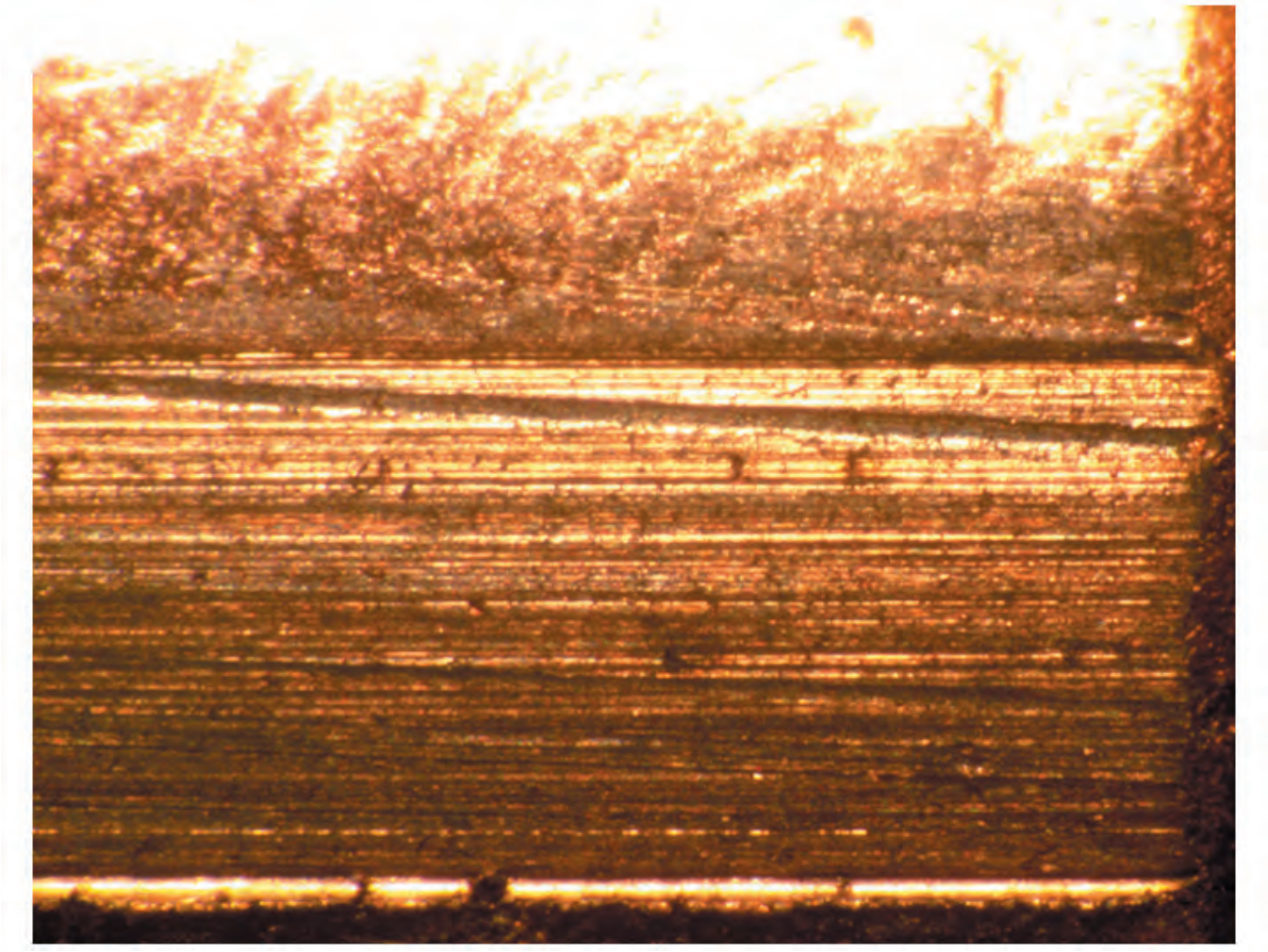

Fig. 12 Landmark 1 on the 92nd shot on a Frangible 115 grain bullet. Note: No buildup of pitting.

Fig. 13 Reproducibility of prominent striations on landmark 1 of Frangible 115 grain bullets. Note that the relative position of these striae to the driving edge was shifted toward the direction of the trailing edge in accordance with successive firing. This photo was made by overlaying segments of photos which were cut from bullet base areas.

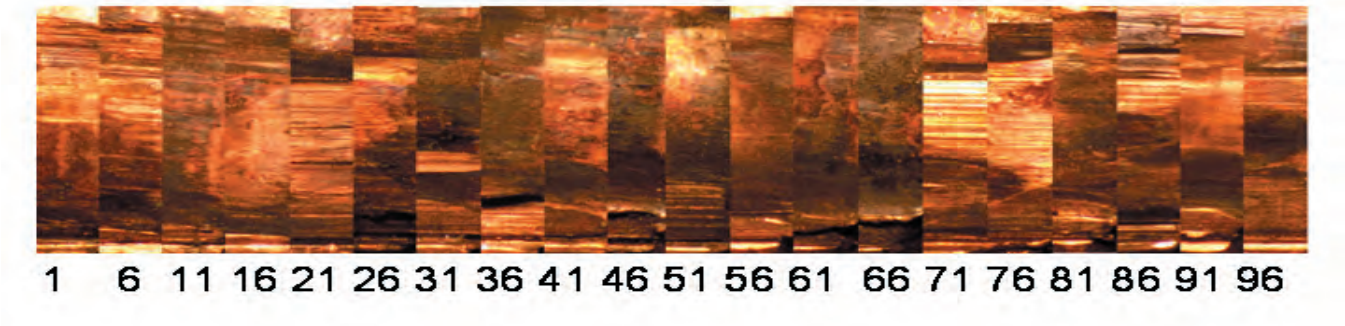

Fig. 14 Reproducibility of striations on landmark 1 of Speer Gold Dot 115 grain bullets (51 is Federal bullet.) Note: No prominent striations on these bullets.

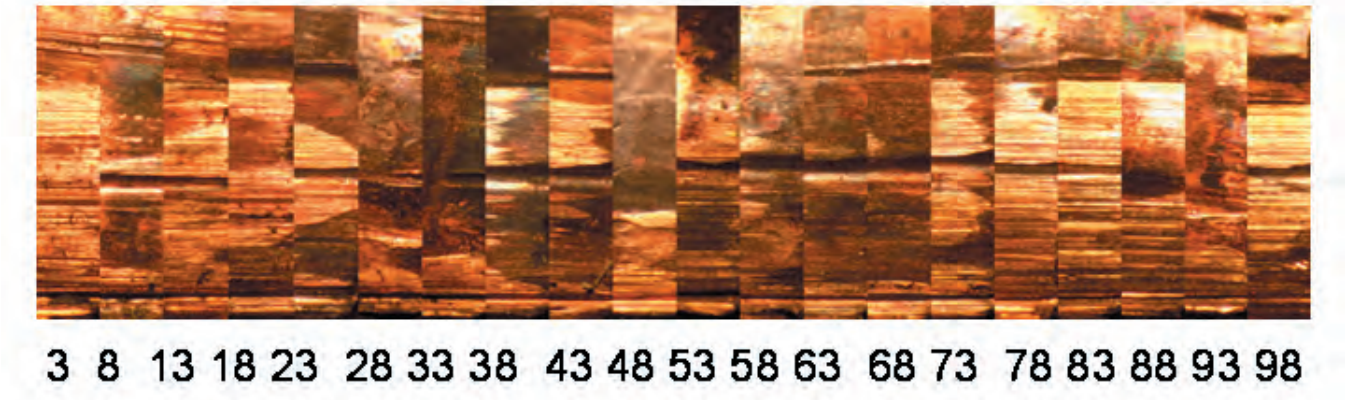

Fig. 15 Reproducibility of striations on landmark 1 of Speer Gold Dot 124 grain bullets (53 is Federal bullet.) Note: Prominent striations were observed on some of these bullets.

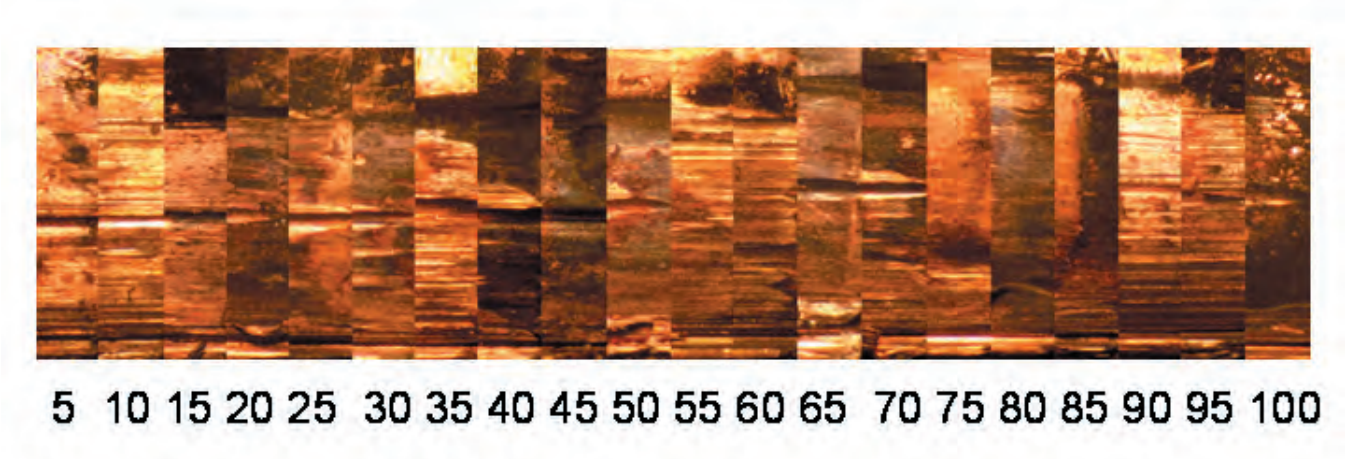

Fig. 16 Reproducibility of striations on landmark 1 of Speer Gold Dot 147 grain bullets
(55 and 60 are Federal bullets.) Note: Prominent striations were observed on some of these bullets.

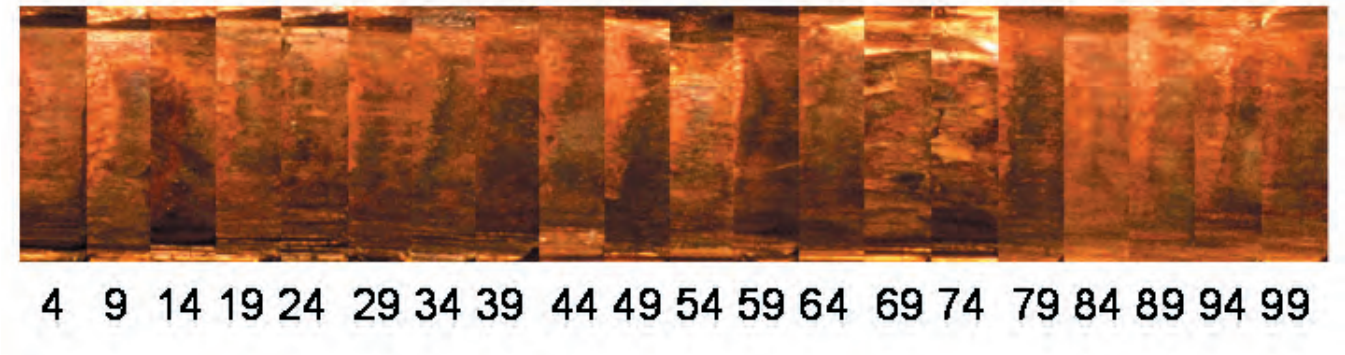

Fig. 17 Reproducibility of striations on landmark 1 of Remington 124 grain bullets
Note: No prominent striations on these bullets.

