Surface Profiles from Standard Reference Material® 2460, Standard Bullet

Standard Reference Material (SRM) 2460 is a bullet signature standard comprising bullet profile signatures of six land engraved areas (LEAs) from fired bullets. A unit of SRM 2460 consists of a SRM standard bullet that is mounted on a blue stub (see Figure 1). This SRM is intended primarily for use as a check standard for crime laboratories to help verify that the computerized optical equipment for bullet imaging and profiling is operating properly. Six master surface profiles, now here in SMATS, were used to create the standard bullet and are intended to help verify the accuracy of instruments for measuring the surface topography profiles of bullet surfaces.

Figure 1. A NIST SRM 2460 standard bullet mounted on a blue stub. A dot (A, not visible) indicates the No. 1 land engraved area (LEA) of the bullet. The No. 3 LEA is facing the reader here in the Figure. A notch (B) on the bullet stub is approximately aligned at 90° with respect to the dot (A). The NIST stylus measurements are traced at the forward sections (C) of each LEA. In order to avoid possible scratches caused by the diamond stylus, it is suggested to avoid the use of the top section (C) for optical measurements.

A Virtual/Physical Bullet Signature Standard: The SRM 2460 physical bullet signature standard is derived from a “virtual” standard. The virtual standard, as shown in Figure 2, is a set of six digitized bullet profile signatures that provided the information for machining the bullet signatures on the physical standards, the SRM 2460 standard bullets [1,2]. The virtual standard also provides the reference profiles for comparison measurements of these bullet signatures [3].

Instructions for Use: These SRM 2460 standard bullets are made of oxygen-free, high conductivity (OFHC) copper rod with about a 1 mm thick bright-copper coating. Six LEAs were machined on the bullet surface by a numerically controlled (NC) diamond turning machine. Each LEA has a unique bullet signature in accordance with the virtual bullet signature standard (see Figure 2), but the SRM bullets are intended to be essentially identical to one another. The bullet LEAs are produced with a 5° right hand twist (see Figure 1), which makes the SRM 2460 resemble a real 9 mm Luger type bullet. There is a dot indentation (near A, but not visible in Figure 1) located close to the nose of each bullet that indicates the No. 1 LEA for each bullet. The No. 3 LEA is facing the reader. The SRM 2460 standard bullet is mounted on a blue stub. A notch on the blue stub (see Figure 1, B) is oriented at approximately 90° with respect to the dot (A). For initial setup on a microscope, the dot indentation designating LEA No. 1 is aligned to face up into the objective of the microscope. The NIST measurements, using a stylus instrument, were performed near the forward sections of each bullet LEA (see Figure 1, C). In order to avoid possible scratches caused by the diamond stylus, the forward section (C) should be avoided for optical measurements.

Analysis: The virtual bullet signature standard was obtained from topographic profiles traced on six master bullets fired at the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) and the Federal Bureau of Investigation (FBI) under standardized shooting procedures [1]. The virtual bullet signature standard was stored in a computer and used for control of the tool path of a NC diamond turning machine at the NIST Instrument Shop to machine the six bullet signatures on the SRM 2460 standard bullets [2]. After machining, a specially designed chemical etching process was used for slightly roughening the surface of the bullet to improve its diffuse reflection and make the SRM bullet appear like a real bullet when observed under an optical microscope. Then, commercial corrosion protection was applied to the surface of the SRM bullets.
Figure 2. The virtual bullet signature standard consists of six digitized bullet profile signatures measured by a stylus instrument on six master bullets fired at the ATF and FBI. The virtual standard profiles shown above are modified profiles after curvature removal and Gaussian filtering with a short-wavelength cutoff of 0.0025 mm and a long-wavelength cutoff of 0.25 mm [4]. The vertical scale is in µm; the horizontal scale is in mm.

In order to evaluate the uniformity and reproducibility of the bullet signatures between the SRM 2460 standard bullets and the virtual bullet signature standard, the NIST bullet signature measurement system was developed [2,3]. This system includes a stylus instrument to measure the profile signature following procedures in ASME B46.1 [4]. The nominal stylus radius is 2 µm. The nominal contact force is 0.001 N. The vertical digital resolution is 0.01 µm. The lateral sampling interval is 0.25 µm over an evaluation length of about 1.4 mm. For the calculation of the bullet signatures, a Gaussian filter [4] with a short-wavelength cutoff of 0.0025 mm is used for removing the high frequency noise. Then the curvature on the traced signature profile is removed, and a Gaussian filter with a long-wavelength cutoff of 0.25 mm is used to attenuate long surface spatial wavelengths. The Gaussian filter truncates the measured profile across the LEA from its measuring length of about 1.9 mm to an evaluation length of about 1.4 mm. Detailed information for the NIST measurement system can be found in reference 3.

