National Institute of Standards and Technology
U.S. Department of Commerce

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Standard Reference Material® 2461

Standard Cartridge Case

CERTIFICATE

Purpose: The Standard Reference Material (SRM) 2461 Standard Cartridge Case is a physical standard that provides markings of a fired cartridge case. The SRM is intended primarily for use as a check standard for forensic laboratories to support measurement quality assurance (QA): first, to help verify that the repeatability and reproducibility of cartridge case topography images (three dimensional images) obtained by computerized optical equipment and associated image correlations are within tolerances set by the laboratory; second, to establish ballistics measurement traceability to a set of three master reference artifacts and their measurements from NIST; and third, to facilitate laboratory assessment and accreditation.

Description: A unit of SRM 2461 consists of a circular electroformed nickel plate, replicated from the head of a fired master cartridge case, which contains a surface topography signature of a breech face impression, a firing pin impression, and an ejector mark. The analyzed breech face impression signature includes a small region of aperture shear marks. The electroformed plate is cemented to a brass cylinder holder (see Figure 1) so that the assembly resembles a real fired cartridge case.

Certified Values: A NIST certified value is a value for which NIST has the highest confidence in its accuracy in that all known or suspected sources of bias have been investigated and taken into account [1]. The similarity of the SRM surface topography to the master reference artifact is characterized for each region by the Normalized Areal Cross Correlation Function Maximum ($ACCF_{\max}$) and Signature Difference (D_s) [2].

These certified values represent the similarity of the population of SRM 2461 Standard Cartridge Cases to three master SRMs at NIST, one for each signature, evaluated using NIST measurements and analysis methods (see Appendix A). The values are not meant to be used as QA thresholds during routine use. Each laboratory should establish their own quality control limits utilizing their own measurement and correlation system.

Table 1. Certified Normalized Areal Cross Correlation ($ACCF_{\max}$) and Signature Difference (D_s) Limits, Each with a 95 % Confidence Level[(a)]

	$ACCF_{\max}$ (%)	D_s (%)
Breech Face Impression	> 97.1	< 6.0
Firing Pin Impression	> 97.6	< 4.9
Ejector Mark	> 99.6	< 0.9

(a) For each region, 95 % of the cartridge case units have an $ACCF_{\max}$ value for that region higher than the value shown in Table 1, with 95 % confidence. Similarly, for each region, 95 % of the cartridge case units have a D_s value lower than the value shown in Table 1, with 95 % confidence.

Values of Potential Interest to Users: Values of potential interest are provided in Appendix A.

Period of Validity: The certified values delivered for **SRM 2461** are valid within the uncertainty specified until **30 May 2033**. The certified values are nullified if the material is stored or used improperly, damaged, contaminated, or otherwise modified.

Maintenance of Certified Values: NIST will monitor this SRM over the period of its validity. If substantive technical changes occur that affect the certification, NIST will issue an amended certificate through the NIST SRM website (https://www.nist.gov/srm) and notify registered users. SRM users can register online from a link available on the NIST SRM website or fill out the user registration form that is supplied with the SRM. Registration will facilitate notification. Before making use of any of the values delivered by this material, users should verify they have the most recent version of this documentation, available through the NIST SRM website (https://www.nist.gov/srm).

Maria E. Nadal, Chief
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Storage: The SRM 2461 Standard Cartridge Cases must be used and kept in a dry and clean environment at temperatures between 10 °C and 30 °C. Touching the surface of the SRM 2461 Standard Cartridge Case with bare hands may cause corrosion on the SRM surface and may change the topography signatures, and therefore should be avoided. Cleaning should also be avoided as much as possible because the cleaning process itself can introduce irreversible changes in the surface topography of the SRM. If visible contamination has been introduced on the surface, then a mild cleaning procedure may be used. The suggested procedure is to carefully clean only the contaminated area with a lab swab/cotton tip applicator moistened with ethyl alcohol.