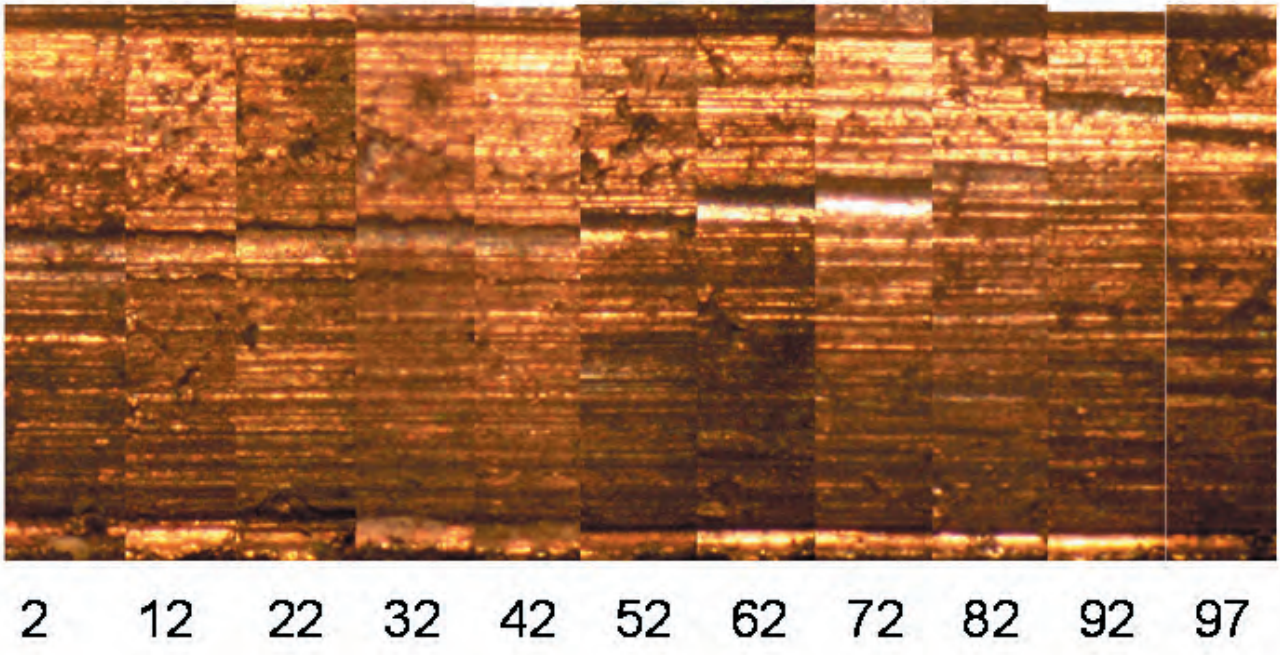

Fig. 18 Reproducibility of striations on landmark 1 of Frangible 115 grain bullets

Fig.19

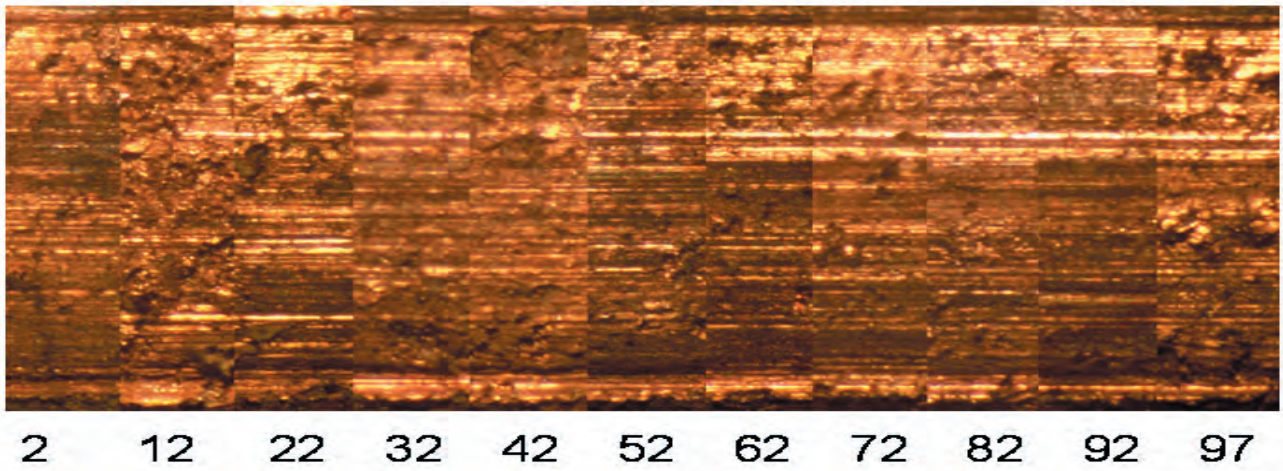

Fig. 19 Reproducibility of striations on landmark 2 of Frangible 115 grain bullets

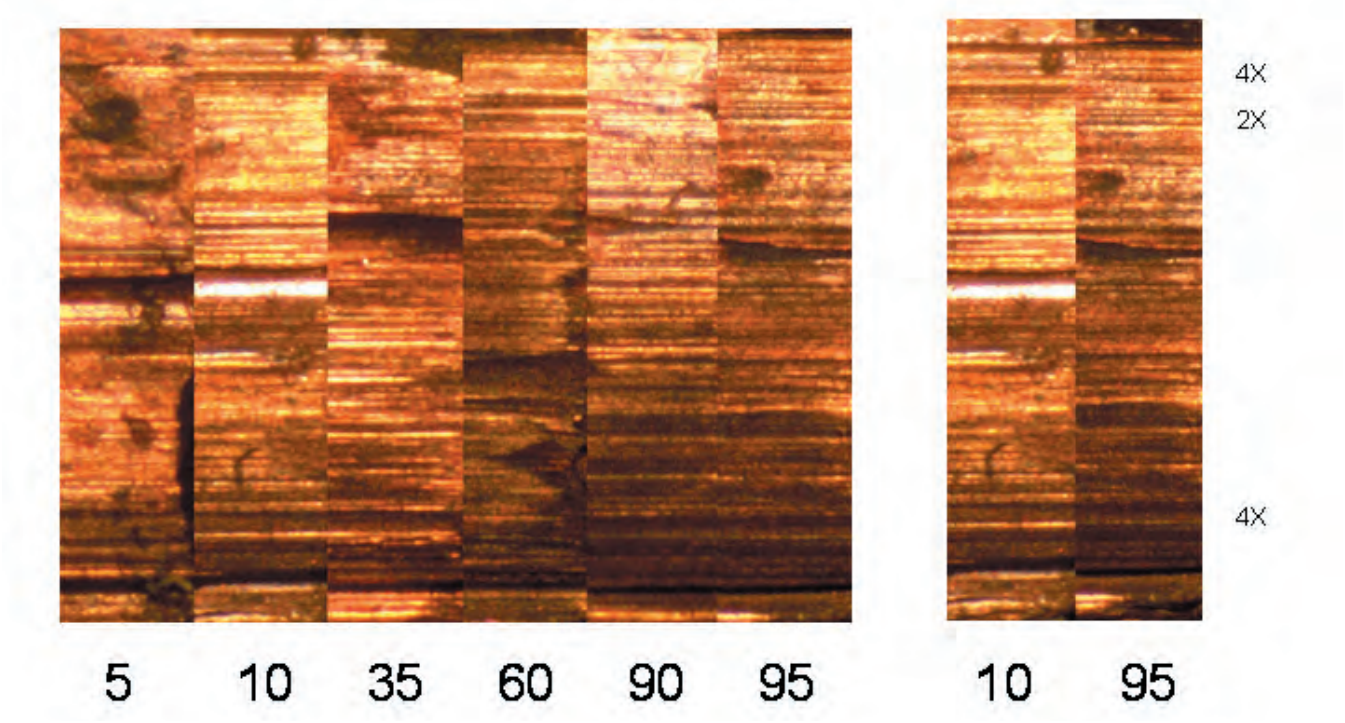

Fig. 20 Striation matching found on base area of landmark 1 of Speer Gold Dot 147 grain bullets. Note: In this area, CMS runs greater than three were observed between the 90th and the 95th shots and between the 10th and the 95th shots.

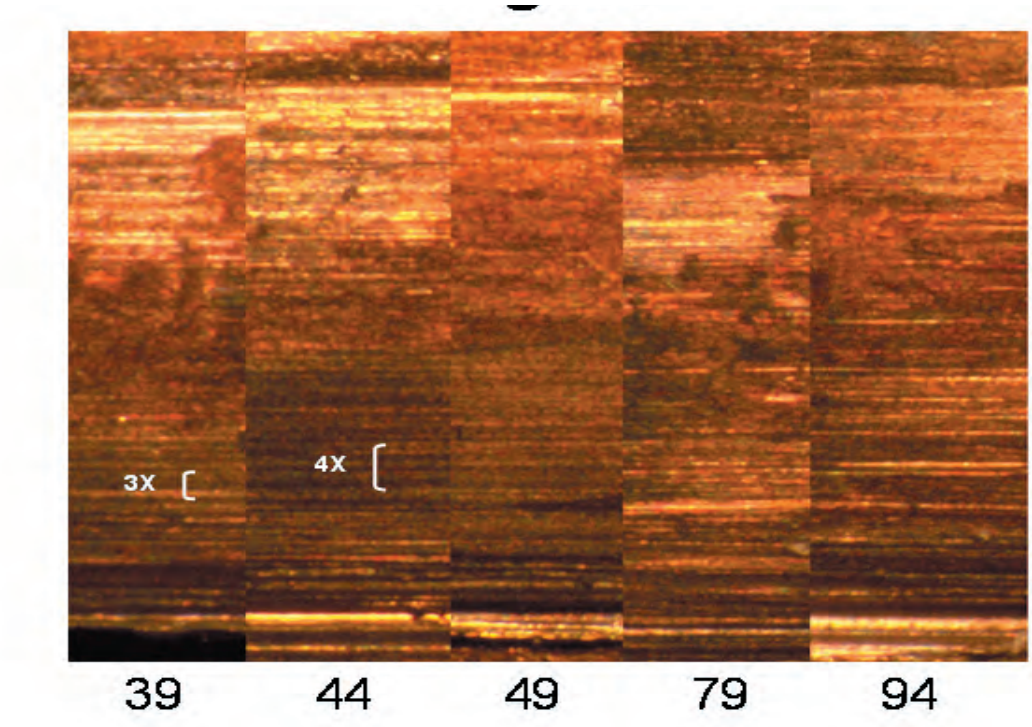

Fig. 21 Striation matching found on nose area of landmark 9 of Remington bullets. Note: In this area, CMS runs greater than three were observed between the 39th and the 44th shots and between the 44th and the 49th shots.

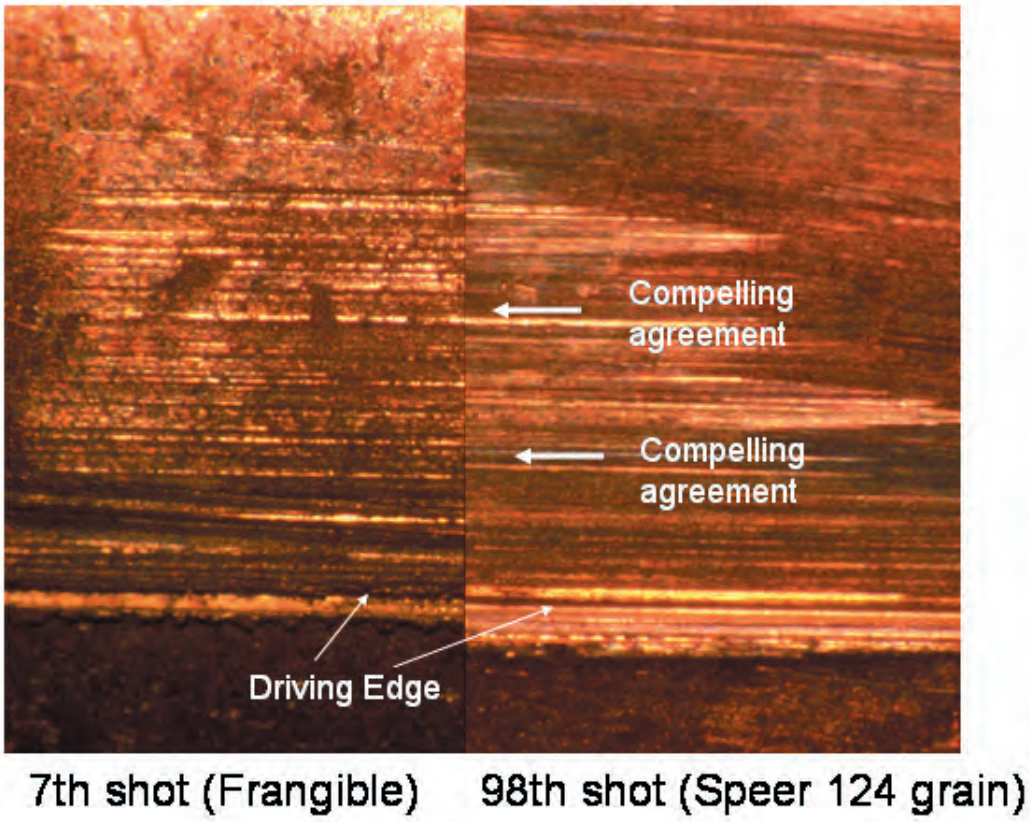

Fig. 22 Comparison between the 7th shot of a Frangible bullet and the 98th shot of a Speer 124 grain bullet. Some compelling agreement of matching striations is observed in this photo, however, CMS runs greater than three were not found with this author's counting procedure.

