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ISO 25178-2

Second edition
2021-12

Geometrical product specifications (GPS) — Surface texture: Areal —

Part 2:
Terms, definitions and surface texture parameters

Spécification géométrique des produits (GPS) — État de surface: Surfacique —

Partie 2: Termes, définitions et paramètres d'états de surface

Reference number
ISO 25178-2:2021(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 290, *Dimensional and geometrical product specification and verification*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 25178-2:2012), which has been technically revised. The main changes to the previous edition are described in Annex E.

A list of all parts in the ISO 25178 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO 14638). It influences the chain link B of the chains of standards on areal surface texture.

The ISO/GPS matrix model given in ISO 14638 gives an overview of the ISO/GPS system of which this document is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to the specifications made in accordance with this document, unless otherwise indicated.

For more detailed information of the relation of this document to other standards and the GPS matrix model, see Annex I. An overview of standards on profiles and areal surface texture is given in Annex H.

This document develops the terminology, concepts and parameters for areal surface texture.

Throughout this document, parameters are written as abbreviations with lower-case suffixes (as in Sq or Vmp) when used in a sentence and are written as symbols with subscripts (as in S_q or V_{mp}) when used in formulae, to avoid misinterpretations of compound letters as an indication of multiplication between quantities in formulae. The parameters in lower case are used in product documentation, drawings and data sheets.

Parameters are calculated from coordinates defined in the specification coordinate system, or from derived quantities (e.g. gradient, curvature).

Parameters are defined for the continuous case, but in verification they are calculated on discrete surfaces such as the primary extracted surface.

A short history of the work done on areal surface texture can be found in Annex C.

Geometrical product specifications (GPS) — Surface texture: Areal —

Part 2:
Terms, definitions and surface texture parameters

1 Scope

This document specifies parameters for the determination of surface texture by areal methods.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16610-1:2015, *Geometrical product specifications (GPS) — Filtration — Part 1: Overview and basic concepts*

ISO 17450-1:2011, *Geometrical product specifications (GPS) — General concepts — Part 1: Model for geometrical specification and verification*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16610-1:2015 and ISO 17450-1:2011 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 General terms

3.1.1
skin model
<of a workpiece> model of the physical interface of the workpiece with its environment

[SOURCE: ISO 17450-1:2011, 3.2.2]

3.1.2
surface texture
<areal> geometrical irregularities contained in a *scale-limited surface* (3.1.9)

Note 1 to entry: Surface texture does not include those geometrical irregularities contributing to the form or shape of the surface.

3.1.3
mechanical surface
boundary of the erosion, by a sphere of radius *r*, of the locus of the centre of an ideal tactile sphere, also with radius *r*, rolled over the *skin model* (3.1.1) of a workpiece

[SOURCE: ISO 14406:2010, 3.1.1, modified — Notes to entry removed.]

3.1.3.1
electromagnetic surface
surface obtained by the electromagnetic interaction with the *skin model* (3.1.1) of a workpiece

[SOURCE: ISO 14406:2010, 3.1.2, modified — Notes to entry removed.]

3.1.3.2
auxiliary surface
surface, other than mechanical or electromagnetic, obtained by an interaction with the *skin model* (3.1.1) of a workpiece

Note 1 to entry: A mathematical surface (softgauge) is an example of an auxiliary surface.

Note 2 to entry: Other physical measurement principles, such as tunnelling microscopy or atomic force microscopy, can also serve as an auxiliary surface. See Figure 1 and Annex G.

3.1.4
specification coordinate system
system of coordinates in which surface texture parameters are specified

Note 1 to entry: If the nominal form of the surface is a plane (or portion of a plane), it is common (practice) to use a rectangular coordinate system in which the axes form a right-handed Cartesian set, the *x*-axis and the *y*-axis also lying on the nominal surface, and the *z*-axis being in an outward direction (from the material to the surrounding medium). This convention is adopted throughout the rest of this document.

3.1.5
primary surface
surface portion obtained when a surface portion is represented as a specified primary mathematical model with specified *nesting index* (3.1.6.4)

Note 1 to entry: In this document, an S-filter is used to derive the primary surface. See Figure 1.

[SOURCE: ISO 16610-1:2015, 3.3, modified — Note 1 to entry added.]