Visual Inspections: All SRM 2461 Standard Cartridge Cases in NIST's inventory were visually inspected under a stereo microscope. In rare cases, local discoloration was observed on some breech face impressions. The samples that exhibited these discolorations were measured and correlated along with the rest. The results show no significant changes in the $ACCF_{\max}$ and D_s values.

Use: The SRM 2461 Standard Cartridge Cases are circular electroformed replicas of a cartridge case head with about a 1 mm thickness of pure nickel, cemented to a brass cylinder holder (see Figure 1). Three topography signatures are included on each SRM surface: breech face impression, firing pin impression, and ejector mark. To protect the outer surface of the SRM cartridge case, the diameter of the brass cylinder (about 12.7 mm) is larger than the diameter of the cartridge case (about 9 mm). The NIST recertification measurements were performed with a coherence scanning interferometric microscope [3] and topography images were obtained for the three areas (see Appendix A for more information). The analyzed breech face impression area includes a small region of aperture shear marks. For the measurement of the breech face and firing pin impression areas, the cylindrical axis of the cartridge case was parallel to the optical axis of the microscope. For the topography measurement of the ejector marks, the SRM cartridge case was rotated such that the ejector mark was at the three o'clock position. The cartridge case was then tilted so that ejector mark surface was approximately perpendicular to the microscope optical axis.

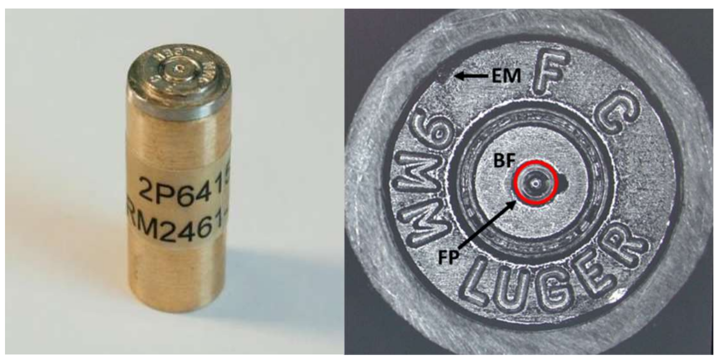

Figure 1. Left – A NIST SRM 2461 Standard Cartridge Case mounted on a brass cylinder holder;
Right – Optical micrograph showing the three certified areas of the SRM: Breech Face Impression (BF), Firing Pin Impression (FP), and Ejector Mark (EM).

REFERENCES

[1] Beauchamp, C.R.; Camara, J.E.; Carney, J.; Choquette, S.J.; Cole, K.D.; DeRose, P.C.; Duewer, D.L.; Epstein, M.S.; Kline, M.C.; Lippa, K.A.; Lucon, E.; Molloy, J.; Nelson, M.A.; Phinney, K.W.; Polakoski, M.; Possolo, A.; Sander, L.C.; Schiel, J.E.; Sharpless, K.E.; Toman, B.; Winchester, M.R.; Windover, D.; *Metrological Tools for the Reference Materials and Reference Instruments of the NIST Material Measurement Laboratory*; NIST Special Publication (NIST SP) 260-136, 2021 edition; National Institute of Standards and Technology, Gaithersburg, MD (2021); available at https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.260-136-2021.pdf (accessed Sep 2023).

[2] Song, J.; Whitenton, E.; Kelley, D.; Clary, R.; Ma, L.; Ballou, S.; Ols, M.; *SRM 2460/2461 Standard Bullets and Cartridge Cases Project*; Journal of Research of NIST, Vol. 109, pp. 533–542, (2004).

[3] ISO 25178-604:2013; *Geometrical Product Specifications (GPS) — Surface Texture: Areal — Part 604: Nominal Characteristics of Non-Contact (Coherence Scanning Interferometry) Instruments*; International Organization for Standardization, (2013).

