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THE INFLUENCE OF CUT-OFF WAVELENGTH FOR ROUGHNESS AND SAMPLING WAVELENGTH FOR ELIMINATING NOISE ON 3D AMPLITUDE PARAMETERS

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ABSTRACT

This paper presents arguments in the favor of selecting the adequate set of filters λc (cut-off wavelength for roughness) and λs (sampling wavelength for eliminating noise), in studying the 3D amplitude parameters, including average arithmetic deviation of the surface (Sa), Ssk, Sku, Sq, Sv, Sp, St. This analysis was carried out for a surface of 1000 μm x1000 μm, from a ball made of chrome steel, with a diameter of 12.7 mm ± 0.0005 mm, which, according to the ISO standard 683-17:2023, they are finely grinded and have a high hardness (62...65 HRC) and a high quality surface. The authors present an analysis for 3D amplitude parameters, for the same surface, but after applying different pair of filtering (λs, λc) and discussed their influence on the values of amplitude parameters. For Sa, standard deviation of values obtained at the same λc, but for λs=0.8-250 μm, is decreasing to a lower value only for λc = 100-250 μm, but values increase from nanometers to higher average value (3.59 μm for λc=900 μm). Similar tendency was noticed for Sq. Ssk and Sku have revealed a convergence towards the largest value of λc, meaning that λs has no significant influence when the cut-off length is almost the dimension of the investigated area, at least for λs=0.8-250 μm. St decreases with the increasing of λs, but it increases with the increases of λc. A larger λs is favorable to avoid recording the deepest valley. It is important to report the λc and λs values as they have directly impact on roughness values (as demonstrate here for 3D amplitrude parameters, like Sa, Sq etc.). This study and the cited references evidence that different settings can produce different results for the same surface. Including them in the report ensures transparency and reproducibility.

Keywords: cut-off length, sampling wavelength, roughness 3D amplitude parameter, average arithmetic deviation of the surface, Sa, mean square deviation of the surface, Sq, skewness, Ssk, kurtosis, Sku, the maximum peak height on the surface, Sp, maximum depth of the surface, Sv, maximum surface height, St

1. Introduction

When characterizing the surface roughness of spherical objects (like balls) in 3D, applying appropriate filters, such as λc (cut-off wavelength for roughness) and λs (sampling wavelength for eliminating noise), it`s essential to obtain accurate and meaningful measurements.

The λc filter, also known as cut-off wavelength, separates surface roughness from waviness. It ensures that measured data focuses on short-wavelength roughness features and excludes longer-wavelength form deviations or curvature effects. For spherical surfaces (like rolling bearing balls), λc should be significantly smaller than the ball's radius, but large enough to include relevant surface roughness features. Usually values for λc could be 0.8 mm, 2.5 mm or 8 mm, depending on the quality of surface texture.

The λs filter, also known as the sampling wavelength, differentiates very short-wavelength features, such as measurement noise or very fine surface details that aren't relevant to roughness. The selection of its value depends on the resolution of the measurement device and the scale of roughness features, usually values being 2.5 µm, 8 µm or 25 µm.

The selection of λs depends on material and surface type. For surfaces with fine textures (like polished), it is recommended to select a smaller λs to retain finer details. For rougher surfaces, a larger λs may be appropriate.

The selection of λc depends on the surface scale of interest: λc should correspond to the largest surface feature or waviness to be analyzed. For instance, if roughness parameters are of interest, λc should be smaller than the wavelengths corresponding to the overall shape or form.

Applying a noise filter could be optional. The main filter is the roughness filter that separates roughness from waviness. The so-called cut-off wavelength, λc, must be given for any study of roughness. All profile motifs smaller than λc get evaluated as roughness and all larger ones as waviness [1]. The authors gave recommendations for selecting λc as a function of evaluating length and estimated two roughness parameters, but for a 2D analysis (Table 1) of aperiodic profiles, as it is the case of finished surfaces.

Table 1. Recommended cut-off length from [1]

Rt [µm]	Ra [µm]	Cut-off length [mm]	Evaluation length [mm]
<	<0.02	0.08	0.40
0.1-0.5	0.02-0.1	0.25	1.25
0.5-10	0.1-2	0.8	4.0
10-50	2-10	2.5	12.5
>50	>10	8	40

Often, the selection of λs and λc might require some trial and error. It si recommended to start with standard values, then refine based on the results.

In a recent review, Pawlus P and Reizer R. [2] uses the file obtained from 3D measurement of a wear scar from four-ball test in order to determined the worn volume.