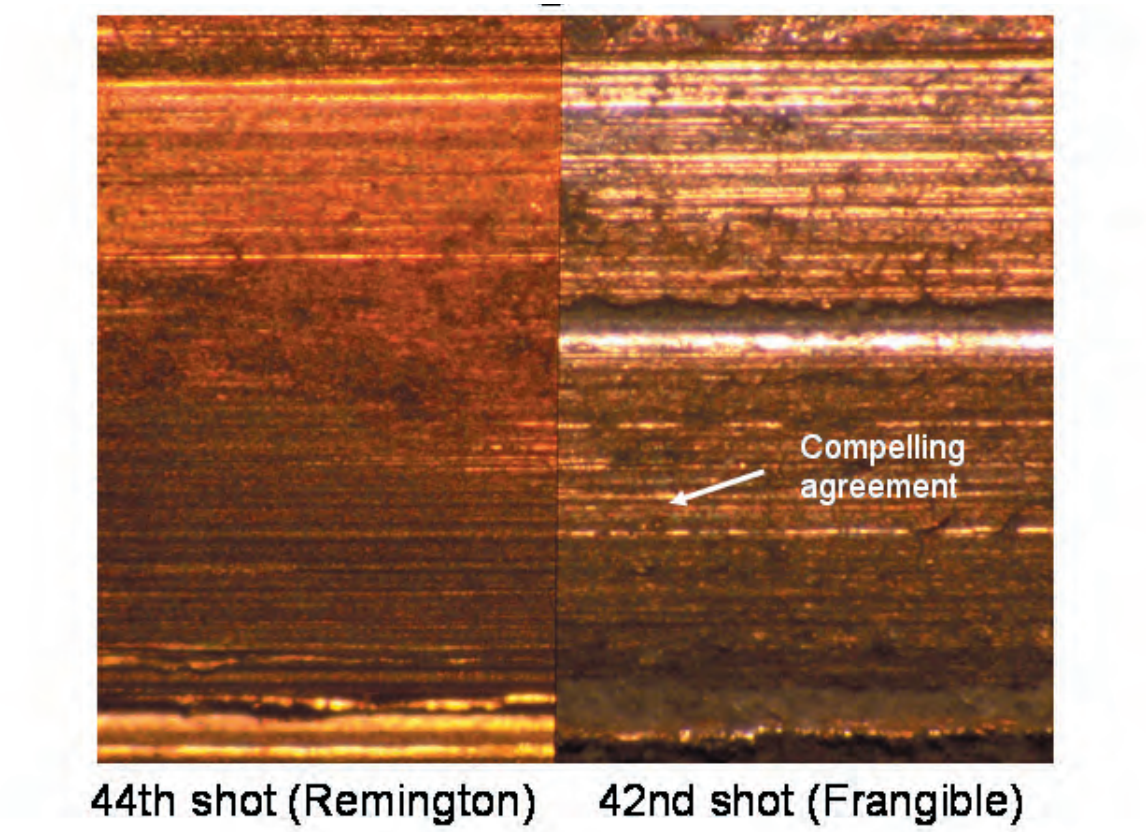

Fig. 23 A rare example of matching striations between a Remington bullet and a Frangible bullet comparison on landmark 1 between 44th and 42nd shot (respectively). Note: Although the firing interval of these shots was only two, the number of corresponding striations was small and CMS runs greater than three were not found.

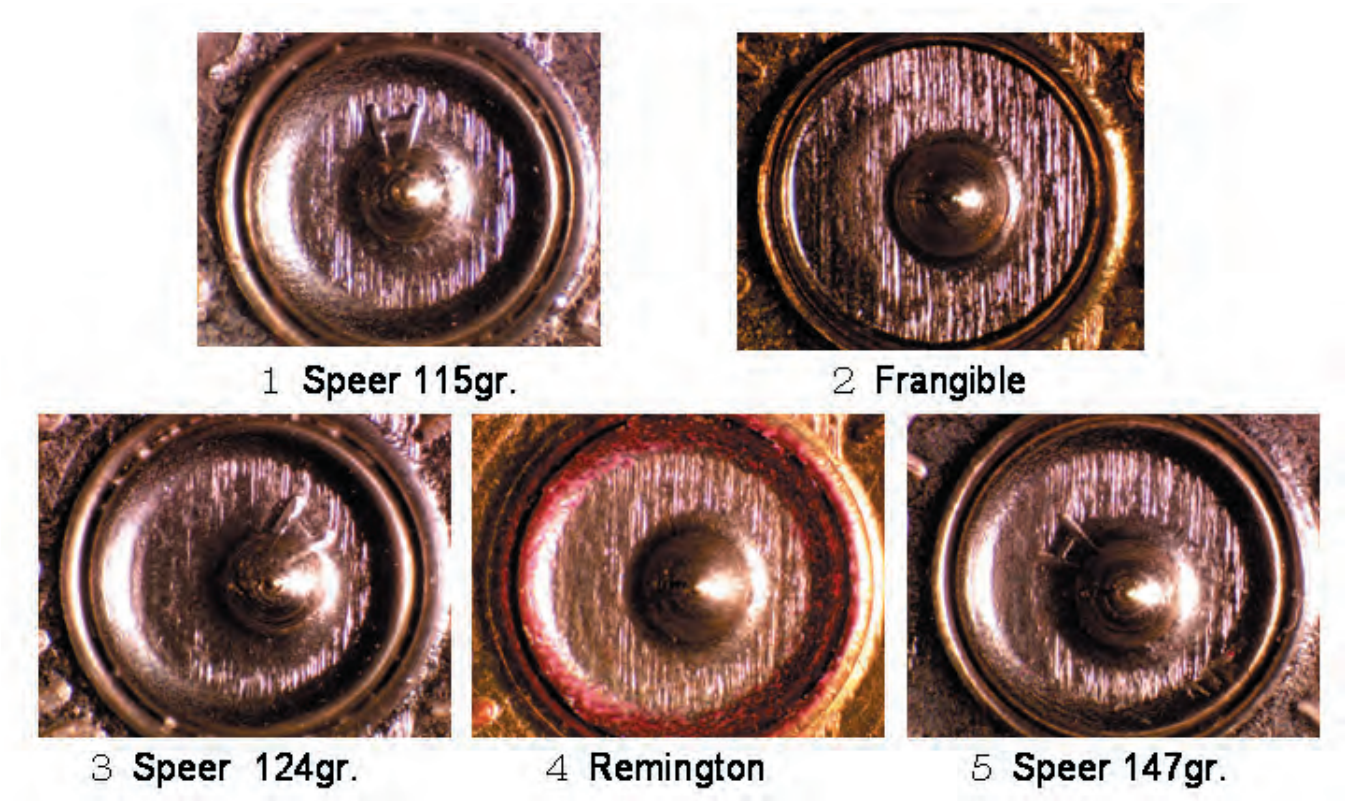

Fig. 24 Breechface marks on the primers of the first five shots.

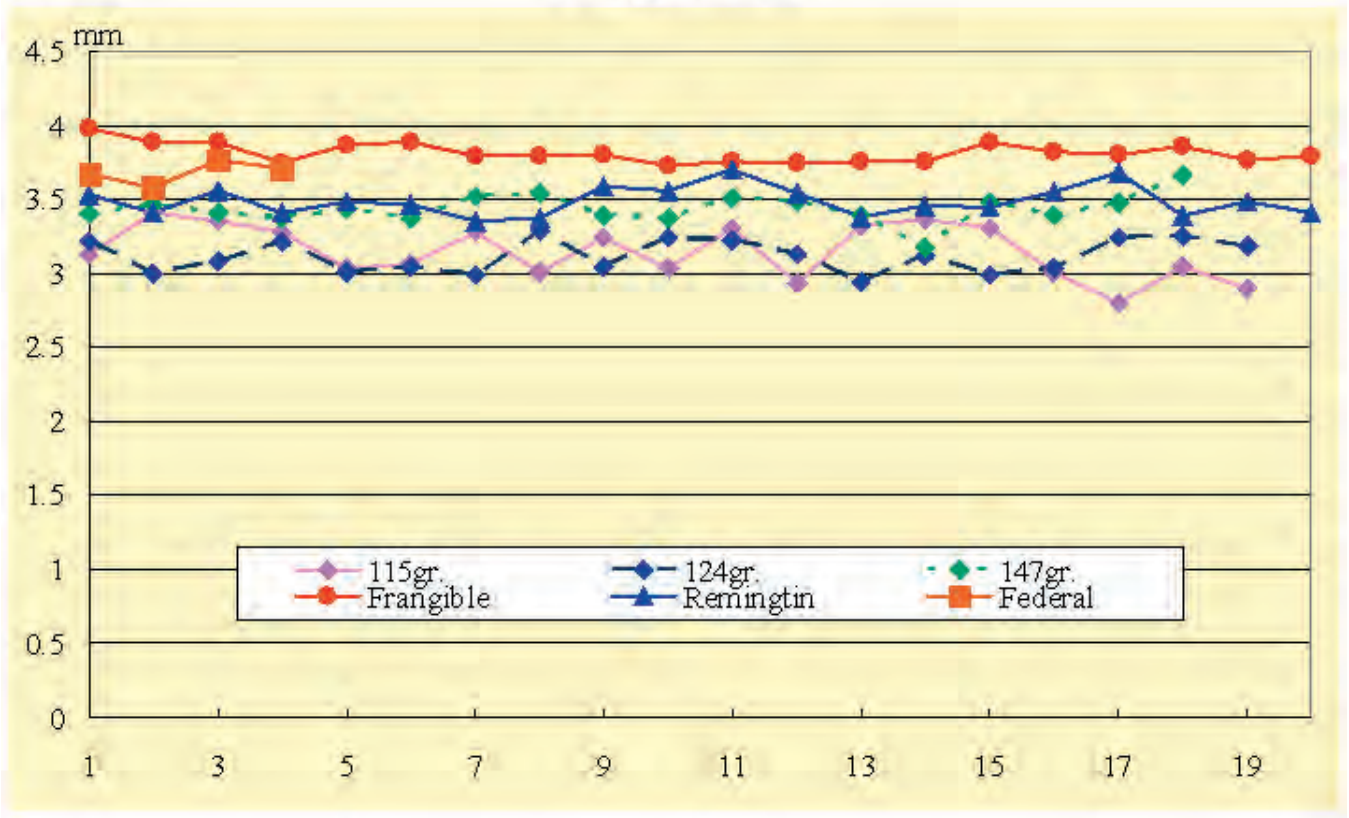

Fig. 25 Diameter of the primer area which contacted the breechface with respect to ammunition type.

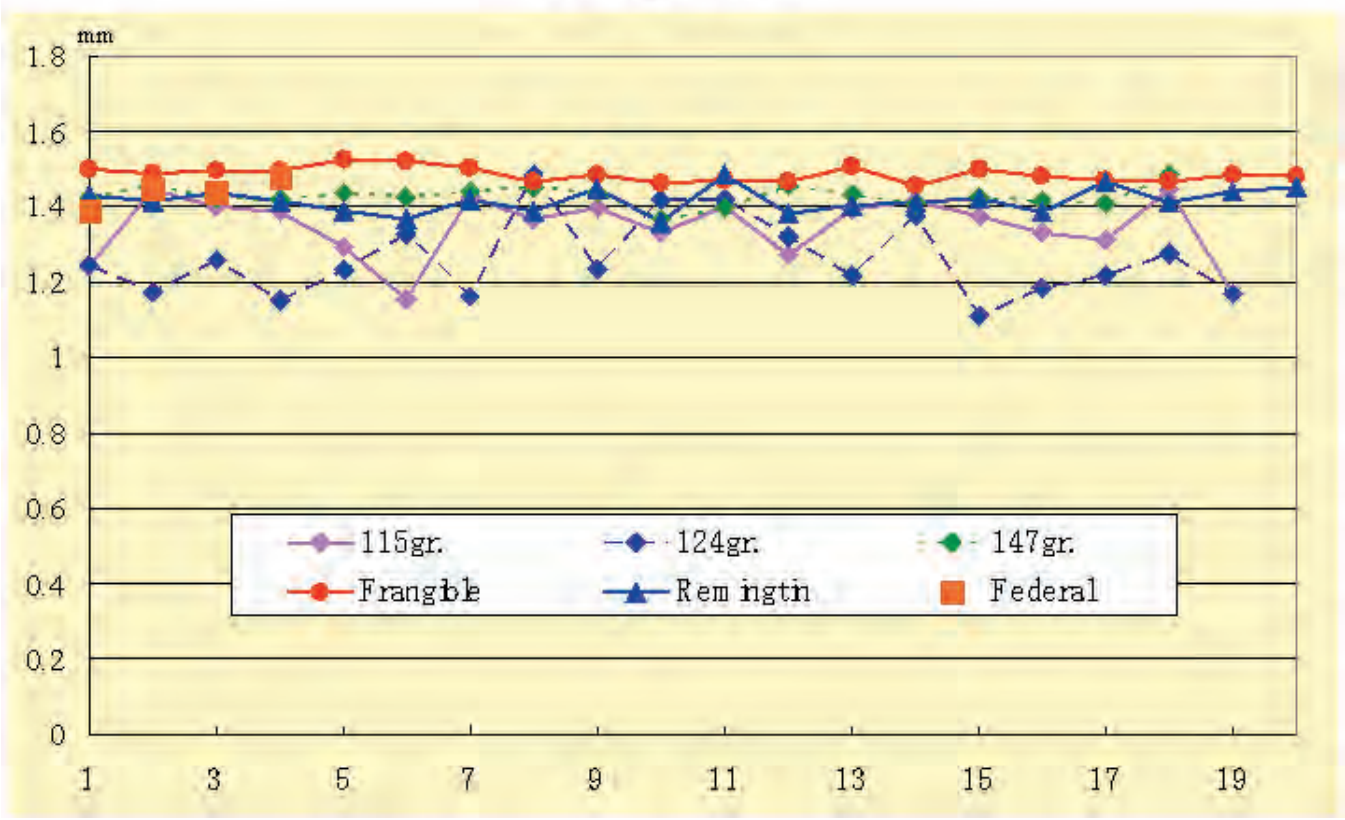

Fig. 26 Diameter of firing pin indentation with respect to ammunition type.