[4] JCGM 100:2008; *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement* (GUM 1995 with Minor Corrections); Joint Committee for Guides in Metrology (2008); available at https://www.bipm.org/en/committees/jc/jcgm/publications (accessed Sep 2023) see also: Taylor, B.N.; Kuyatt, C.E.; *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*; NIST

Technical Note 1297; U.S. Government Printing Office: Washington, DC (1994); available at https://www.nist.gov/pml/nist-technical-note-1297 (accessed Sep 2023).
[5] Hahn, G.J.; Meeker, W.Q.; *Statistical Intervals: A Guide for Practitioners*; Wiley-Interscience, New York, NY (1991).
[6] Song, J.; Rubert, P.; Zheng, A.; Vorburger, T.; *Topography Measurements for Determining the Decay Factors in Surface Replication*; Meas. Sci. Technol., Vol. 19, 084005 (2008).
[7] ISO 25178-2:2021; *Geometrical Product Specifications (GPS) — Surface Texture: Areal — Part 2: Terms, Definitions and Surface Texture Parameters*; International Organization for Standardization, Geneva, Switzerland (2021).
[8] ASME B46.1-2019; *Surface Texture (Surface Roughness, Waviness, and Lay)*; Am. Soc. Mech. Eng., New York, NY (2020).

If you use this SRM in published work, please reference:

Song J, Whitenton E, Kelley D, Clary R, Ma L, Ballou S, Ols M (2004) SRM 2460/2461 Standard Bullets and Cartridge Cases Project. Journal of Research of NIST, Vol. 109, pp. 533–542 (2004).

Certificate Revision History: 11 September 2023 (Updated certified values in Table 1; addition of values of potential interest in Appendix A; revised figures in Appendix A; change of period of validity; updated format; editorial changes); 22 June 2012 (Original certificate date).

Certain commercial equipment, instruments, or materials may be identified in this Certificate to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Users of this SRM should ensure that the Certificate in their possession is current. This can be accomplished by contacting the Office of Reference Materials 100 Bureau Drive, Stop 2300, Gaithersburg, MD 20899-2300; telephone (301) 975-2200; e-mail srminfo@nist.gov; or the Internet at https://www.nist.gov/srm.

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Appendix A

Values of Potential Interest: Values of potential interest are values that may be of interest to the SRM user, but insufficient information is available to assess the uncertainty associated with the value [1]. Values of potential interest cannot be used to establish metrological traceability to the International System of Units (SI) or other higher-order reference system, such as traceability to the master cartridges.

To facilitate quantitative comparisons, both the measured topography data and the trimmed data for all three regions on the NIST master SRMs are available for downloading from the NIST website (https://tsapps.nist.gov/NRBTD/Home/SRMBulletCC).

Recertification Measurements: NIST analyzed a set of 14 sealed SRM 2461s (Serial Numbers: 119, 134, 141, 144, 168, 197, 212, 214, 237, 246, 247, 251, 252, 277) randomly selected from the available inventory. These SRMs, and the NIST master SRMs, were visually inspected and remeasured. This was done to evaluate the condition of the specimens and to update confidence regions for the similarity of the breech face impression, firing pin impression, and ejector mark signatures of the SRMs [2]. The signature measurements were used to compute one-sided tolerance intervals that specify a degree of similarity met by a stated proportion of the SRMs with given confidence [4,5]. The similarity metrics used are the Normalized Areal Cross Correlation Function Maximum ($ACCF_{\max}$) and Signature Difference (D_s) [2]. For each region, 95 % of the cartridge case units have an $ACCF_{\max}$ value for that region higher than the value shown in Table 1, with 95 % confidence. Similarly, for each region, 95 % of the cartridge case units have a D_s value lower than the value shown in Table 1, with 95 % confidence.