Multiscale analysis (using filters with various cut-off) of original surfaces was preferred by Marteau et al. [3]. To decrease the errors, surface filtration is recommended. The correct choice of the cut-off (nesting index) is a problem. The variation in the parameters of leveled, form-removed and filtered surfaces is higher than that of the original.

When optical profilometer was used for surface topography measurement, the valley part seems to be more stable than the peak part due to the problem of spikes [4]. The valley part is also affected by the presence of non-measured points, however, this issue is also related to the peak portion [2] [5]. Therefore, when replica of surface topography is measured by optical method, the peak part of original surface (valley portion of replica) is probably more robust than the valley portion.

The filtration is applied in order to separate surface measurement data into large-scale and small-scale components. Filtration is essential for further investigation of the data, because each component will be the result of the fabrication process, and each component will influence the functioning quality and durability of the surface [6].

The λs and λc low-pass and high-pass filters with Gaussian characteristics are used to differentiate the surfaces in the roughness evaluation. In the determination of surface parameters the choice of the cut-off wavelength is of high importance [7].

Francois Blateyron points out that 3D parameters are defined on the evaluation area. This simply means that parameters are calculated on the measured surface without segmenting it into small sub-areas that depend on the cut-off length/nesting index [8].

This study presents an analysis of the amplitude parameters of the same surface from a rolling bearing ball, with different combination of (λc, λs), in order to point out ranges for these two filters adequate to be applied for this type of surface (fine finished spherical surfaces).

2. Surface to be studied and the methodology proposed

Surface measurement was carried out with the help of the NANOFOCUS µSCAN laser profilometer, fromthe "Ştefan cel Mare" University of Suceava. This is an optical non-contact profilometer for measuring surface microtropography, with a measuring area of 150 mm x 200 mm, a vertical measurement range of 1.00 µm to 18 mm, a vertical resolution of 25 nm [9]. For calculating the texture parameters, a dedicated software was used, MountainsMap Imaging Topography 10, from Digital Surf [10], [11].

The surface to be investigated is placed on a rolling bearing ball. The initial measured suared surface has 1500 µm as side. The measurement step is 5 µm between lines and 5 µm between points on each line. Equal steps between lines and points on the same line is still applicable for most applications [12].

This analysis was carried out for a surface of 1000 μm x1000 μm (Fig. 1), from a ball of made of chrome steel, with a diameter of 12.7 mm ± 0.0005 mm, according to ISO 683-17:2014 [13], they are finely grinded and have a high hardness (62...65 HRC) and a high quality surface.

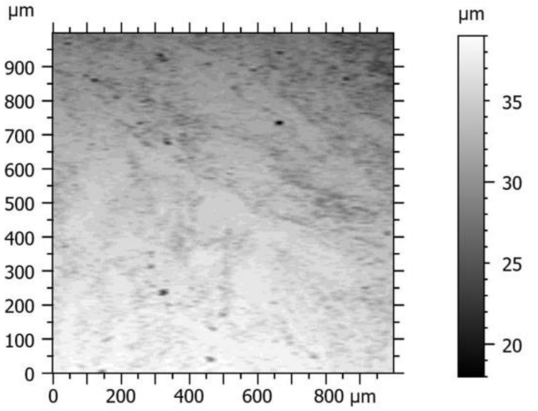

Fig. 1. Image virtually re-built from the recorded surface, after leveling and form removal

The calculation of the 3D surface parameters was carried out after the raw surface was leveled in three points (three of the quare corners). Then a surface of 1000 μm x 1000 μm was extracted. This was again leveled in three points and the form was removed with the help of LSP 2 (polynomial). Form removal is undertaken in order to minimise the influence of form on the areal parameters [14]. If the primary (raw) surface is associated with a particular geometric form, in this study – a sphere, the F-operation removes this form, the resulting so-called S-F-surface being planar; repeating the form removal process, would generate an unchanged S-F-surface.

The average arithmetic deviation of the surface, Sa [μm]:

$$Sa = \frac{1}{M\cdot N}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|z(x_i, y_j)\right| \qquad (1)$$

where $z(x_i, y_j)$ is the height of the rated point, at any position (x_i, y_j), i=1, ..., M and j=1, ..., N. Sa is commonly used parameter in profilometric studies, especially for assessing quality of fine finished surfaces.