Cross Correlation Function Maximum $CCF_{\text{max}}$ and Signature Difference $D_s$: The profile signature of the virtual bullet signature standard (see Figure 2) is used as a reference standard against which the corresponding profile signature on each SRM bullet is compared. Two parameters are used for the comparison of bullet signatures to determine the similarity of two profile signatures [2,3]. One of these is called $CCF_{\text{max}}$. This is the maximum value of the cross correlation function $CCF$ [1], which occurs when the two correlated profile signatures, the compared bullet signature $Z_{(B)}$ of the SRM bullet and the virtual signature standard $Z_{(A)}$, are in phase. At this position, a signature difference profile $Z_{(B - A)}$ is also calculated, which equals the difference between signature $Z_{(B)}$ and $Z_{(A)}$.

$$Z_{(B - A)} = Z_{(B)} - Z_{(A)}$$  \hspace{1cm} (1)

The second parameter, the signature difference, $D_s$, is defined as a ratio of the mean-square roughness $Rq^2$ [4] of the signature difference profile $Z_{(B - A)}$ and the mean-square roughness of the virtual standard signature $Z_{(A)}$:

$$D_s = \frac{Rq^2_{(B - A)}}{Rq^2_{(A)}}$$  \hspace{1cm} (2)
When the measured signature $Z_{(B)}$ is exactly the same as the virtual signature standard $Z_{(A)}$ (point by point), $CCF_{\text{max}}$ is equal to 100 %, and $D_s$ is equal to 0.

The six bullet signatures on 40 SRM bullets were measured by the signature measurement system and correlated with the virtual bullet signature standard. The measurements were performed before the surface etching process and statistically verified after the etching and corrosion protection process for the SRM 2460 standard bullets. Statistical analyses show that there is no significant change for the bullet signatures before and after the etching and protection process.

The $CCF_{\text{max}}$ and $D_s$ values from the measurements of the six LEAs of each SRM bullet were averaged as $\overline{CCF_{\text{max}}}$ and $\overline{D_s}$. The $\overline{CCF_{\text{max}}}$ and $\overline{D_s}$ values for the 40 SRM bullets were statistically analyzed and collectively reported with a confidence level of $\alpha = 95 \%$ [5]. That means 95 % of the measured SRM standard bullet signatures have $\overline{CCF_{\text{max}}}$ values higher and $\overline{D_s}$ values lower than the values shown below in Table 1:

<table>
<thead>
<tr>
<th>Average Cross Correlation Maximum $\overline{CCF_{\text{max}}}$</th>
<th>Average Signature Difference $\overline{D_s}$</th>
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<tbody>
<tr>
<td>$\overline{CCF_{\text{max}}} &gt; 98.67 % (\alpha = 95 %)$</td>
<td>$\overline{D_s} &lt; 2.64 % (\alpha = 95 %)$</td>
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The virtual bullet signature standard, including six digitized bullet profile signatures, is illustrated in Figure 2. The profiles may be downloaded from this Surface Metrology Algorithm Testing Service (SMATS) Website in the sdf, smd, and XML formats for testing and comparison with profiles of the LEAs measured by the user on the SRM 2460 standard bullet and modified by the filters described above.

The SRM 2460 standard bullets were manufactured by R. Clary and B. Dutterer of the NIST Manufacturing Engineering Laboratory, and D. Kelley and C. Johnson of the NIST Materials Science and Engineering Laboratory. Preparation of and analytical measurements on the SRM were performed by J. Song, T.V. Vorburger, E. Whitenton, B. Renegar and A. Zheng of the NIST Manufacturing Engineering Laboratory, L. Ma of the Materials Science and Engineering Laboratory, and M. Ols of the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) (Ammendale, MD). Consultation on the statistical design of the experimental work and evaluation of the data were provided by J. Yen of the NIST Statistical Engineering Division. Funding support for research leading to this Standard Reference Material was provided by the National Institute of Justice (NIJ) and managed through the NIST Office of Law Enforcement Standards (OLES).

REFERENCES