Repeatability and Reproducibility: Sources of measurement uncertainty include those from instrument noise and calibration, topography digitization including both the quantization level and sampling interval, dropouts, effective lateral resolution and instrument transfer function, image distortion caused by the optical system, errors due to the stitching of two images for the ejector mark and nine images for the breech face impression, trimming the 3D images to the region of interest (ROI), software performance for filtering, registration, leveling and numerical comparison, and variations from the environment and measurement setup. A reproducibility study was conducted by comparing the master SRM topography data with ten measurements performed on different days where the master sample was removed from the microscope after each measurement. The reproducibility results for each of the ROIs are shown in Table A1:

Table A1. Values of Potential Interest Measurement Reproducibility Values for $ACCF_{\max}$

	Mean (%)	Standard Deviation (%)
Breech Face Impression	99.89	0.023
Firing Pin Impression	99.73	0.012
Ejector Mark	99.94	0.015

The uncertainty due to basing the certified values obtained during the recertification on the 14 SRM samples instead of the complete set of 137 produced SRMs is captured as a Type A variation in similarity values when the cartridge case topography images of the selected SRMs are correlated with the images of the master SRMs. Uncertainties in the measurement system that result in variations of the $ACCF_{\max}$ and D_s parameters for the 137 SRM 2461 cartridge cases are judged to be included in the observed Type A variations of those parameters.

Measurement Summary Statistics: The means and standard deviations of the $ACCF_{\max}$ and D_s measurements of the 14 sampled SRM 2461 Standard Cartridge Cases are shown in Table A2.

Table A2. Values of Potential Interest for Means and Standard deviations (Std. Dev.) of the $ACCF_{\max}$ and D_s values for the sampled SRM 2461 Standard Cartridge Cases.

	Mean ($ACCF_{\max}$) (%)	Std. Dev. ($ACCF_{\max}$) (%)	Mean (D_s) (%)	Std. Dev. (D_s (%)
Breech Face Impression	99.01	0.87	2.01	1.77
Firing Pin Impression	99.46	0.53	1.10	1.11
Ejector Mark	99.77	0.08	0.46	0.16

Electroformed Replicas from a Master Cartridge Case Fired at the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF): The master cartridge case was fired at the National Laboratory Center of the ATF [2]. The signature reproducibility of the replicated SRM cartridge cases depends on the master cartridge case and on the electroforming process. To ensure that the SRM cartridge cases have virtually the same surface topography signatures, it was necessary to test for differences in the replica surfaces [6]. The results showed that the electroforming process was stable and capable of producing a large number of surfaces that are approximately identical.

Certified Normalized Areal Cross Correlation Function Maximum $ACCF_{\max}$ and Signature Difference D_s: Two metrics are used to characterize the similarity of the SRM surface topography: the normalized areal cross correlation function maximum $ACCF_{\max}$, or correlation coefficient, and the signature difference D_s [2]. The certified values are obtained from statistical correlations between the surface topography of the breech face impression, firing pin impression, and ejector mark regions of the SRM 2461 cartridge cases and those of a reference standard. The reference standard consists of the surface topography of the breech face impression, firing pin impression, and ejector mark captured from three reference SRM cartridge cases, one for each ROI, with Serial Numbers 155, 153, and 260, respectively. When two correlated cartridge case signatures are exactly the same (point by point), D_s equals 0 (0 %) and $ACCF_{\max}$ equals 1 (100 %).

Preparation and Analysis: The reference images for topography correlations of breech face impression, firing pin impression, and ejector mark of the SRM cartridge cases were captured by a coherence scanning interferometric microscope from three different reference SRM cartridge cases. The breech face impression signature standard was captured from SRM 2461-155; the firing pin impression signature standard was captured from SRM 2461-153; and the ejector mark signature standard was captured from SRM 2461-260. The images were acquired with a 10X objective for the breech face impression, and a 20X objective for the firing pin impression and ejector mark. The final image for the breech face impression was obtained by stitching nine partially overlapping images, and that for the ejector mark by stitching two partially overlapping images. The firing pin impression was obtained from one measured image which was trimmed to a circle with a diameter of 500 µm. This trimming was applied to remove surface areas which contained many non-measured data points due to the high local slope angle. The nominal pixel spacing was 1.725 µm for the breech face impression and 0.870 µm for the firing pin impression and ejector mark. Topography images of the 14 randomly selected SRM samples were obtained using the same measurement instrument and measurement procedure. To evaluate the uniformity and reproducibility of the cartridge case signatures between the 14 SRM 2461 cartridge cases and the reference standards, two metrics are used to quantify the similarity of a pair of cartridge case topography signatures [2]. One of these is the $ACCF_{\max}$: the maximum value of the normalized areal cross correlation function (correlation coefficient) defined as:

$$ACCF_{max} = \frac{\sum_m \sum_n (\mathrm{A}_{mn} - \bar{\mathrm{A}}_{mn})(\mathrm{B}_{mn} - \bar{\mathrm{B}}_{mn})}{\sqrt{\sum_m \sum_n (\mathrm{A}_{mn} - \bar{\mathrm{A}}_{mn})^2 \cdot \sum_m \sum_n (\mathrm{B}_{mn} - \bar{\mathrm{B}}_{mn})^2}} \quad (1)$$

Here one of the compared images is automatically rotated and translated to obtain the image registration location that maximizes the $ACCF$. The overlapping sets of points, $\mathbf{A}_{mn}$ and $\mathbf{B}_{mn}$, exclude any data dropouts. The values $(\mathrm{A}_{mn} - \bar{\mathrm{A}}_{mn})\ and\ (\mathrm{B}_{mn} - \bar{\mathrm{B}}_{mn})$ represent the band-pass filtered image heights at the overlapping sets of points corrected for offset, tilt, and form.

Before calculating the similarity metric, the topography data are processed by:

1) Trimming the topography images to the region of interest.
2) Removing a least-squares fitted quadratic surface to reduce the form component in the data.

3) Applying a low-pass first order Gaussian regression filter to reduce noise and a high-pass first order Gaussian regression filter to further reduce any remaining form and waviness components. For the breech face impression, the S-filter nesting index (low-pass filter cutoff length) was 25 µm, and the L-Filter nesting index (high-pass filter cutoff length) was 400 µm [7]. For the firing pin impression and ejector mark, the S-filter nesting index was 15 µm, and the L-Filter nesting index was 150 µm.
4) Registering the two topography images by optimizing the $ACCF_{\max}$ for x-y translations and rotations around z of the compared image relative to the reference image.
5) Repeat of steps 2 and 3 for overlapping data points of the registered original image data, after which any residual offset and tilt terms are removed.

At the maximum correlation position, a difference image $\mathbf{Z}_{mn}$ is calculated, which equals the difference between the compared and reference images, $\mathbf{B}_{mn}$ and $\mathbf{A}_{mn}$, respectively:

$$Z_{mn} = (B_{mn} - \bar{B}_{mn}) - (\mathrm{A}_{mn} - \bar{\mathrm{A}}_{mn}) \tag{2}$$

The second similarity metric, the signature difference, D_s [2], is defined as a ratio of the areal mean-square roughness Sq^2 [7, 8] of the signature difference image **Z** to the areal mean-square roughness of the reference image **A**:

$$D_s = Sq^2_{(\mathrm{Z})} / Sq^2_{(\mathrm{A})} \tag{3}$$

When the compared image **B** is exactly the same as the reference image **A** (point by point), $ACCF_{\max}$ equals 1 (100 %) and D_s equals 0 (0 %).

Figure A1 shows an example of the comparison between the topography images of the breech face impression of the SRM reference cartridge case S/N 155 (top, left) and the SRM cartridge case S/N 141 (top, right). The L-Filter nesting index (high-pass filter cutoff length) was 400 µm, and the S-filter nesting index (low-pass filter cutoff length) was 25 µm [7]. At the maximum correlation position, the $ACCF_{\max}$ is calculated to be 99.65 %. The topography difference **Z** is also calculated (see bottom, right), and from it, the signature difference D_s is calculated to be 0.71 %.