The amplitude profile parameters defined in ISO 4287 (which are 2D parameters) are calculated based on mathematical relationships that could be extend to a surface [11]

Blunt L. and Jiang X. [15] define the mean square deviation of the surface as being:

$$Sq = \sqrt{\frac{1}{M\cdot N}\sum_{j=1}^{N}\sum_{i=1}^{M} z^2(x_i, y_j)} \qquad (2)$$

where M is the number of points on a profile and N is the number of profiles on the investigated surface; $z(x_i, y_i)$ is the set of raw data, obtained for the investigated surface.

The asymmetry factor of evaluated surface, also known as skewness, Ssk, is a measure of the surface deviation asymmetry from the mean/median plane. It is strongly influenced by isolated peaks or voids.

$$Ssk = \frac{1}{M\cdot N\cdot Sq^3}\sum_{j=1}^{N}\sum_{i=1}^{M} z^3(x_i, y_j) \qquad (3)$$

Physically, Ssk provides information on the presence of sharp features on the investigated microtopography.

The flattening factor of the surface (kurtosis), Sku, is a measure of the curvature of the flattening or "sharpness" of the surface heights distribution curve. This parameter provides information on the surface shape:

$$Sku = \frac{1}{M\cdot N\cdot Sq^4}\sum_{j=1}^{N}\sum_{i=1}^{M} z^4(x_i, y_j) \qquad (4)$$

For a Gaussian surface with uniformly distributed peaks and valleys, the value of this parameter is 3. Physically, kurtosis indicates the peaks on a surface.

The maximum peak height on the surface, Sp, is the height of the highest peak from the reference surface, for the sampling area:

$$Sp = max(z(x_i, y_j)) \qquad (5)$$

The maximum depth (or valley) of the surface, measured from the reference surface, Sv, is the larger value of the valley depth till the reference plane, for the sampling area.

$$Sv = \left|min(z(x_i, y_j))\right| \qquad (6)$$

The maximum surface height, St, is the distance between the highest peak and the deepest valley on the investigated area.

If working with unfiltered raw profiles relative to a reference line/surface:

$$St = (|Sp| + |Sv|) \qquad (7)$$

The parameters Sp, Sv, and St as the sum of these two, are sensitive to random irregularities, which are not representative of the surface structure, as they detect the highest peak or the lowest void, record singular scratches, dirt marks or any atypical defect.

3. Results and Comments

Selecting the proper combination (λc, λs) depends on material and surface finish and the ojective of the study. For a precision rolling-bearing ball (like in this study), surface is very fine. Therefore, λc = 0.8 mm and λs = 2.5 μm is a common combination. If interested in fine surface textures, a smaller λc and λs are preferable. For rougher surfaces, larger values may be more appropriate. These larger values for both λc and λs could be applied for evaluating worn surfaces.
Figure 2 presents the values of parameters Sa, calculated for the same surface (1000 μm x 1000 μm) from a rolling bearing ball. For low values of λc, ranging from 8 μm to 100 μm, the values are grouped, with a low sensitivity to λs. But starting with λc =250 μm, the values for Sa increases to 0.5 μm. From these points, Sa increases with high slope till λc =900 μm. From this figure, one may conclude that the choice of the cutoff wavelength will severely impact the

resulting Sa. A similar tendency was obtained in [16], but for λc of 2.5 mm to 0.08 mm.

Balachandran et al. [17] demonstrated that changing the cut-off wavelength, λc, affects the roughness parameters Ra and Rt.

Rosentritt et al. [7] used the following parameters, cut-off wavelength λs = 0.8 µm and λc = 0.08 mm for comparing four surface finishing techniques for dental materials.

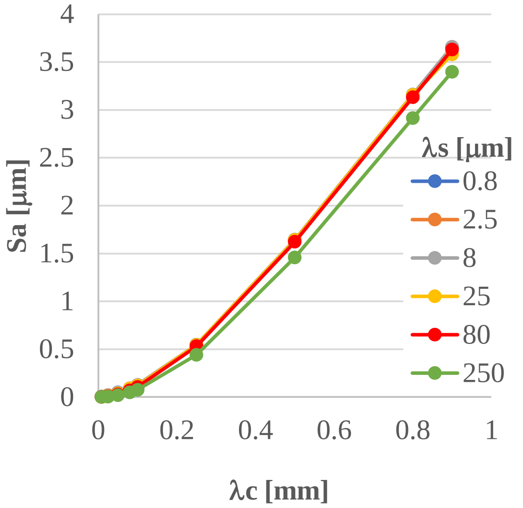

Fig. 2. Influence of λs and λc on Sa

Sa and Sq provide no information on the distribution of heights or on the lateral position of these heights. These two parameters are strongly correlated to each other [15], this being visible when comparing Figures 2 and 3. Sq has statistical significance (it is the standard deviation of the height distribution).