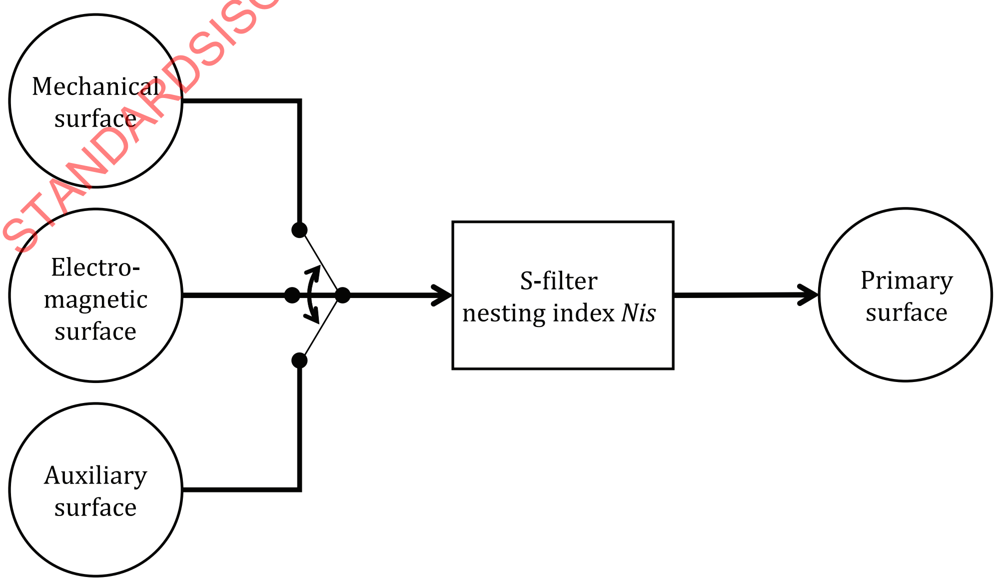


Figure 1 — Definition of primary surface

3.1.5.1
primary extracted surface
finite set of data points sampled from the *primary surface* (3.1.5)

[SOURCE: ISO 14406:2010, 3.7, modified — Notes to entry removed.]

3.1.6
surface filter
filtration operator applied to a surface

3.1.6.1
S-filter
surface filter (3.1.6) which removes small-scale lateral components from the surface, resulting in the *primary surface* (3.1.5)

3.1.6.2
L-filter
surface filter (3.1.6) which removes large-scale lateral components from the *primary surface* (3.1.5) or *S-F surface* (3.1.7)

Note 1 to entry: When the L-filter is not tolerant to form, it needs to be applied on an S-F surface; when it is tolerant to form, it can be applied either on the primary surface or on an S-F surface.

3.1.6.3
F-operation
operation which removes form from the *primary surface* (3.1.5)

Note 1 to entry: Some F-operations (such as association) have a very different action to that of filtration. Though their action can limit the larger lateral scales of a surface, this action is very fuzzy. It is represented in Figure 2 using the same convention as for a filter.

Note 2 to entry: Some L-filters are not tolerant to form and require an F-operation first as a prefilter before being applied.

Note 3 to entry: An F-operation can be a filtration operation such as a robust Gaussian filter.

3.1.6.4
nesting index
N_{is}, N_{ic}, N_{if}
number or set of numbers indicating the relative level of nesting for a particular primary mathematical model

[SOURCE: ISO 16610-1:2015, 3.2.1, modified — definition revised and notes to entry removed.]

3.1.7
S-F surface
surface derived from the *primary surface* (3.1.5) by removing the form using an *F-operation* (3.1.6.3)

Note 1 to entry: Figure 2 illustrates the relationship between the S-F surface and the S-filter and F-operation.

Note 2 to entry: If filtered with N_{is} nesting index to remove the shortest wavelengths from the surface, the surface is equivalent to a “primary surface”. In this case, N_{is} is the areal equivalent of the λs cut-off. See key reference 4 in Figure 2 and Annex G.

Note 3 to entry: If filtered with N_{ic} nesting index to separate longer from shorter wavelengths, the surface is equivalent to a “waviness surface”. In this case, N_{ic} is the areal equivalent of the λc cut-off. See key reference 5 in Figure 2 and Annex G.