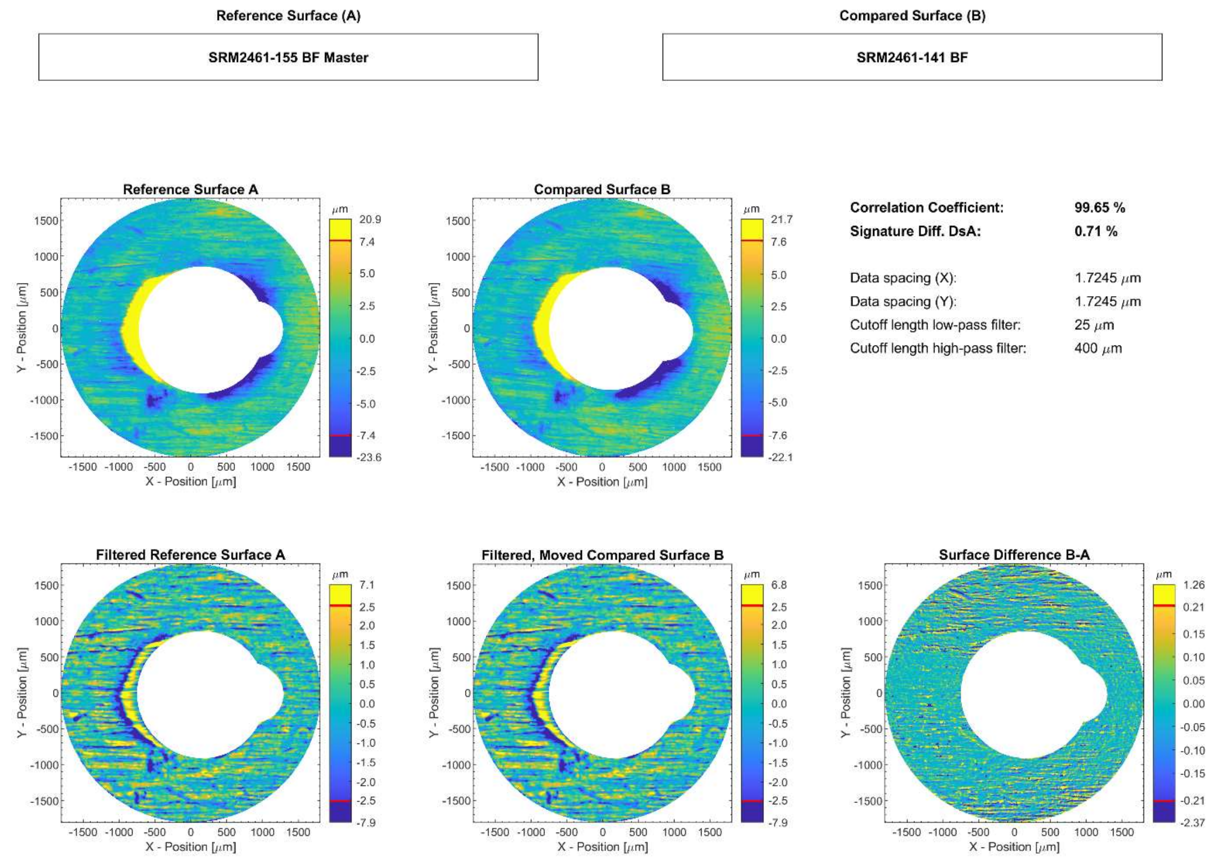

Figure A1. Topography comparison between the breech face images of SRM 2461 Standard Cartridge Cases 155 (top, left, used here as a reference) and 141 (top, right). The bottom row shows filtered images for the two cartridge cases (left and center) and the topography difference (right). $ACCF_{\max}$ = 99.65 % and D_s = 0.71 %. The regions on the color bar between the two red lines represent +/- two standard deviations of the height values.

Figure A2 shows an example of the comparison between the topography images of the firing pin impressions of the SRM reference cartridge case S/N 153 (top, left) and the SRM compared cartridge case S/N 144 (top, right). The L-Filter nesting index (high-pass filter cutoff length) was 150 µm, and the S-filter nesting index (low-pass filter cutoff length) was 15 µm [7]. At the maximum correlation position, the $ACCF_{max}$ is calculated to be 99.57 %. The topography difference **Z** is also calculated (see bottom, right), and from it, the signature difference D_s is calculated to be 0.86 %.