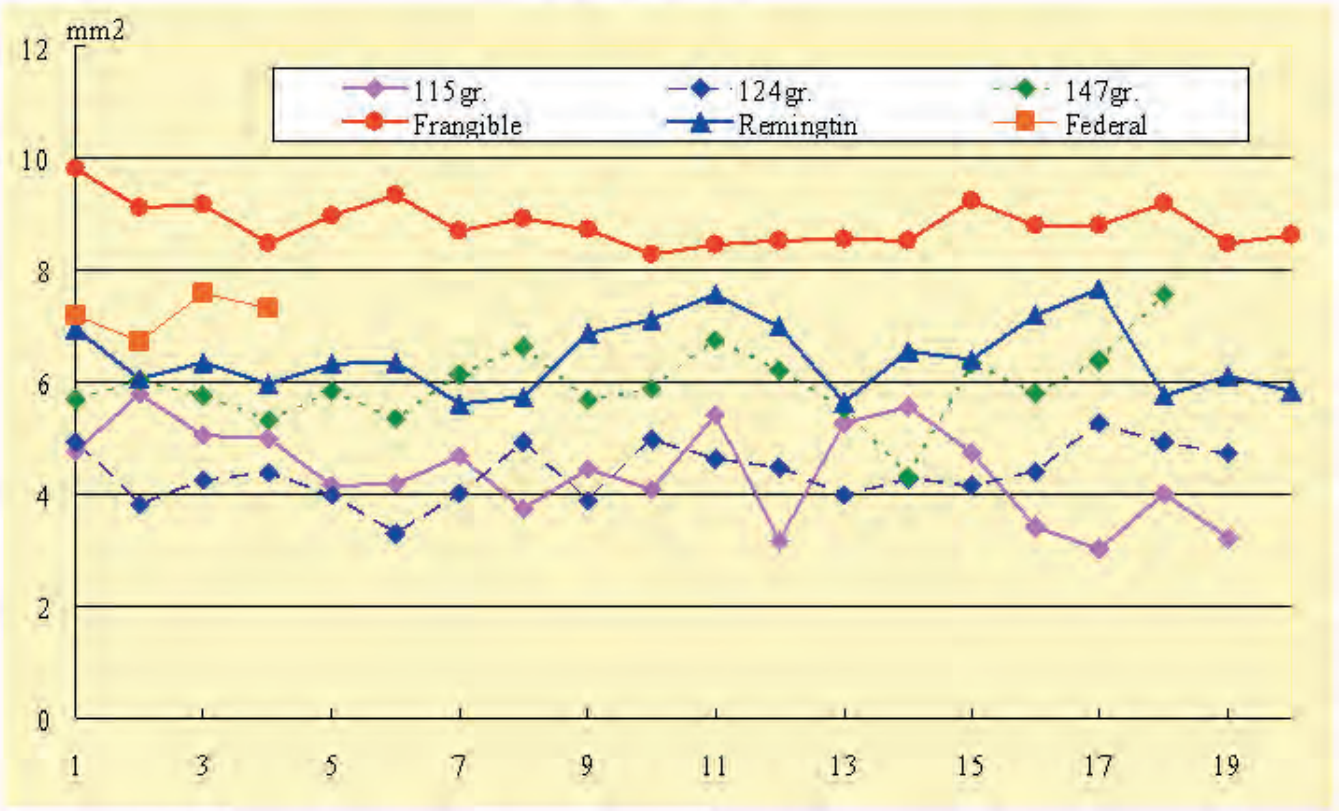

Fig. 27 Area of primer that contacted the breechface calculated from the results shown in Fig. 25 and Fig. 26.

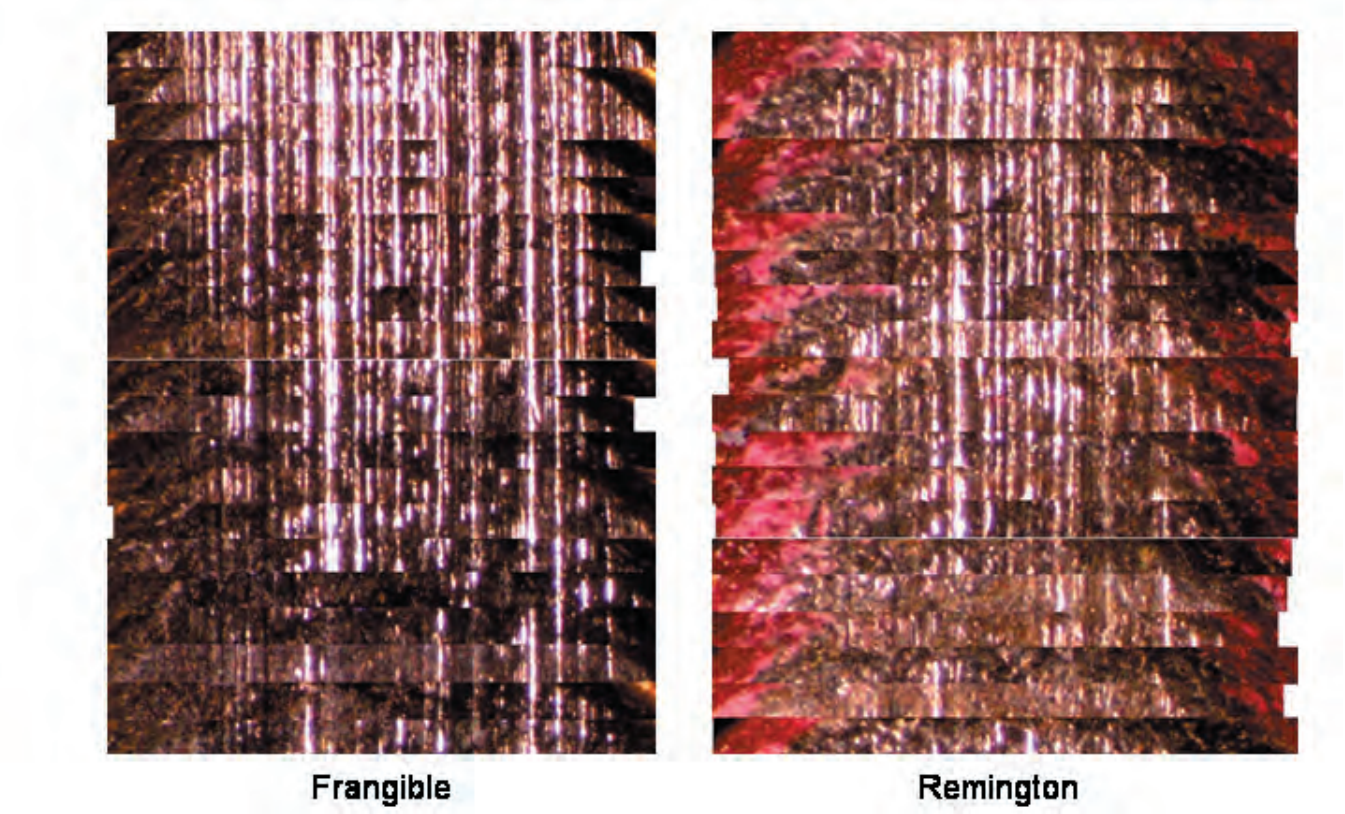

Fig. 28 Reproducibility of breechface marks on the primers of Frangible and Remington cartridge cases. Portions of photographs of breechface marks are arranged from top to bottom in firing order from 1 to 100.

Fig.29

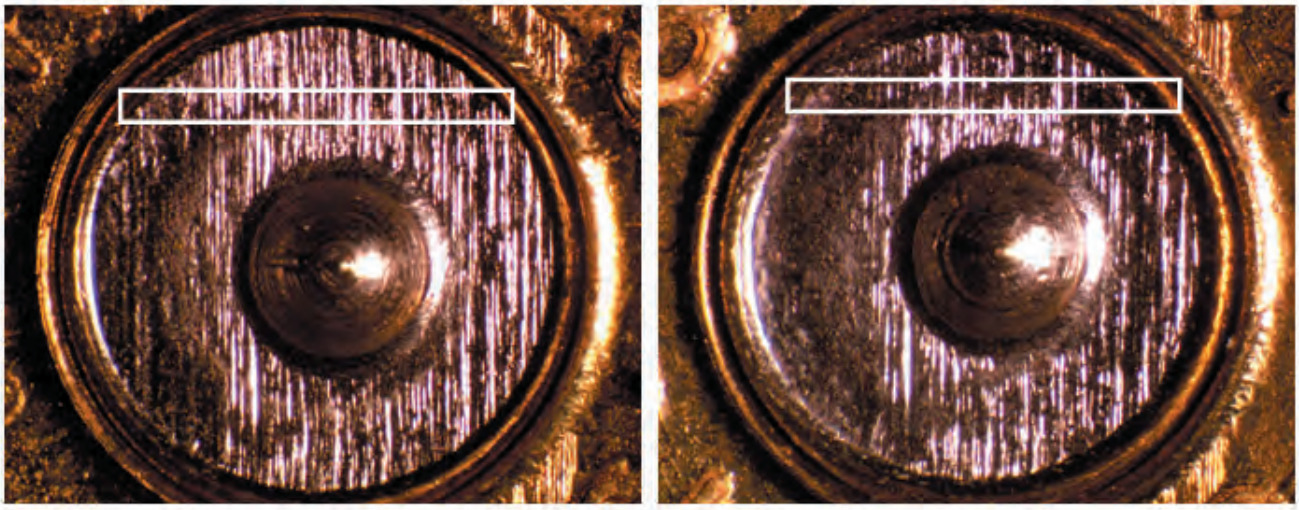

Fig. 29 Each segment of a photo was cut from the middle area between the upper edge of the primer and the firing pin indentation. The reproducibility of parallel striations was very good until around the 70th shot. Some striations became shallow in this area after the 72nd shot.

Fig.30

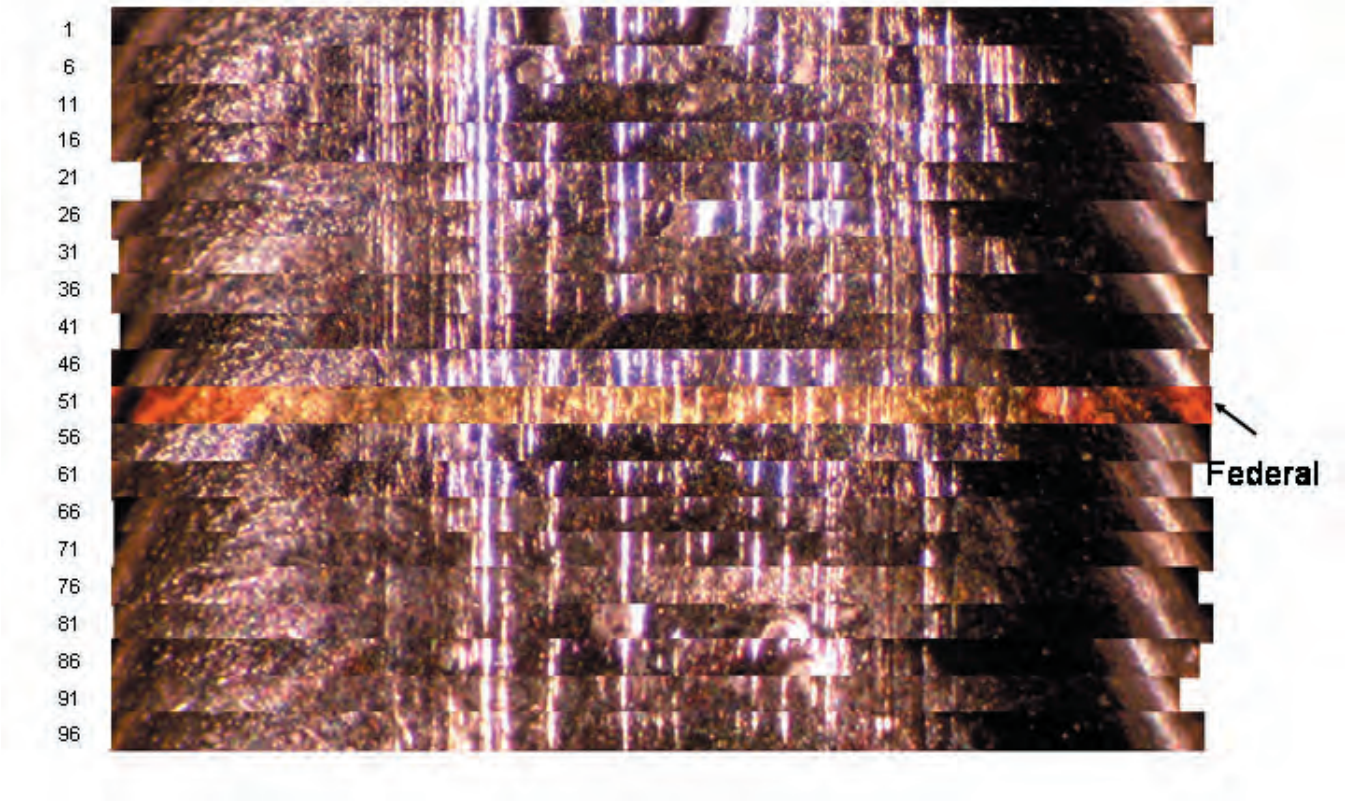

Fig. 30 Reproducibility of breechface marks on the primers of Speer 115 grain (bullet) cartridge cases.