But when using different combinations of λc and λs, their dependence is not following a mathematical relationship as suggested by [18]. For ideal Gaussian surface, Sq/Sa≈1.25, but this is a theoretical value for a normal distributionof heights, commonly seen in surfaces generated by grinding or polishing. For surfaces almost Gaussian, this ration is around 1.2 to 1.3. For rough or structured surfaces with sharp peaks or deep valleys (non-Gaussian, skewed distribution), this ratio increases significantly (1.4 to 2.0 or higher). For highly textured or non-homogeneous surfaces, with irregular asperities, values may be much higher (>2). The ratio Sq/Sa is a valuable metric for understanding surface topography beyond simple average roughness. Higher ratios indicate more pronounced and potentially problematic surface features. But when scanning a range of (λc, λs), values in Table 2 underlines that this ratio is also depending on this pair of parameters.

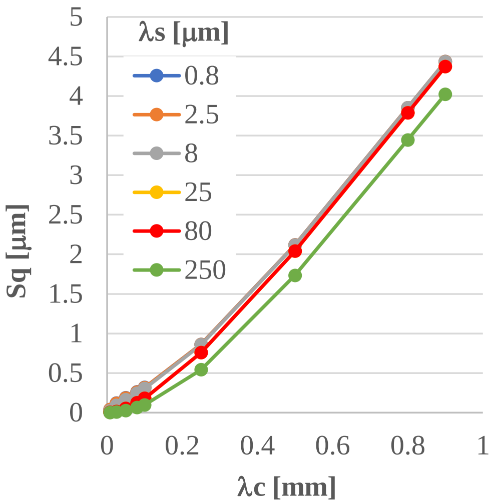

Fig. 3. Influence of λs and λc on Sq

For the investigated surface, Sa and Sq have similar trends as function of λc. For the same λs, Sa and Sq increase when λc increases. Values that could reflect this surface quality could be considered for λc=100-500 µm. Table 2 presents the ratio Sq/Sa. Too small λs and λc produces high value of this ratio (green cells). For λc=0.500-0.900 mm, this ratio is less sensitive to λs, the values being 1.18-1.28.

The influence of the cut-off length (λc) and noise length (λs) on surface roughness parameters like Sku and Ssk is crucial in surface metrology.

Analyzing Figures 4 and 5, a longer λc includes larger surface features (waviness), leading to smoother profiles and to screen small, but important details as, for instance, small grooves or pits (valleys) that act like lubricant reservoirs in lubricating contacts. It may reduce Sku and Ssk values if large features dominate the surface. Selecting large λc could make surface details smoothed out, at smaller scales, potentially underestimating peakiness (Sku). The values calculated for Ssk has an obvious convergence starting from λc=0.250 mm, and for λc=0.900 mm, Ssk is around -1 (Fig. 4).

Table 2. The ratio Sq/Sa for the investigated pairs (λc, λs)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [µm]	**0.8**	8.118	6.184	3.944	2.893	2.516	1.579	1.289	1.220	1.213
	2.5	8.331	6.098	3.913	2.880	2.508	1.577	1.289	1.220	1.213
	8	7.816	5.438	3.689	2.779	2.441	1.568	1.288	1.219	1.213
	25	1.132	1.233	1.384	1.361	1.501	1.391	1.244	1.200	1.222
	80	1.944	1.922	1.861	1.771	1.713	1.425	1.258	1.209	1.205
	250	1.267	1.266	1.264	1.260	1.257	1.224	1.188	1.183	1.184

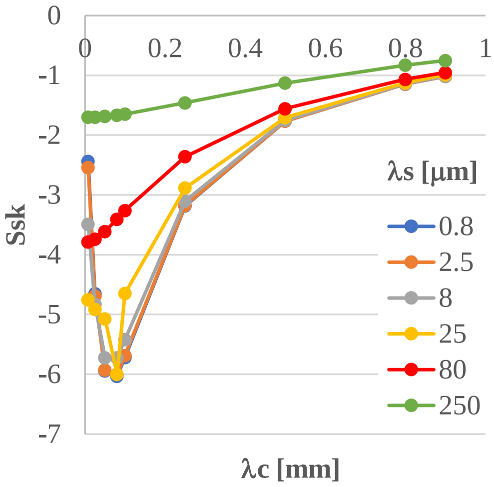

Fig. 4. Influence of λs and λc on Ssk

For λc=900 μm, a cut-off length approaching the length of the investigated square area (1000 μm), Ssk is very little dependent on λs: Ssk=-1.017 (for λs=0.8 μm) and Ssk=-0.751 (for λs=250 μm), resulting a standard deviation of 0.104 (10.87% of the average value for the same λc=900 μm).