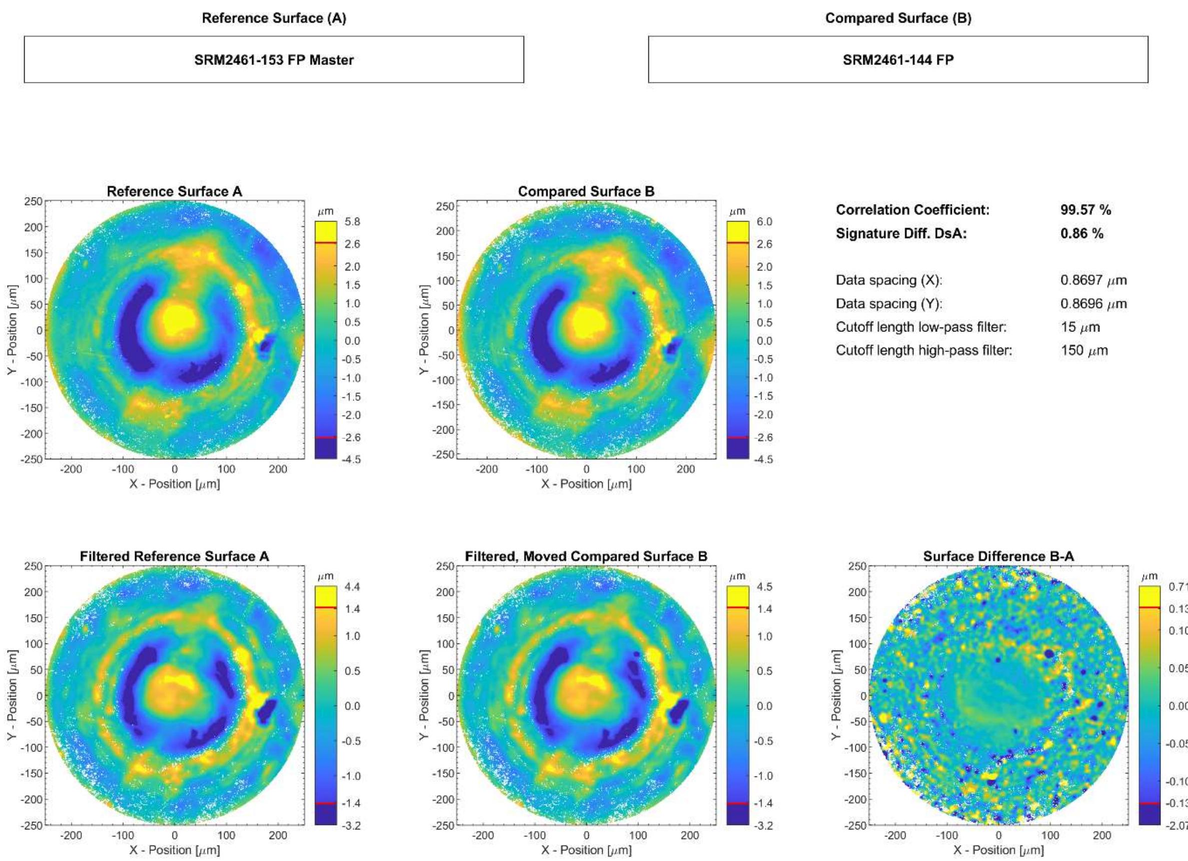

Figure A2. Topography comparison between the firing pin impression images of SRM 2461 Standard Cartridge Cases 153 (top, left, used here as a reference) and 144 (top, right). The bottom row shows filtered images for the two cartridge cases (left and center) and the topography difference (right). $ACCF_{max}$ = 99.57 % and D_s = 0.86 %. The regions on the color bar between the two red lines represent +/- two standard deviations of the height values.

Figure A3 shows an example of the comparison between the topography images of the ejector marks of SRM reference cartridge case S/N 260 (top, left) and the SRM compared cartridge case S/N 214 (top, right). The L-Filter nesting index (high-pass filter cutoff length) was 150 µm, and the S-Filter nesting index (low-pass filter cutoff length) was 15 µm [7]. At the maximum correlation position, the $ACCF_{\max}$ is calculated to be 99.86 %. The topography difference **Z** is also calculated (see bottom, right), and from it, the signature difference D_s is calculated to be 0.29 %.