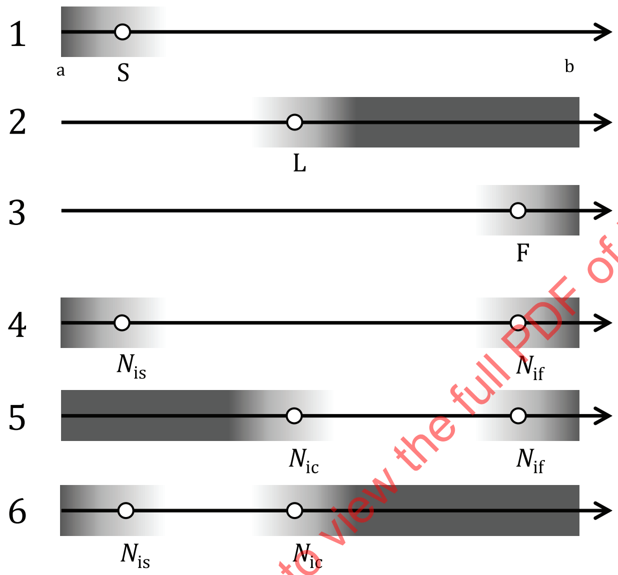
Note 4 to entry: The concepts of “roughness” or “waviness” are less important in areal surface texture than in profile surface texture. Some surfaces can exhibit roughness in one direction and waviness in the perpendicular direction. That is why the concepts of S-L surface and S-F surface are preferred in this document.

3.1.8
S-L surface
surface derived from the *S-F surface* (3.1.7) by removing the large-scale components using an *L-filter* (3.1.6.2)

Note 1 to entry: Figure 2 illustrates the relationship between the S-L surface and the S-filter and L-filter.

Note 2 to entry: If the S-filter nesting index N_{is} is chosen to remove the shortest wavelengths from the surface and the L-filter nesting index N_{ic} is chosen in order to separate longer from shorter wavelengths, the surface is equivalent to a "roughness surface". See key reference 6 in Figure 2 and Annex G.

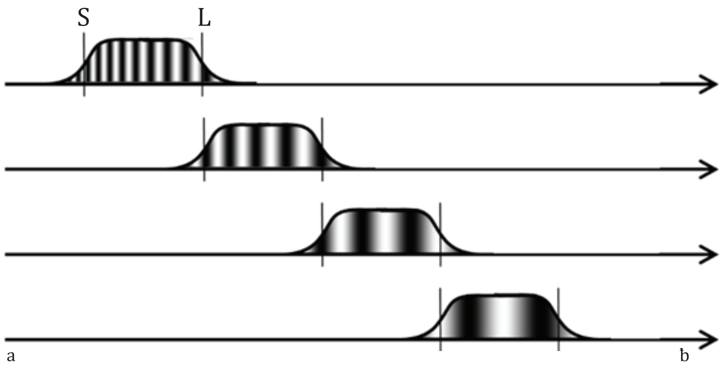
Note 3 to entry: A series of S-L surfaces can be generated with narrow bandwidth using an S-filter and an L-filter of close nesting indices (or equal), in order to achieve a multiscale exploration of the surface. See Figure 3.



Key

1 S-filter
2 L-filter
3 F-operation
4 S-F surface
5 S-F surface
6 S-L surface
A small scale
B large scale

Figure 2 — Relationships between the S-filter, L-filter, F-operation and S-F and S-L surfaces



Key

S S-filter

L L-filter

A small scale

B large scale

Figure 3 — Example of bandpass filters used to generate a bank of S-L surfaces

3.1.9
scale-limited surface
S-F surface (3.1.7) or *S-L surface* (3.1.8)

3.1.10
reference surface
<surface texture> surface associated to the *scale-limited surface* (3.1.9) according to a criterion

Note 1 to entry: This reference surface is used as the origin of heights for surface texture parameters.

EXAMPLE Plane, cylinder and sphere.

3.1.11
evaluation area
A
$\tilde{A}$
portion of the *scale-limited surface* (3.1.9) for specifying the area under evaluation

Note 1 to entry: See ISO 25178-3 for more information.