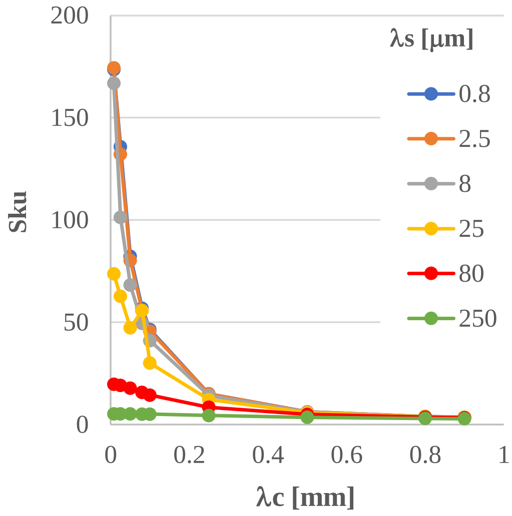

Fig. 5. Influence of λs and λc on Sku

The kurtosis, Sku, has a very different dependency on (λs, λc). For small values of λs (0.8 μm to 25 μm), the dependency of Sku to λc is a power law function. For the higher values of λc (80 μm and 250 μm), the curves for Sku have o smaller range of variance. For λs≥500 μm, the curves for all values of λc are almost overlapping (Fig. 5).

Sku has a trend of convergence, starting from λc=250 μm. At λc=900 μm, Sku varied from 3.605 (for the lowest λs=0.8 μm) to 2.859 (for the largest λs=250 μm), meaning a standard deviation of 0.293 (meaning 8.55% of the average Sku calculated for all λs at λc=900 μm).

For small λc (0.8 μm to 8 μm) the lines for Sv are higher, but for greater values these lines reveal smaller values, if λs increases to 250 μm, meaning that for greater value for λs, the including of the deepest values are less probably.

Sp has dispersed points for λc<250 μm, but for λc=250 μm till λc=900 μm, the points of Sp are superimposed. For this range of λs, the dependency of Sp is obviously increasing with λc, but the lines obtained for each λs, overlaps quite obviously (Fig. 6).

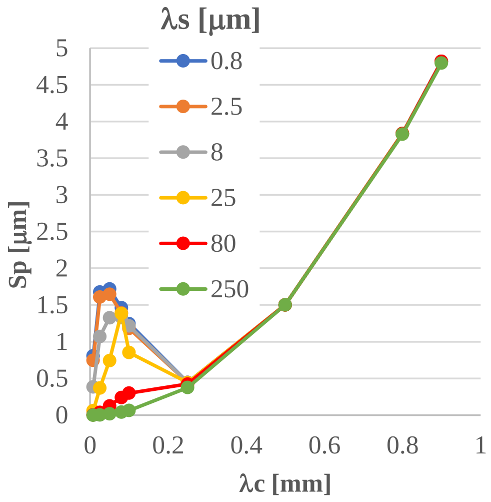

Fig. 6. Influence of λs and λc on Sp

The shape of curves for St (Fig. 7) is more influenced by the shape for Sv (Fig. 8). Two zones are distinctly visible on Figure 8: the zone of small values for λs (till 100 μm) and the other one on the range 250 μm to 900 μm. St decreases with the increasing of λs, but it increases with the increases with λc. A larger λs is favorable to avoid recording the deepest valley

Even if this parameter is a singular one, it is important in evaluating the tribological behavior of such surfaces as a too hight asperity could locally destroy the lubricant film, generating direct contact and alterating the functioning conditions.