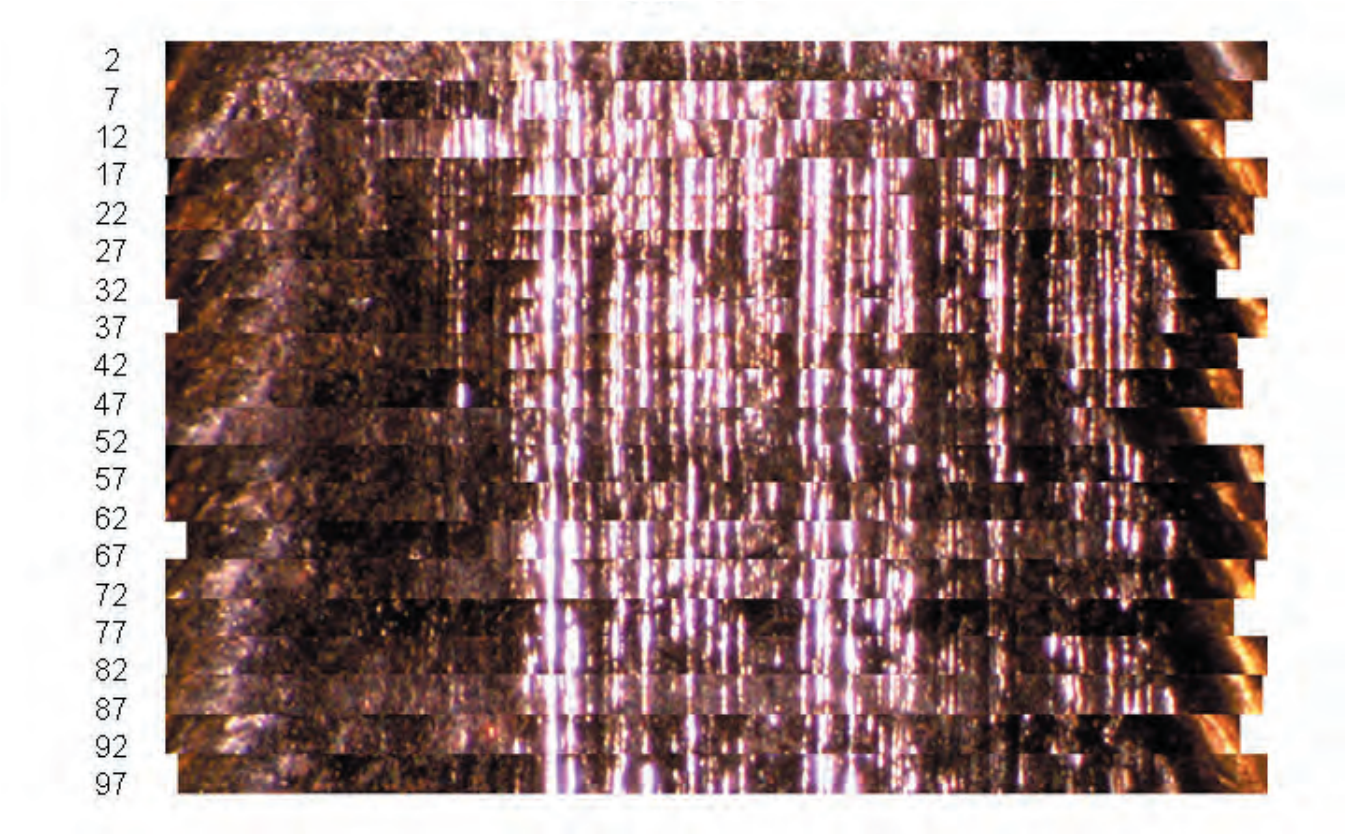

Fig. 31 Reproducibility of breechface marks on primers of Frangible (bullet) cartridge cases.

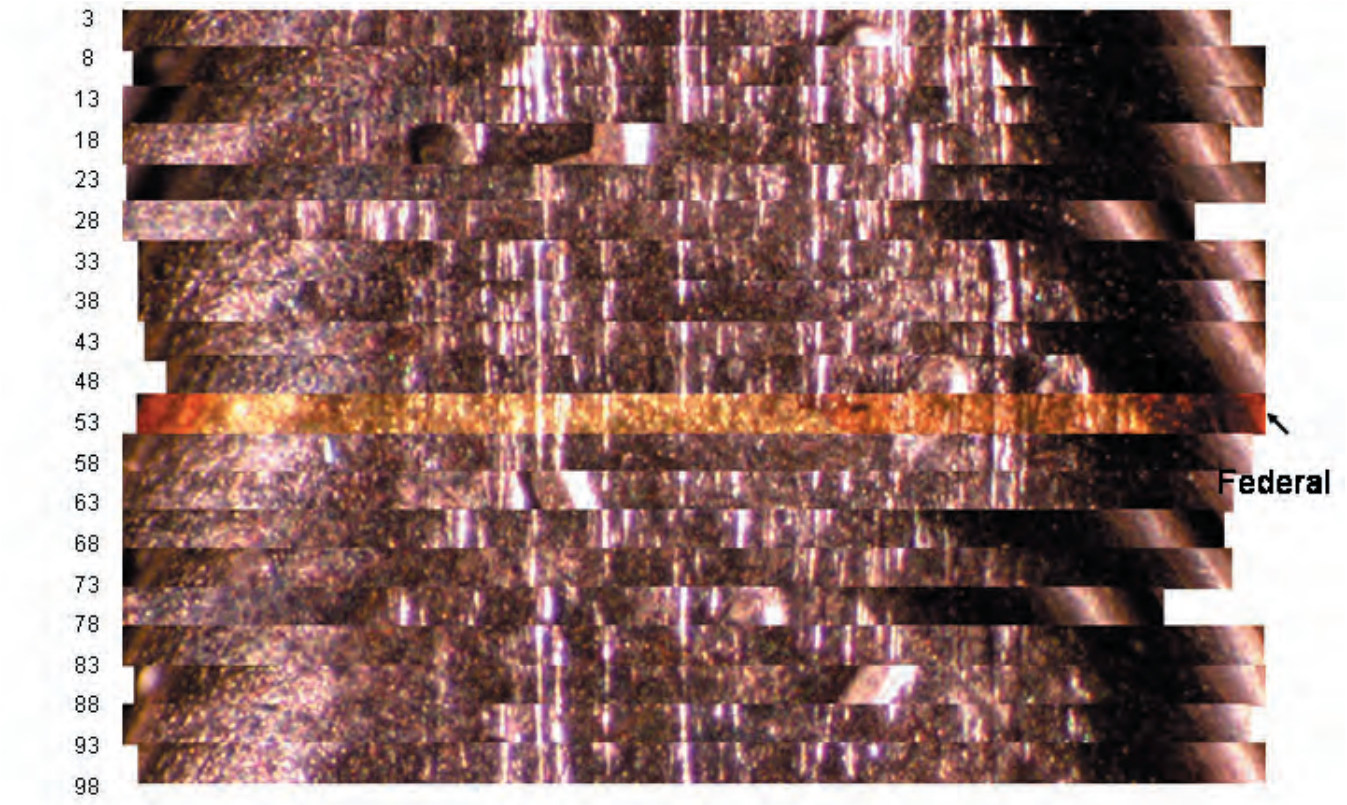

Fig. 32 Reproducibility of breechface mark on primers of Speer 124 grain (bullet) cartridge cases.

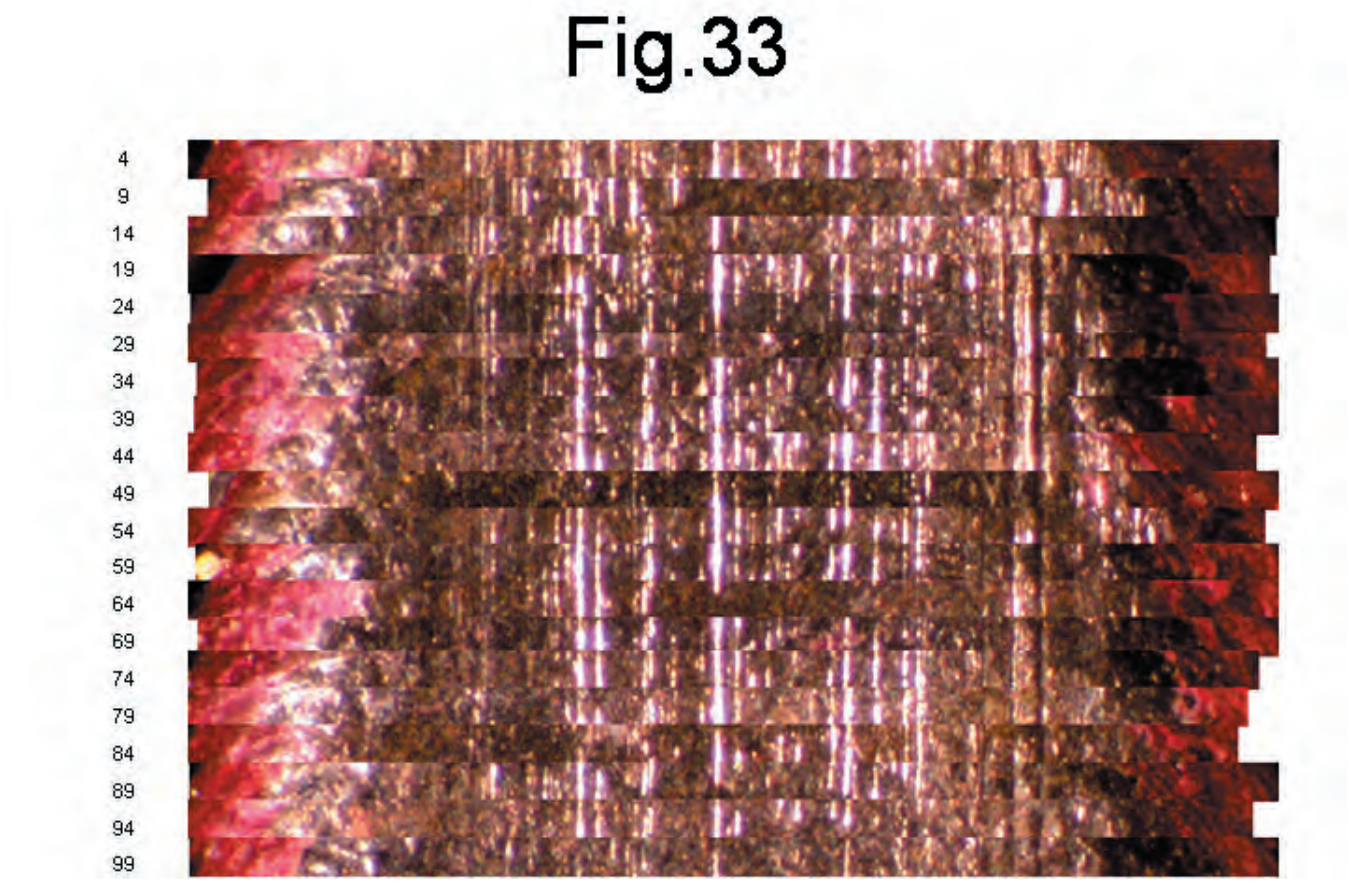

Fig. 33 Reproducibility of breechface marks on primers of Remington (bullet) cartridge cases.