Note 2 to entry: Throughout this document, the symbol A is used for the numerical value of the evaluation area and the symbol $\tilde{A}$ for the domain (of integration or definition).

3.2 Geometrical parameter terms

3.2.1
field parameter
parameter defined from all the points on a *scale-limited surface* (3.1.9)

Note 1 to entry: Field parameters are defined in Clause 4.

3.2.2
feature parameter
parameter defined from a subset of predefined topographic features from the *scale-limited surface* (3.1.9)

Note 1 to entry: Feature parameters are defined in Clause 5.

3.2.3
V-parameter
material volume or void volume *field parameter* (3.2.1)

3.2.4
S-parameter
field parameter (3.2.1) or *feature parameter* (3.2.2) that is not a *V-parameter* (3.2.3)

3.2.5
height
ordinate value
$z(x,y)$
signed normal distance from the *reference surface* (3.1.10) to the *scale-limited surface* (3.1.9)

Note 1 to entry: Throughout this document, the term "height" is either used for a distance or for an absolute coordinate. For example, *Sz*, maximum height, is a distance and *Sp*, maximum peak height, is an absolute height.

3.2.5.1
depth
opposite value of *height* (3.2.5)

3.2.6
local gradient vector
$\left(\frac{\partial z(x,y)}{\partial x}, \frac{\partial z(x,y)}{\partial y}\right)$
first derivative along x and y of the *scale-limited surface* (3.1.9) at position (x, y)

Note 1 to entry: See Annex D for implementation details.

3.2.7
local mean curvature
arithmetic mean of the principal curvatures at position (x, y)

Note 1 to entry: Principal curvatures are two numbers, k_1 and k_2, representing the maximum and minimum curvatures at a point. The local mean curvature is therefore $\frac{k_1 + k_2}{2}$.

Note 2 to entry: See Annex D for implementation details.

3.2.8
material ratio
$M_r(c)$
ratio of the area A_c of the surface portion intersected by a plane at level c, to the *evaluation area* (3.1.11), A

Note 1 to entry: The curve representing material ratio as a function of the level is also called Abbott Firestone curve.

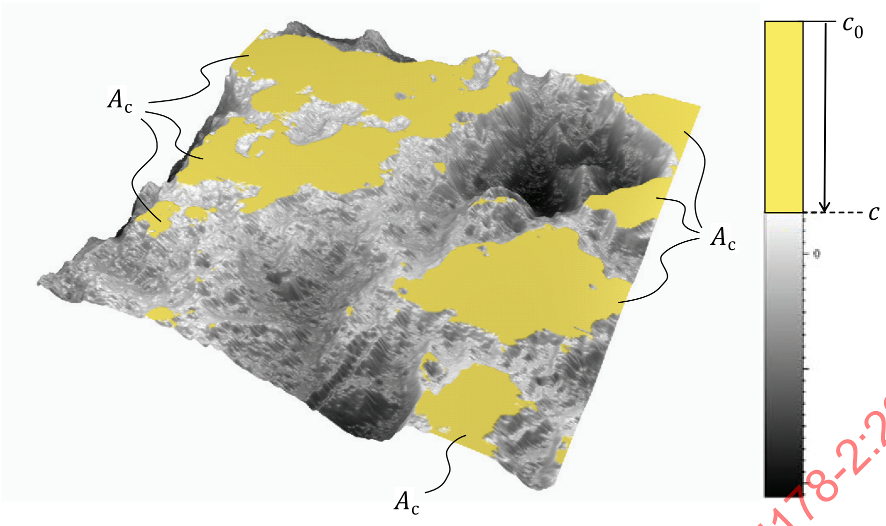
Note 2 to entry: The level c is usually defined as a height taken with respect to a reference c_0. By default, the reference is at the highest point of the surface. In the first edition of this document, the reference height was set to the *reference surface* (3.1.10).

Note 3 to entry: The material ratio may be given as a percentage or a value between 0 and 1.

Note 4 to entry: See Figure 4 and Formula (1).