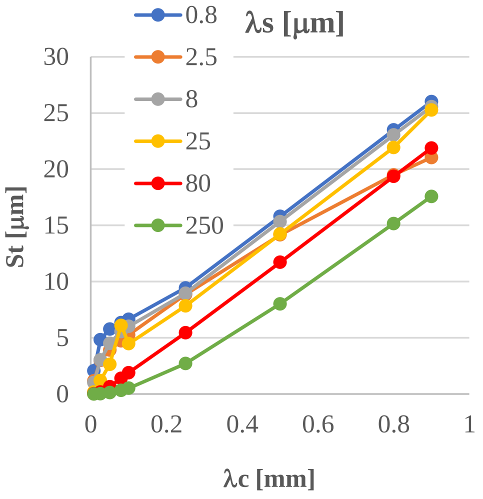

Fig. 7. Influence of λs and λc on St

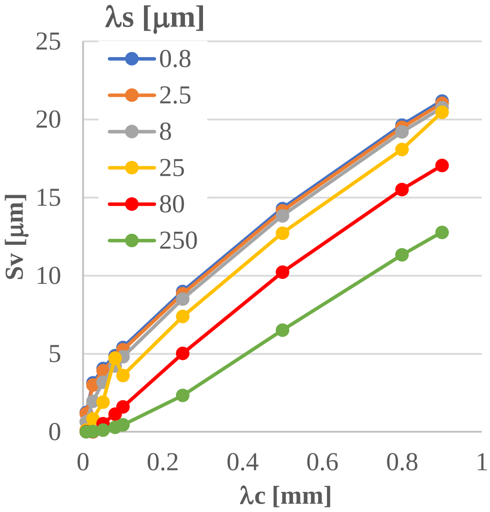

Fig. 8. Influence of λs and λc on Sv

The influence of for the same value of λc is given in the tables in the Annex. The authors calculated the average of a parameters for five different values of λs and for the same λc, the standard deviation of this set of measurements and they also expressed a percentage of standard deviation related to the average value (coded as SD%). Taking it into account this, the lowest values for SD% were obtained for all λs, for the largest cut-off length, λc=900 µm, meaning that a larger cut-off makes λs less influencing the results.

For Sa, SD% is decreasing to lower value only for λc = 100-250 µm, but values increase from nanometers to higher average value (3.59 µm for λc=900 µm).

Ssk and Sku revealed a convergence towards the largest value of λc, meaning that λs has almost no influence when the cut-off length is almost the dimension of the investigated area, at least for λs=0.8-250 µm.

Considering the results for this ball bearing surface, a too large λc might include the overall curvature or form deviations, leading to an inflated roughness values (see Figures 2 to 8). If λs is too large, fine scratches, micro-defects or micro-valleys (beneficial in lubricated contacts) could be missed, underestimating the roughness in surface exploitation.

As λs removes short-wavelength components, such as high-frequency noise and very fine surface details that are not functionally relevant, it has the following impact on amplitude roughness parameters:

- noise reduction by filtering out very short wavelengths, preventing measurement noise from artificially inflating roughness values,
- excluding micro-texture if λs is set too high as it can eliminate actual surface roughness features, underestimating parameters like Sa or Sq,
- characterization of fine high-precision surfaces because using a smaller λs (2.5 µm) ensures that only relevant roughness details are considered.

λc separates roughness from waviness by filtering out long-wavelength components and it influences the roughness parameters by

- excluding waviness: if λc is too small, some longer surface features (considered waviness) might be included in the roughness profile, inflating values like Sa (arithmetical mean roughness) or St,
- including large features: if λc is too large, it might miss important roughness features, reducing the roughness values.

The selected pair (λc, λs) has practical considerations: for precision-engineered surfaces, smaller λc values (0.8 µm) are typical to focus on fine roughness details and for coarser surfaces, larger λc values are appropriate.

6. Conclusions

After analyzing the results for amplitude parameters for a selected area of 1000 µm x 1000 µm on a finished rolling bearing ball, the following conclusions could be formulated.

The choice of λs and λc is critical to obtaining meaningful data from a 3D profilometry measurement. It balances between filtering out irrelevant noise and retaining essential surface details.

It is important to report the λc and λs values as they have directly impact on roughness values (as demonstrate here for 3D amplitrude parameters, like Sa, Sq etc.). This study and the cited references evidence that different settings can produce different results for the same surface. Including them in the report ensures transparency and reproducibility.

Trying a range around the recommended λc and λs helps identify the most representative values and establish how sensitive the roughness parameters are to filter settings. The analysis of a range for λc and λs avoids missing critical surface details or including irrelevant ones (like waviness or noise).

Analyzing the values of amplitude parameters for a given surface and the selected ranges for λc and λs, the authors could formulate several recommendations for best practices when carrying out a profilometric study:

- clearly mention the methodology for the final areal investigation (meaning all modifications of the raw texture, including leveling, form removal and filtering),
- use λc and λs values from standards (like ISO 16610-1:2015 [18], [19]); this will allow for easier comparison of data from references,
- explain filter selection and why a specific range was chosen and how it affects the results,
- show comparative data, including roughness values calculated with different λc and λs values to highlight their impact.

This approach strengthens your conclusions and demonstrates a thorough understanding of surface metrology.