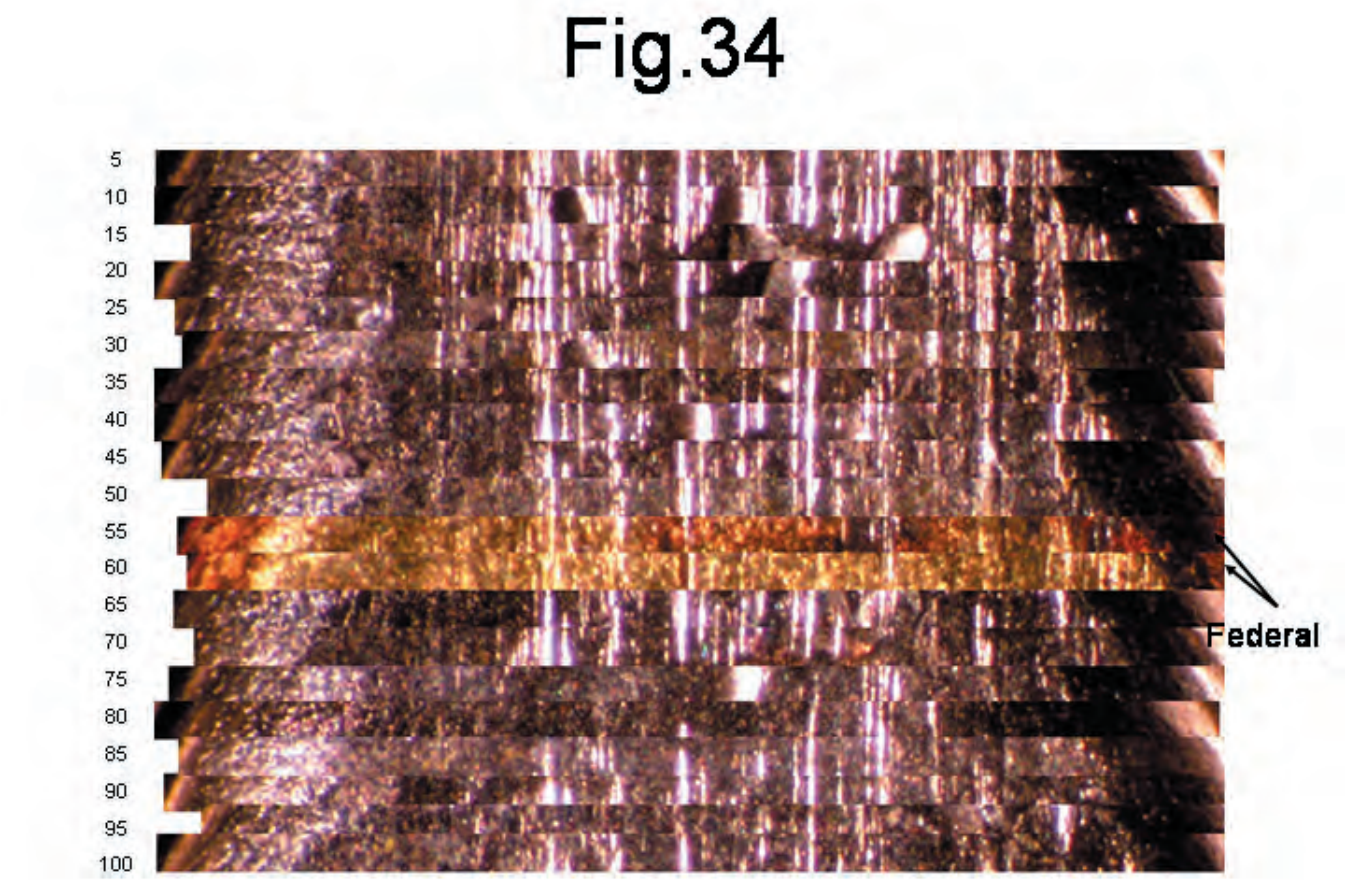

Fig. 34 Reproducibility of breechface marks on primers of Speer 147 grain (bullet) cartridge cases.

Fig.35

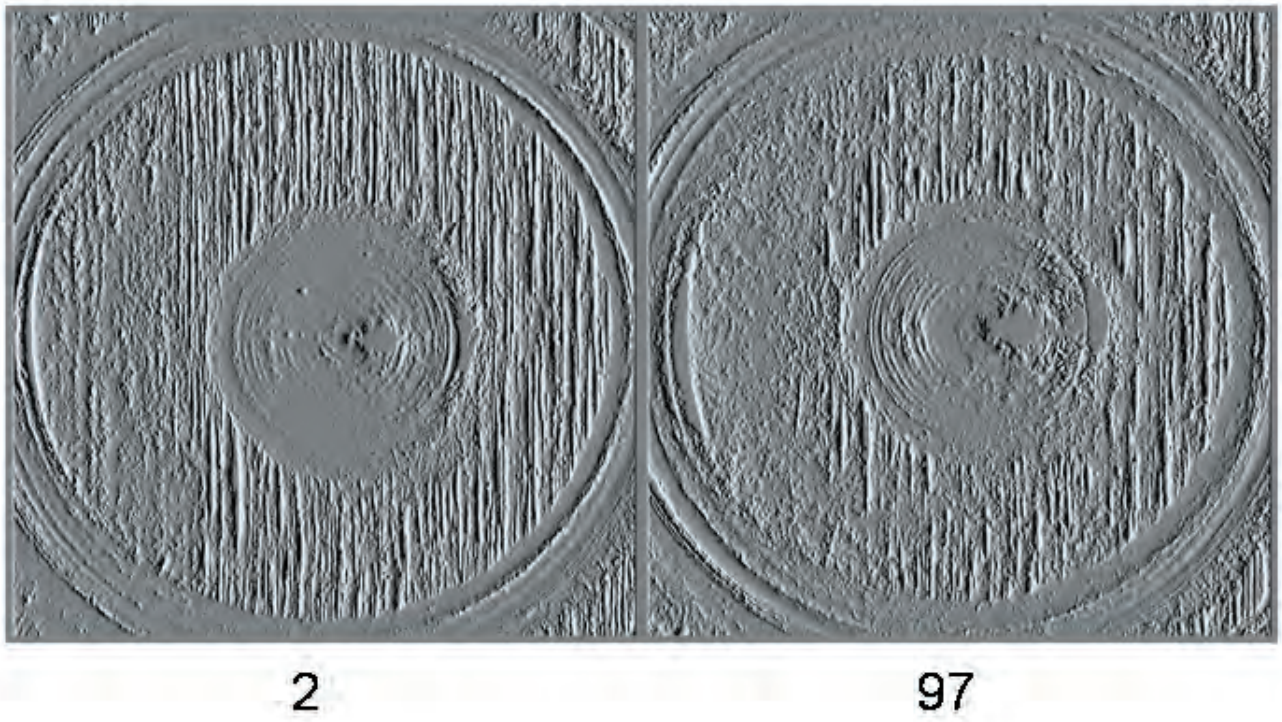

Fig. 35 Enhanced primer image using Sobel X filter.

Fig.36

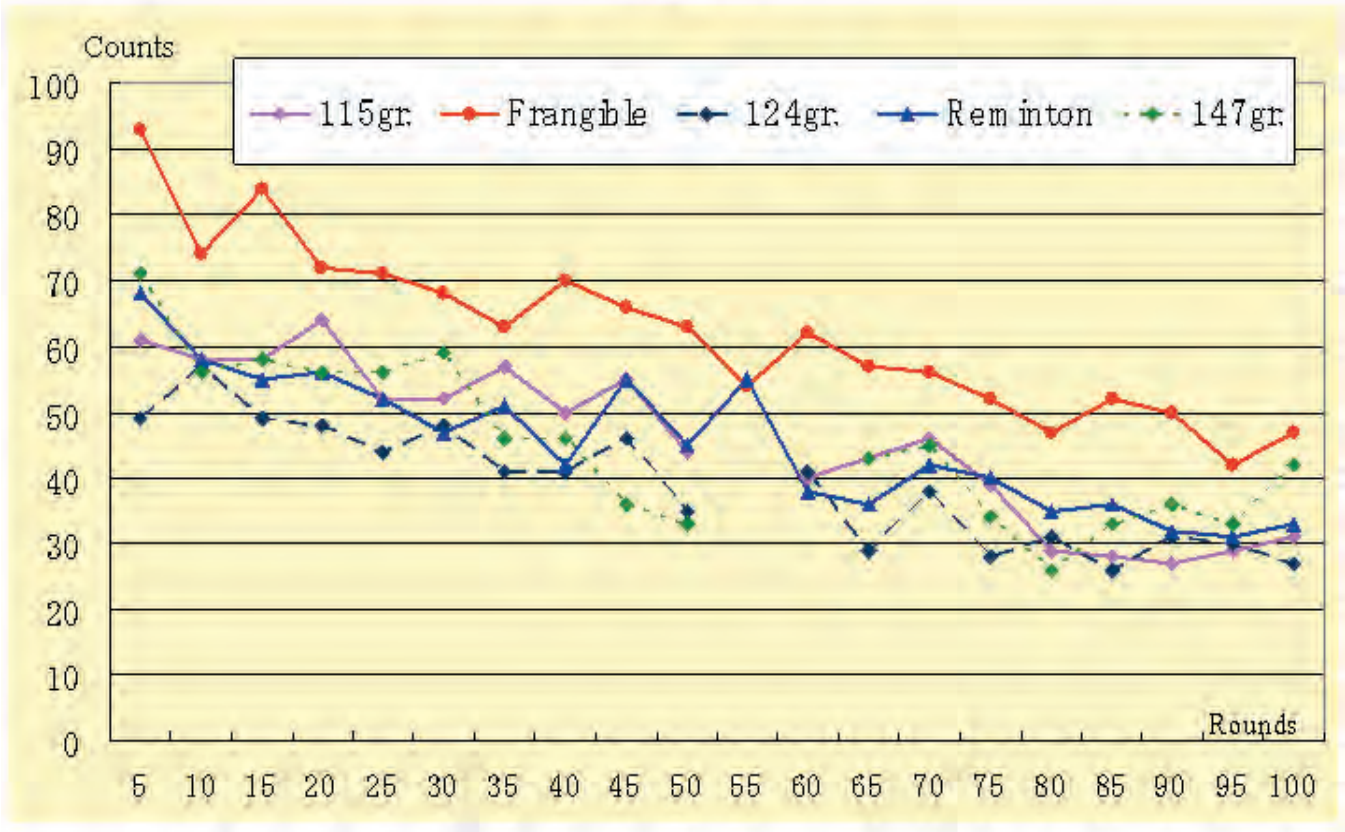

Fig. 36 Line counts of breechface marks on primers of each type of cartridge.