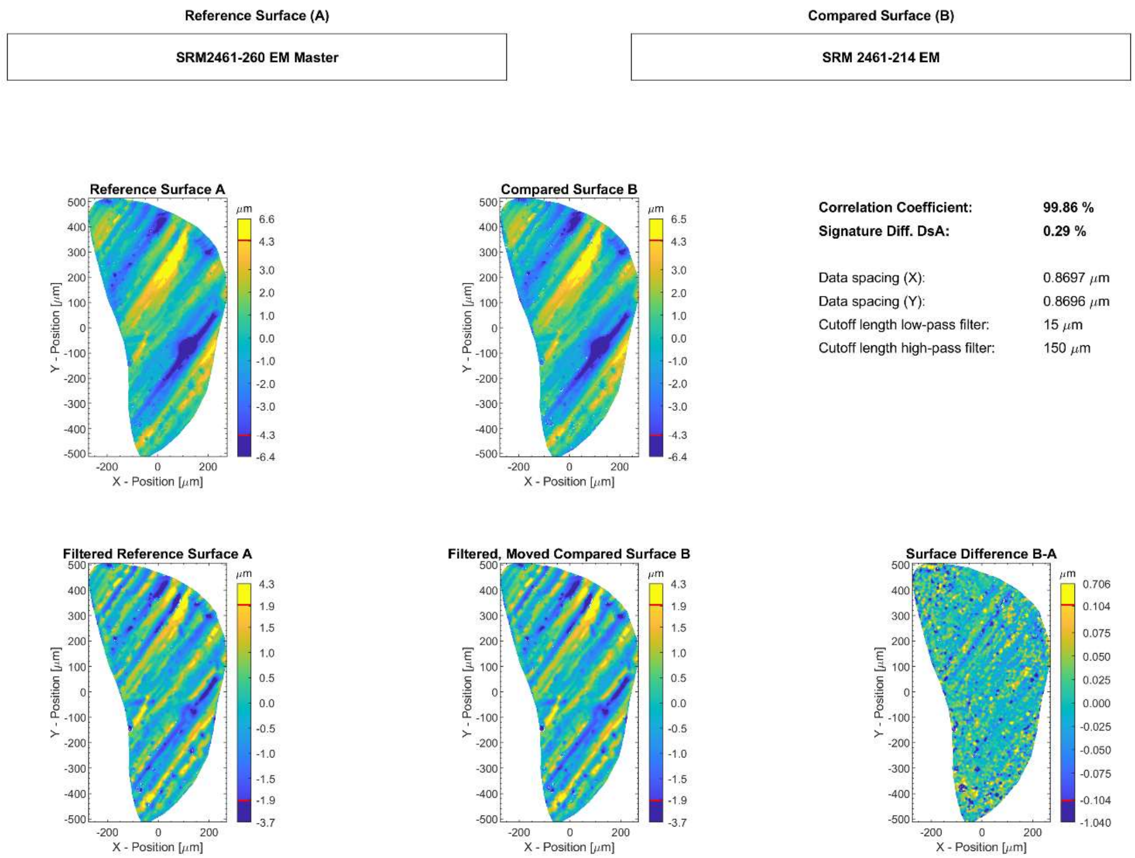

Figure A3. Topography comparison between ejector mark images of SRM 2461 Standard Cartridge Cases 260 (top left, used here as a reference) and 214 (top, right). The bottom row shows filtered images for the two cartridge cases (left and center) and the topography difference (right). $ACCF_{\max}$ = 99.86 % and D_s = 0.29 %. The regions on the color bar between the red lines represent +/- two standard deviations of the height values.

Source: The master cartridge case and reflection optical microscopy images were provided by M.G. Ols of the ATF National Laboratory Center (Ammendale, MD). Funding support for research leading to this Standard Reference Material was provided by the National Institute of Justice (NIJ).

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