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Annex

Table A.1. Data calculated for Sa (in μm), for the same value of λc and different values of λs (see Fig. 2)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [μm]	0.80	0.005	0.019	0.047	0.090	0.126	0.546	1.642	3.158	3.656
	2.50	0.004	0.019	0.047	0.090	0.126	0.546	1.642	3.158	3.656
	8	0.003	0.017	0.044	0.088	0.124	0.546	1.642	3.158	3.656
	25	0.001	0.011	0.037	0.089	0.119	0.545	1.640	3.155	3.579
	80	0.001	0.007	0.028	0.069	0.104	0.532	1.622	3.132	3.629
	250	0.000	0.005	0.019	0.049	0.076	0.441	1.459	2.913	3.396
	max	0.005	0.019	0.047	0.090	0.126	0.546	1.642	3.158	3.656
	min	0.000	0.005	0.019	0.049	0.076	0.441	1.459	2.913	3.396
	average	0.002	0.013	0.037	0.079	0.112	0.526	1.608	3.112	3.595
	SD	0.002	0.006	0.011	0.017	0.019	0.042	0.073	0.098	0.102
	SD%	77.036	47.777	30.604	21.442	17.318	7.946	4.561	3.155	2.841

Table A.2. Data calculated for Sq (in μm), for the same value of λc and different values of λs (see Fig. 3)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [μm]	**0.80**	0.039	0.119	0.185	0.262	0.317	0.862	2.117	3.852	4.435
	2.50	0.037	0.116	0.183	0.260	0.315	0.861	2.117	3.852	4.435
	8	0.023	0.091	**0.164**	**0.245**	**0.303**	**0.856**	**2.115**	3.851	4.434
	25	0.001	0.014	0.052	0.122	0.179	0.758	2.040	3.787	4.372
	80	0.001	0.014	0.052	0.122	0.179	0.758	2.040	3.787	4.372
	250	0.001	0.006	0.024	0.062	0.096	0.540	1.734	3.445	4.022
	max	0.039	0.119	0.185	0.262	0.317	0.862	2.117	3.852	4.435
	min	0.001	0.006	0.024	0.062	0.096	0.540	1.734	3.445	4.022
	average	0.017	0.060	0.110	0.179	0.231	0.772	2.027	3.762	4.345
	SD	0.018	0.054	0.075	0.087	0.093	0.124	0.148	0.159	0.161
	SD%	106.907	90.618	67.967	48.796	40.185	16.095	7.321	4.217	3.710

Table A.3. Data calculated for Ssk, for the same value of λc and different values of λs (see Fig. 4)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [μm]	**0.80**	-2.438	-4.652	-5.944	-6.033	-5.718	-3.182	-1.766	-1.145	-1.017
	2.50	-2.541	-4.687	-5.927	-6.000	-5.684	-3.173	-1.764	-1.145	-1.017
	8	-3.490	-4.828	-5.722	-5.722	-5.420	**-3.102**	**-1.751**	-1.141	-1.014
	25	-4.755	-4.913	-5.072	-5.997	-4.649	-2.884	-1.707	-1.126	-0.990
	80	-3.785	-3.741	-3.611	-3.406	-3.261	-2.359	-1.556	-1.065	-0.953
	250	-1.699	-1.696	-1.686	-1.666	-1.649	-1.459	-1.129	-0.829	-0.751
	max	-1.699	-1.696	-1.686	-1.666	-1.649	-1.459	-1.129	-0.829	-0.751
	min	-4.755	-4.913	-5.944	-6.033	-5.718	-3.182	-1.766	-1.145	-1.017
	average	-3.118	-4.086	-4.660	-4.804	-4.397	-2.693	-1.612	-1.075	-0.957
	SD	1.102	1.245	1.703	1.844	1.634	0.679	0.250	0.124	0.104
	SD%	35.343	30.463	36.537	38.392	37.168	25.225	15.485	11.574	10.876

Table A.4. Data calculated for Sku, for the same value of λc and different values of λs (see Fig. 5)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [μm]	**0.80**	173.500	135.900	82.220	56.870	46.480	15.040	6.194	3.939	3.605
	2.50	174.400	132.100	80.170	55.820	45.730	14.940	6.181	3.936	3.603
	8	166.900	101.300	68.150	49.450	41.020	14.220	6.088	3.915	3.587
	25	73.640	62.720	47.270	55.710	30.030	12.210	5.793	3.840	3.541
	80	19.680	19.160	17.750	15.720	14.440	8.461	5.011	3.598	3.353
	250	5.269	5.258	5.221	5.148	5.084	4.453	3.566	2.979	2.859
	max	174.400	135.900	82.220	56.870	46.480	15.040	6.194	3.939	3.605
	min	5.269	5.258	5.221	5.148	5.084	4.453	3.566	2.979	2.859
	average	102.232	76.073	50.130	39.786	30.464	11.554	5.472	3.701	3.425
	SD	79.377	56.190	32.651	23.130	17.333	4.270	1.035	0.377	0.293
	SD%	77.644	73.864	65.132	58.134	56.895	36.953	18.906	10.173	8.556