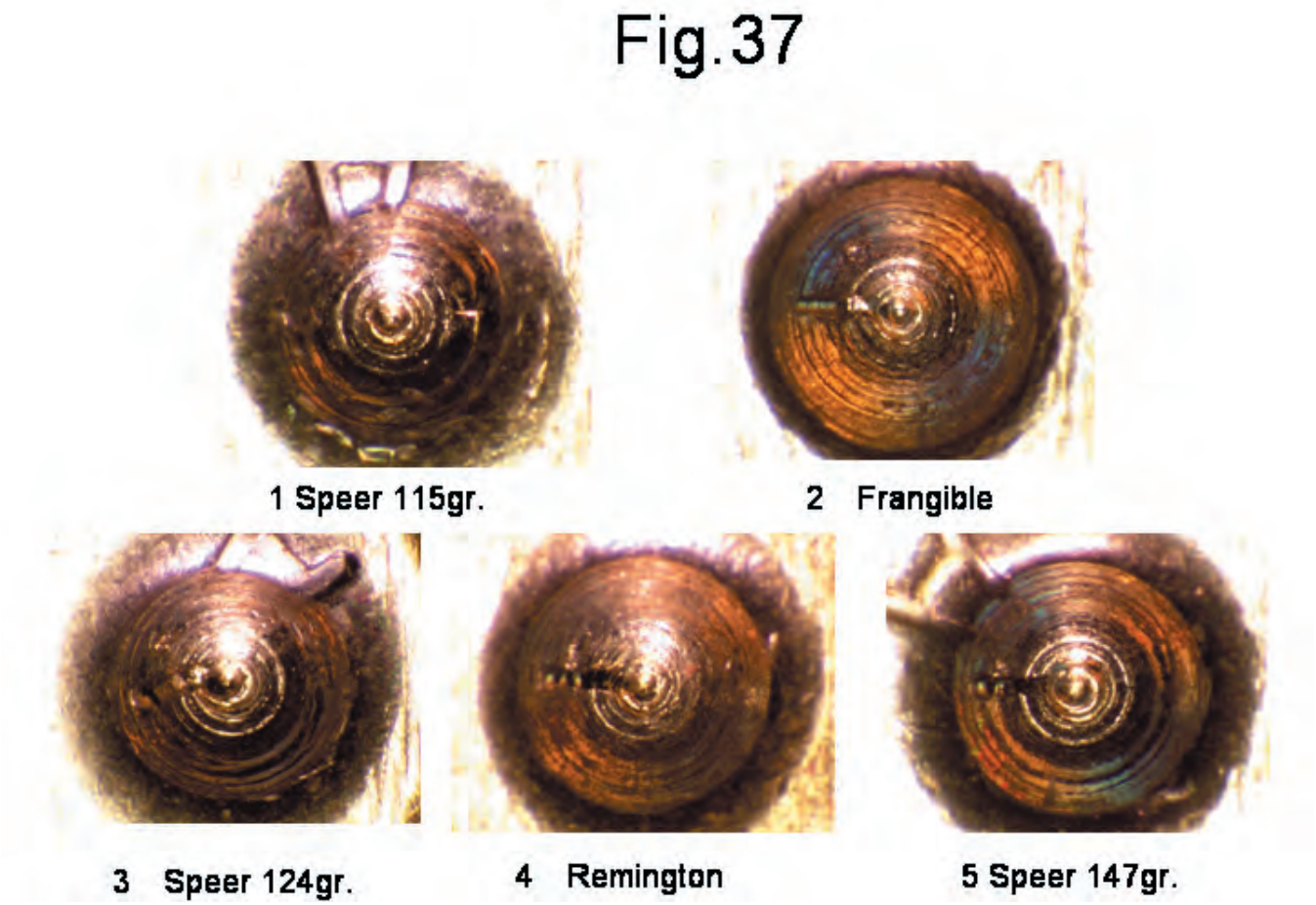

Fig. 37. Firing pin indentations of the fifth shot fired for each cartridge type

Fig.38

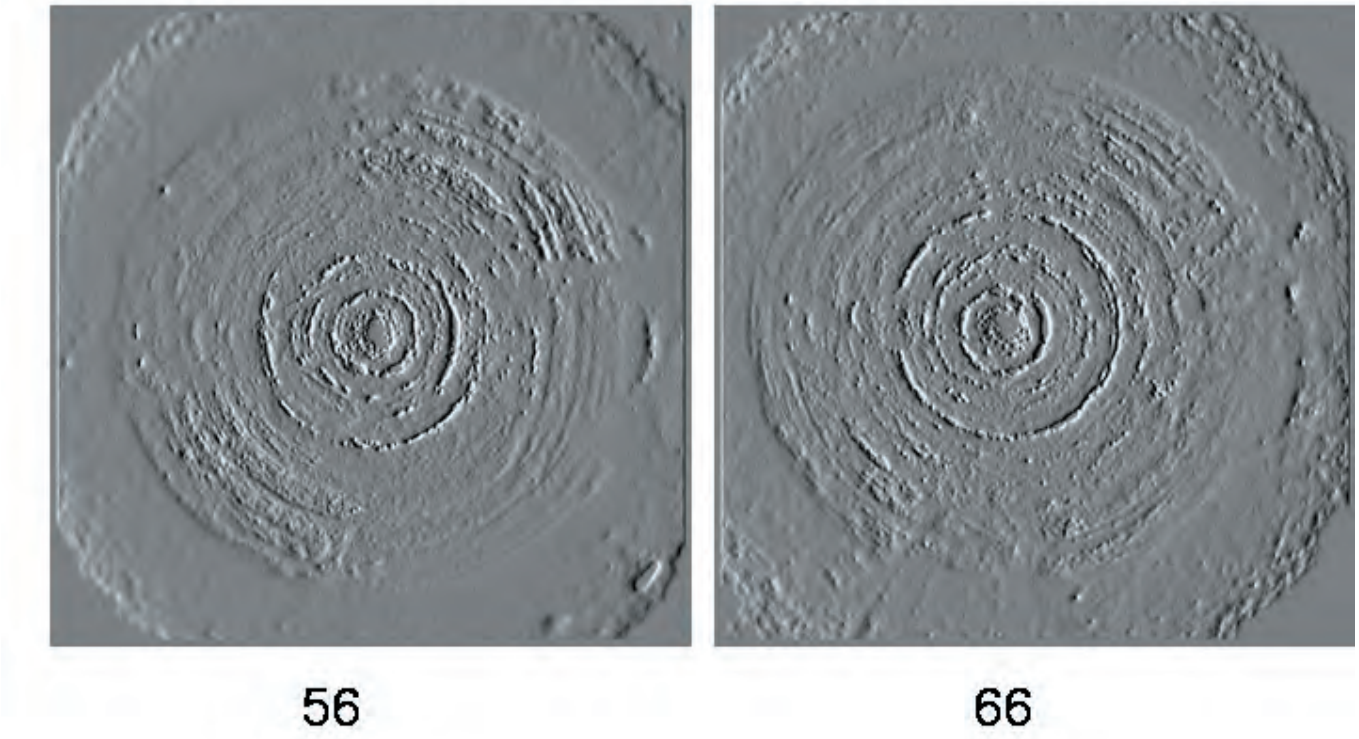

Fig. 38 Images of enhanced firing pin marks using Sobel X filter. These marks are from ten shots apart (56th and 66th shots) using Speer 115 grain (bullet) cartridges.

Fig.39

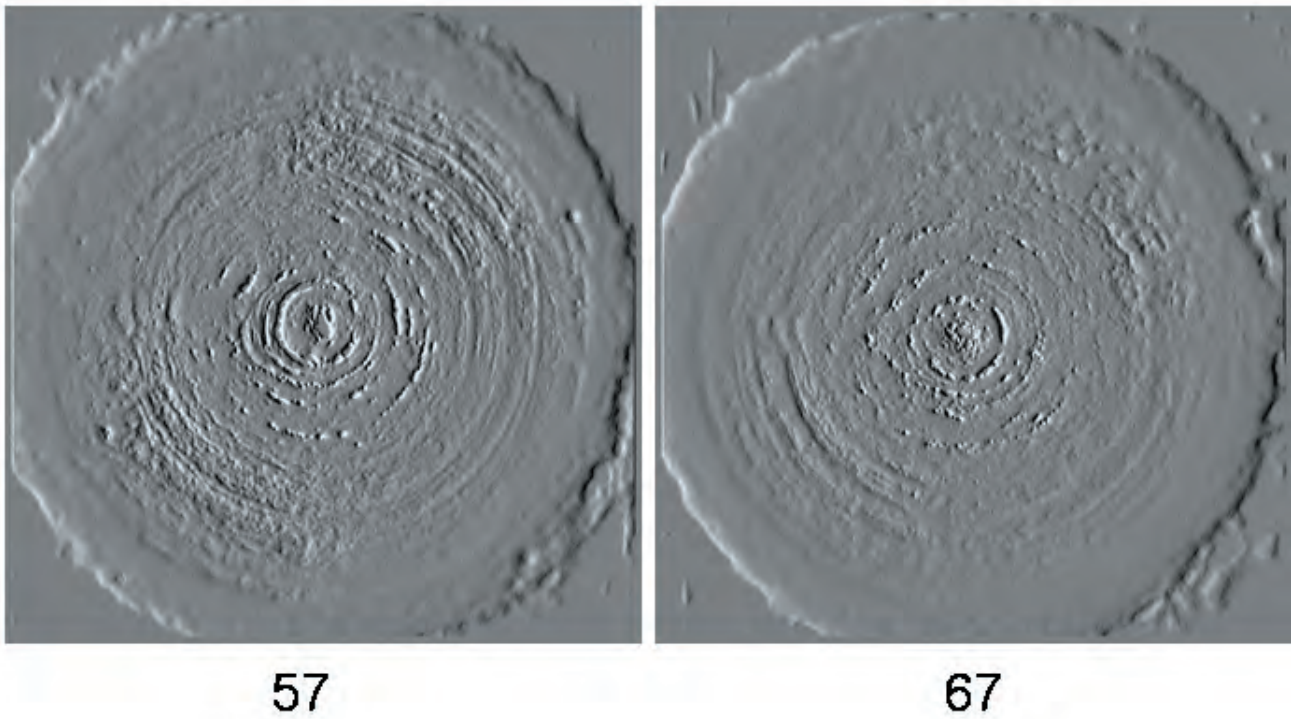

Fig. 39 Images of enhanced firing pin marks using Sobel X filter. These marks are from ten shots apart (56th and 66th shots) using Frangible (bullet) cartridges.

Fig.40

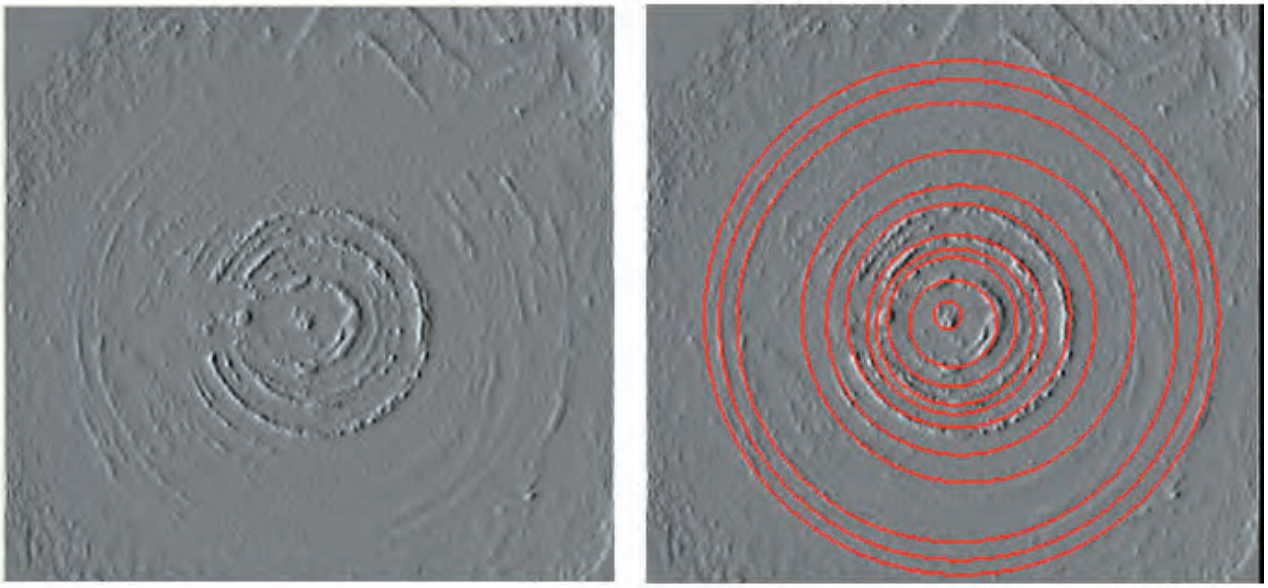

Fig. 40 Measurement of diameter of circular lines on enhanced image using three points method.

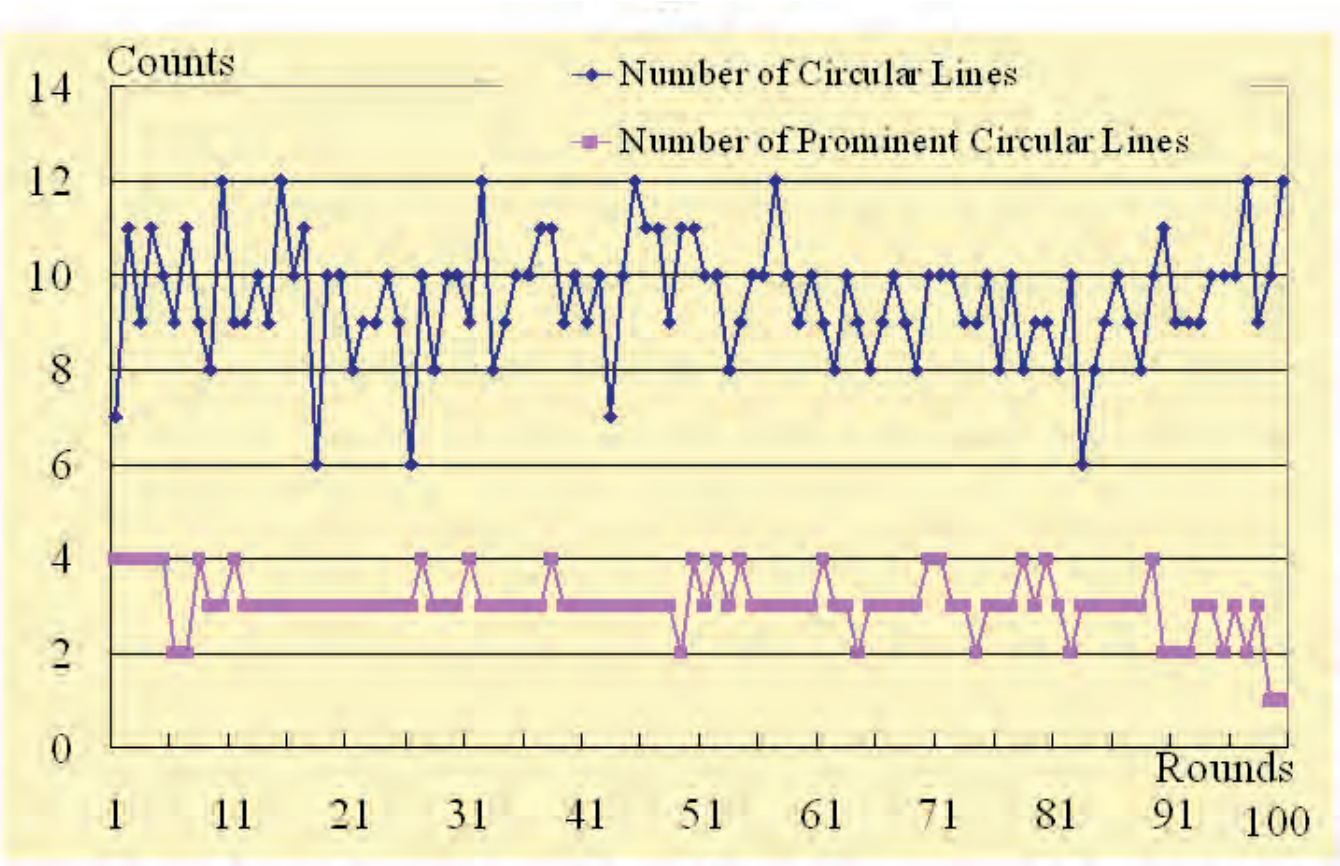

Fig. 41 Number of circular lines on each firing pin indentation.