Note 5 to entry: See Annex D for the determination of the material ratio curve.

$$M_r(c) = \frac{A_c(c)}{A} .100\ \% \qquad (1)$$



Key

c intersecting level

c_0 reference height

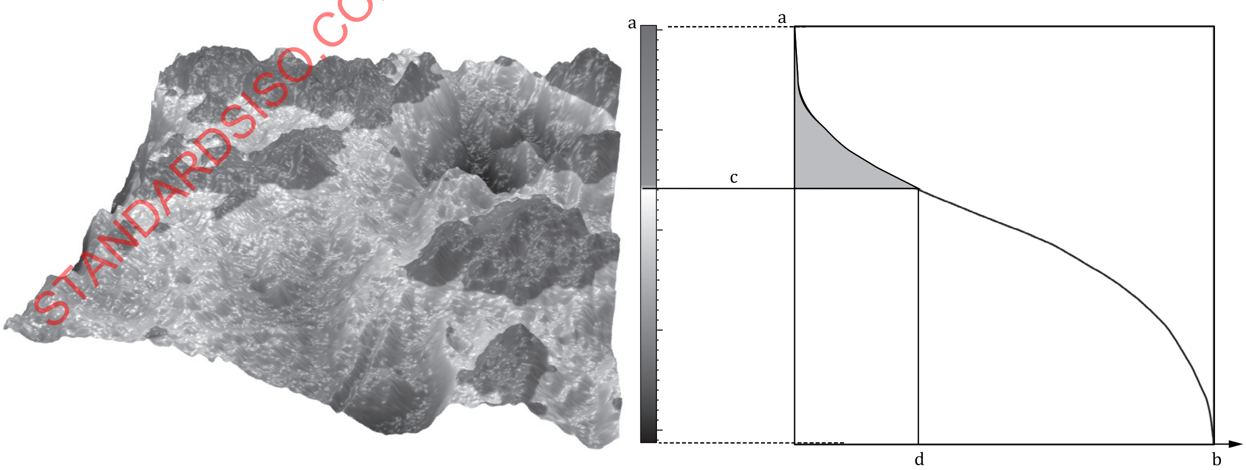
A_c areal portions intersected by plane at height c

Figure 4 — Area of the surface portion intersected by plane at level *c*

3.2.9
areal material ratio curve
material ratio function
function representing the areal *material ratio* (3.2.8) of the *scale-limited surface* (3.1.9) as a function of a level c

Note 1 to entry: This function can be interpreted as the cumulative probability function of the ordinates $z(x,y)$ within the evaluation area. See Annex D.

Note 2 to entry: See Figure 5.



Key

A height

B areal material ratio

C intersection level c

D material ratio at level c

Figure 5 — Material ratio curve

3.2.10
inverse material ratio
$C(p)$
intersecting level at which a given areal *material ratio* (3.2.8) p is satisfied

Note 1 to entry: See Formula (2).

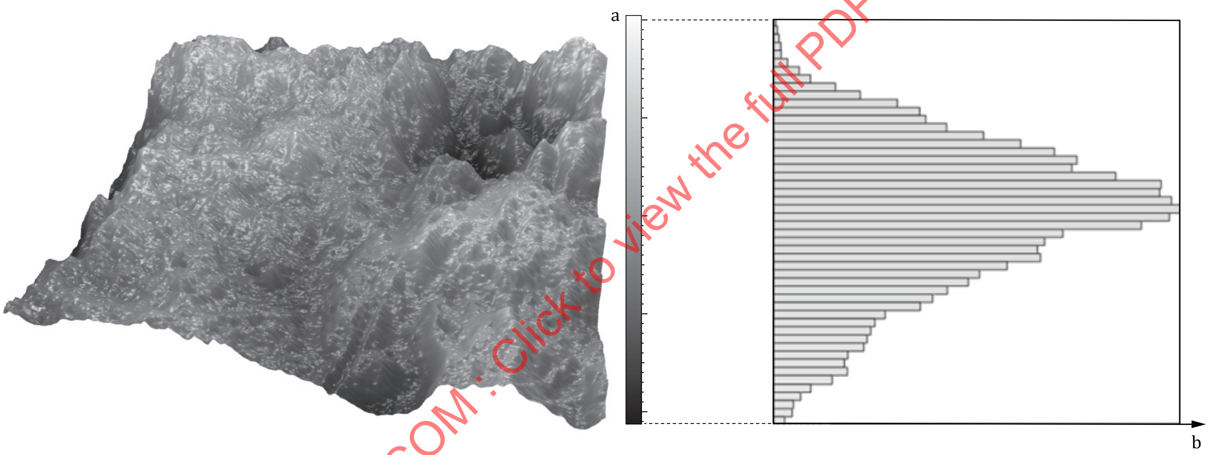
$$C(p)=M_r^{-1}(p) \quad (2)$$

3.2.11
height density curve
height density function
$h(c)$
curve representing the density of points laying at level c on the *scale-limited surface* (3.1.9)