Table A.5. Data calculated for Sp (in µm), for the same value of λc and different values of λs (see Fig. 6)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [µm]	**0.80**	0.807	1.676	1.719	1.462	1.248	0.444	1.503	3.837	4.821
	2.50	0.745	1.608	1.647	1.392	1.180	0.444	1.503	3.837	4.821
	8	0.385	1.072	**1.327**	**1.332**	**1.214**	**0.444**	**1.503**	3.837	4.821
	25	0.059	0.369	0.743	1.384	0.853	0.441	1.503	3.837	4.808
	80	0.004	0.036	0.125	0.239	0.298	0.423	1.503	3.836	4.819
	250	0.000	0.004	0.016	0.040	0.063	0.376	1.503	3.827	4.797
		0.008	0.025	0.050	0.080	0.100	0.250	0.500	0.800	0.900
	max	0.807	1.676	1.719	1.462	1.248	0.444	1.503	3.837	4.821
	min	0.000	0.004	0.016	0.040	0.063	0.376	1.503	3.827	4.797
	average	0.334	0.794	0.929	0.975	0.809	0.429	1.503	3.835	4.815
	SD	0.372	0.761	0.750	0.651	0.513	0.027	0.000	0.004	0.010
	SD%	111.501	95.824	80.705	66.808	63.348	6.304	0.000	0.105	0.207

Table A.6. Data calculated for Sv (in µm), for the same value of λc and different values of λs (see Fig. 7)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [µm]	**0.80**	1.252	3.144	4.057	4.890	5.407	8.996	14.300	19.650	21.190
	2.50	1.173	2.998	3.907	4.739	5.256	8.845	14.150	19.500	21.040
	8	0.643	1.962	**3.176**	**4.225**	**4.805**	**8.514**	**13.840**	19.210	20.750
	25	0.119	0.822	1.900	4.721	3.616	7.389	12.730	18.090	20.460
	80	0.015	0.144.3	0.524	1.144	1.597	5.019	10.220	15.520	17.060
	250	0.003	0.029	0.116	0.292	0.449	2.336	6.512	11.340	12.780
	max	1.252	3.144	4.057	4.890	5.407	8.996	14.300	19.650	21.190
	min	0.003	0.029	0.116	0.292	0.449	2.336	6.512	11.340	12.780
	average	0.534	1.791	2.280	3.335	3.522	6.850	11.959	17.218	18.880
	SD	0.576	1.356	1.704	2.057	2.067	2.660	3.069	3.264	3.362
	SD%	107.866	75.727	74.736	61.683	58.693	38.831	25.667	18.959	17.808

Table A.7. Data calculated for St (in µm), for the same value of λc and different values of λs (see Fig. 8)

		λc [mm]								
		0.008	**0.025**	**0.050**	**0.080**	**0.100**	**0.250**	**0.500**	**0.800**	**0.900**
λs [µm]	**0.80**	2.059	4.820	5.776	6.352	6.656	9.440	15.800	23.490	26.020
	2.50	1.173	2.998	3.907	4.739	5.256	8.845	14.150	19.500	21.040
	8	1.028	3.034	4.503	5.557	6.019	8.958	15.343	23.047	25.571
	25	0.178	1.191	2.643	6.105	4.469	7.830	14.230	21.930	25.270
	80	0.019	0.181	0.649	1.383	1.895	5.441	11.720	19.360	21.880
	250	0.003	0.033	0.132	0.333	0.512	2.712	8.015	15.170	17.580
	max	2.059	4.820	5.776	6.352	6.656	9.440	15.800	23.490	26.020
	min	0.003	0.033	0.132	0.333	0.512	2.712	8.015	15.170	17.580
	average	0.743	2.043	2.935	4.078	4.134	7.204	13.210	20.416	22.894
	SD	0.823	1.889	2.220	2.577	2.426	2.625	2.912	3.103	3.325
	SD%	110.749	92.460	75.644	63.183	58.668	36.433	22.042	15.198	14.525