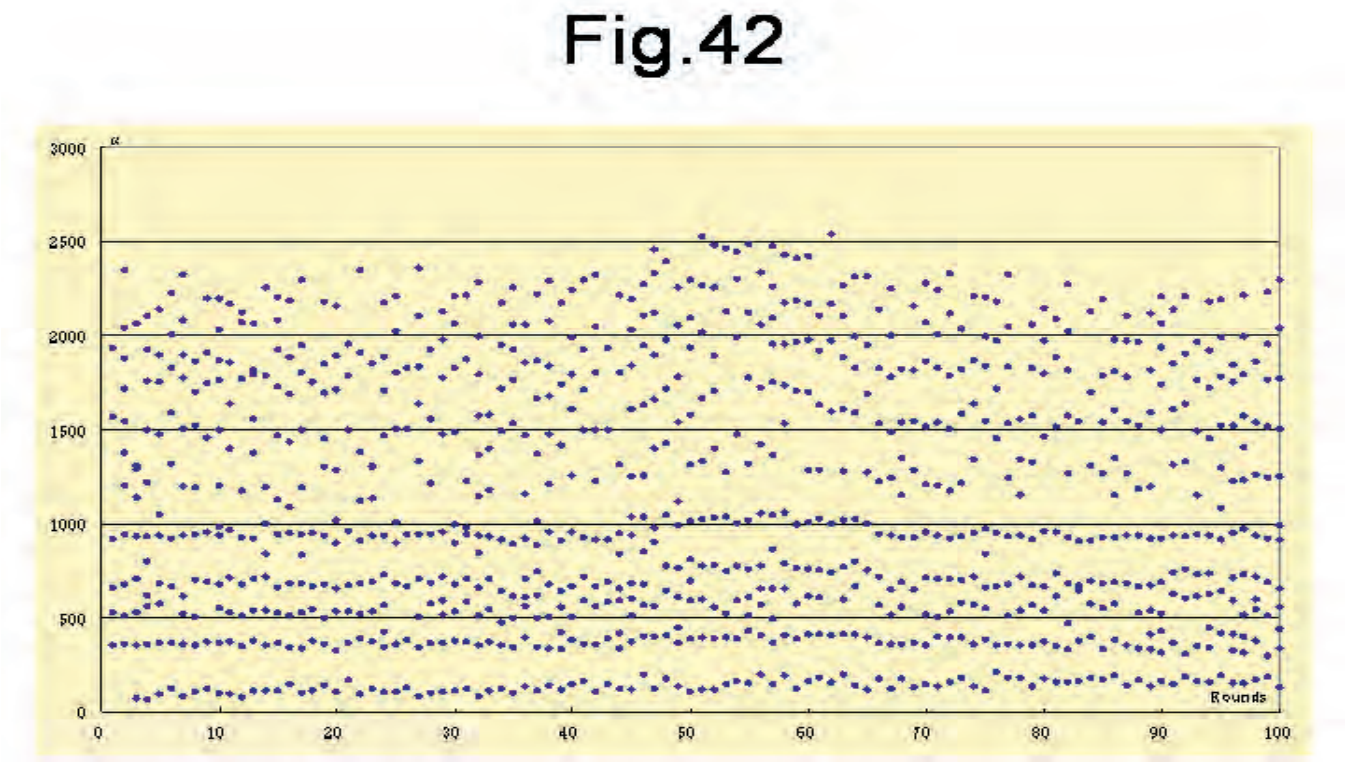

Fig. 42 Diameter of circular lines observed on each firing pin indentation.

Fig.43

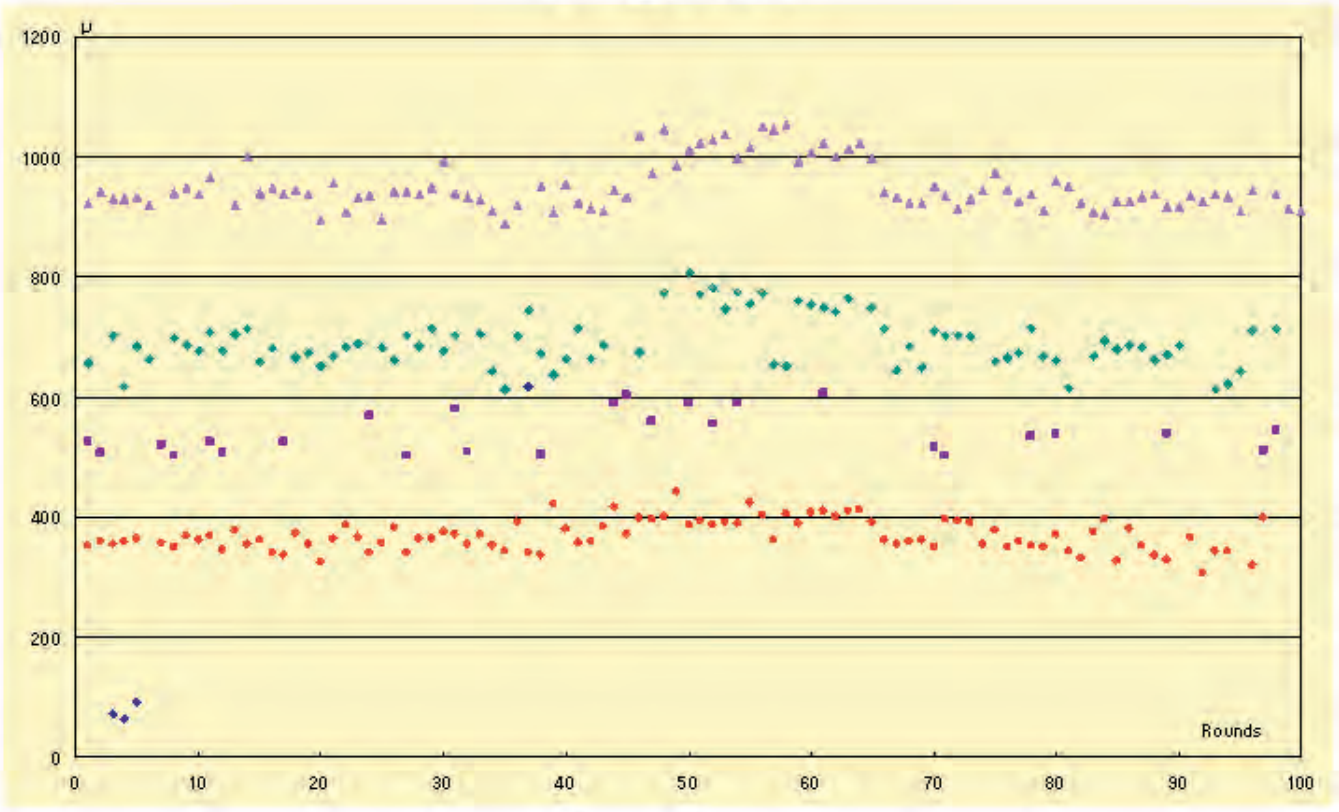

Fig. 43 Diameter of prominent circular lines observed on each firing pin indentation.

Fig.44

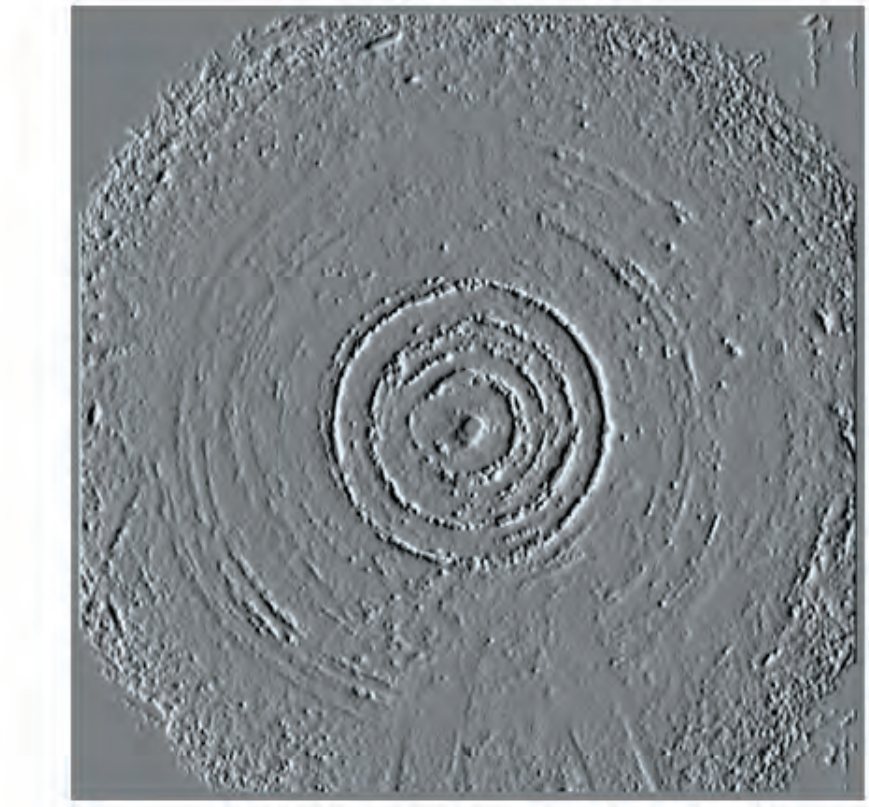

Fig. 44 Example of four prominent circular lines appearing in the 13th shot (Speer 124 grain (bullet) cartridge cases).

Fig.45

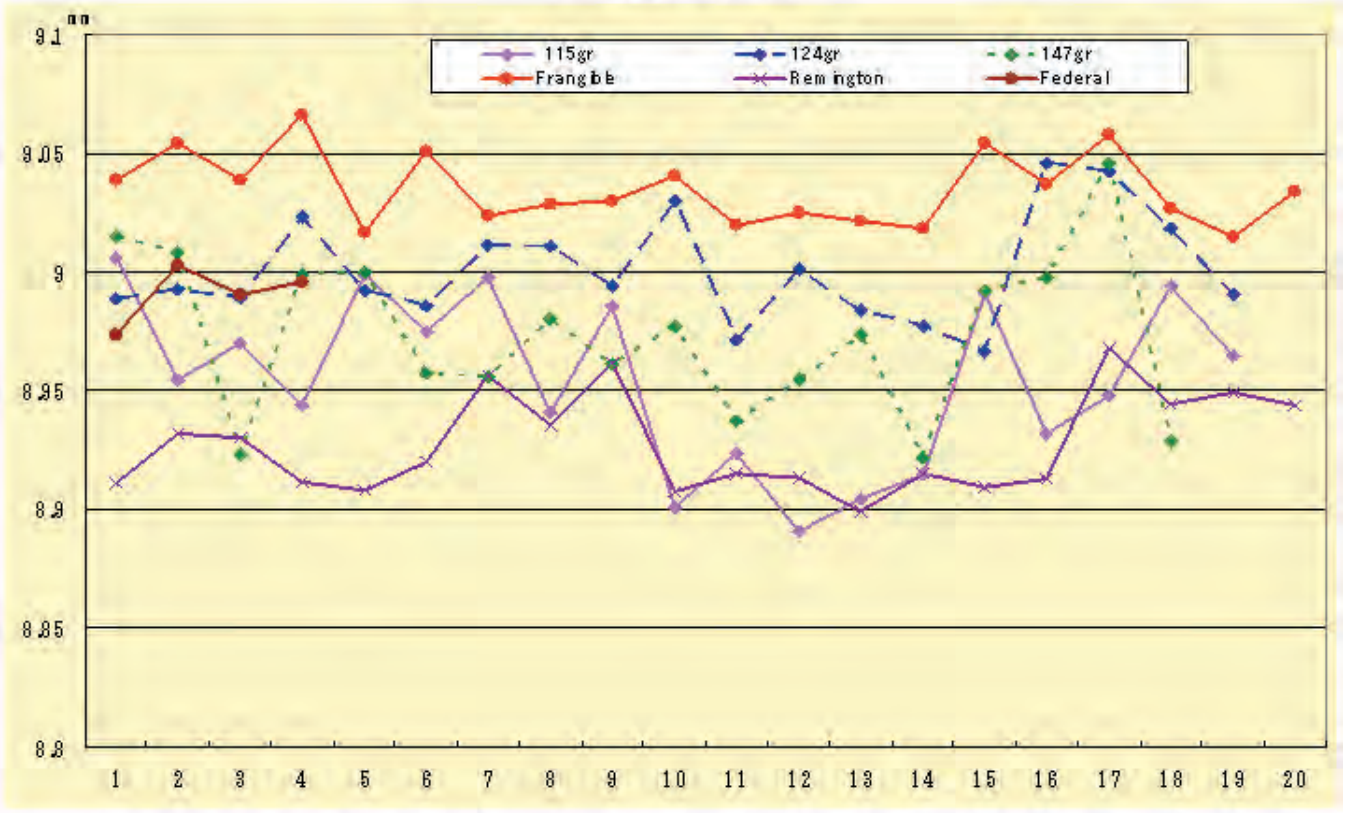

Fig. 45 Average diameter of each fired bullet.