Note 1 to entry: When represented as a histogram with bins, the percentage per bin depends on their width.

Note 2 to entry: See Figure 6 and Formula (3).

$$h(c)=-\frac{dM_r(c)}{dc} \quad (3)$$



Key
A height
B density

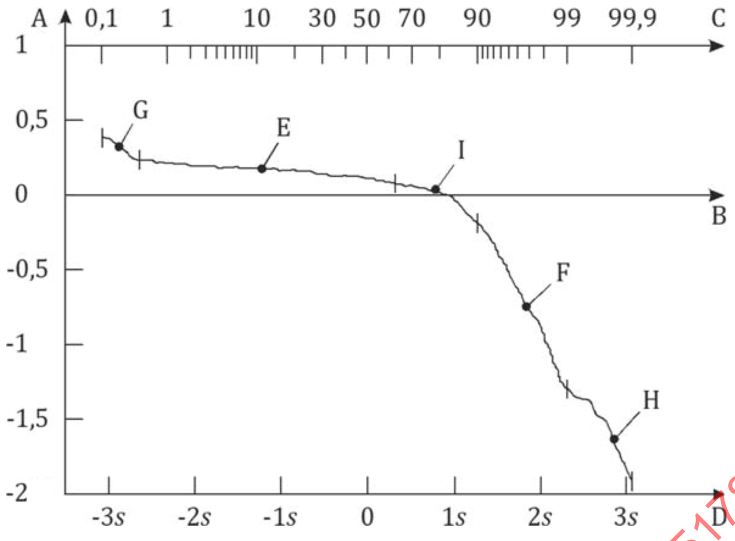
Figure 6 — Height density curve

3.2.12
core surface
scale-limited surface (3.1.9) excluding core-protruding hills and dales

Note 1 to entry: The terms hills and dales in this definition refer to 3.3.1.2 and 3.3.2.2 but are defined by graphical construction. See Figure 14 and Annex B.3.

3.2.13
areal material probability curve
representation of the *areal material ratio curve* (3.2.9) in which the areal material area ratio is expressed as a Gaussian probability in standard deviation values, plotted linearly on the horizontal axis

Note 1 to entry: This scale is expressed linearly in standard deviations according to the Gaussian distribution. In this scale, the areal material ratio curve of a Gaussian distribution becomes a straight line. For stratified surfaces composed of two Gaussian distributions, the areal material probability curve will exhibit two linear regions (see E and F in Figure 7).



Key

A amplitude

B reference line

C material ratio expressed as a Gaussian probability in per cent

D material ratio expressed as a Gaussian probability in standard deviation

E plateau region

F dale region

G outlying hills (possibly including debris or dirt particles)

H outlying dales (possibly deep scratches)

I unstable region (curvature) introduced at the plateau-to-dale transition point based on the combination of two distributions horizontal axis *s* is the standard deviation

Figure 7 — Areal material probability curve

3.2.14
autocorrelation function
$f_{ACF}(t_x, t_y)$
function which describes the correlation between a surface and the same surface translated by (t_x, t_y)

Note 1 to entry: The autocorrelation used here is normalized between −1 and 1. The maximum value is always met but the minimum may not always be at −1, it depends on the surface (it may be −0,76).

Note 2 to entry: See Formula (4).

$$f_{ACF}\left(t_x, t_y\right) = \frac{\frac{1}{B}\iint_{\tilde{B}} z(x,y)\,z\left(x+t_x, y+t_y\right)dxdy}{\frac{1}{A}\iint_{\tilde{A}} z^2(x,y)\,dxdy} \quad (4)$$

where $\tilde{B}$ is the intersecting area of the two surfaces at shifts t_x and t_y.

3.2.15
Fourier transformation
$F(p, q)$
operator which transforms *ordinate values* (3.2.5) of the *scale-limited surface* (3.1.9) into Fourier space

Note 1 to entry: The Fourier transformation defined here is using a limited support $\tilde{A}$, therefore it approximates the mathematical function called Fourier transformation which has an infinite support.

Note 2 to entry: See Formula (5).

$$F(p,q)=\iint_{\tilde{A}} z(x,y)e^{-2i\pi(px+qy)}dxdy \quad (5)$$

where

p and *q* are spatial frequencies in x and y direction, respectively;

i is the imaginary unit.

3.2.15.1
angular spectrum
$F_{AS}(r, \theta)$
Fourier transformation (3.2.15) expressed in polar coordinates, with respect to a reference direction θ_{ref} in the plane of the *evaluation area* (3.1.11)

Note 1 to entry: The positive *x*-axis is defined as the zero angle.

Note 2 to entry: The angle is positive in an anticlockwise direction from the *x*-axis.

Note 3 to entry: See Formula (6).

$$F_{AS}(r,\theta)=F(r\ \cos(\theta-\theta_{ref}),\ r\ \sin(\theta-\theta_{ref})) \quad (6)$$

where

r is a spatial frequency;

θ is the specified direction;

F is the Fourier transformation.

3.2.15.2
angular amplitude density
angular amplitude distribution
$f_{AAD}(\theta)$
integrated amplitude of the *angular spectrum* (3.2.15.1) for a given direction θ

Note 1 to entry: The term "density" refers to the value at a given angle and the term "distribution" refers to the graph representing the values for all angles.

Note 2 to entry: See Formula (7).

$$f_{AAD}(\theta)=\int_{R_1}^{R_2} |F_{AS}(r,\ \theta)| rdr \quad (7)$$

where

r is a spatial frequency;

R_1 to R_2 ($R_1 < R_2$) is the range of integration of the frequencies in the radial direction;

θ is the specified direction;

F_{AS} is the angular spectrum function.

3.2.15.3
angular power density
angular power distribution
$f_{APD}(\theta)$
integrated squared amplitude of the *angular spectrum* (3.2.15.1) for a given direction θ

Note 1 to entry: The term "density" refers to the value at a given angle and the term "distribution" refers to the graph representing the values for all angles.

Note 2 to entry: See Formula (8).

$$f_{APD}(\theta) = \int_{R_1}^{R_2} F_{AS}{}^2(r,\theta) r\, dr \tag{8}$$

where

r	is a spatial frequency;
R_1 to R_2 ($R_1 < R_2$)	is the range of integration of the frequencies in the radial direction;
θ	is the specified direction;
F_{AS}	is the angular spectrum function.

3.2.16
areal power spectral density
f_{APSD}
squared magnitude of the *Fourier transformation* (3.2.15) using an appropriate weighting function

Note 1 to entry: The areal power spectral density describes surface texture in a spatial frequency context allowing the waviness or ripples in the surface to be described and controlled.

Note 2 to entry: See Formula (9).

Note 3 to entry: The areal power spectral density can also be calculated from a polar spectrum. It is usually the case when exploring optics surfaces (see ISO 10110-8).

$$f_{APSD}(p,q) = \frac{1}{A}\left|F(p,q)\right|^2 \tag{9}$$

3.3 Geometrical feature terms

3.3.1
peak
point on the surface which is higher than all other points within a neighbourhood of that point

Note 1 to entry: There is a theoretical possibility of a plateau. In practice, this can be avoided by the use of an infinitesimal tilt.

Note 2 to entry: See Figure 8.

3.3.1.1
hill
<watershed segmentation> region around a *peak* (3.3.1) such that all maximal upward paths end at the peak

Note 1 to entry: This definition is used for feature parameters.

Note 2 to entry: See Figure 8.

3.3.1.2
hill
<reference plane> outwardly directed (from material to surrounding medium) contiguous portion of the *scale-limited surface* (3.1.9) above the *reference surface* (3.1.10)

Note 1 to entry: This definition is used for field parameters.

Note 2 to entry: The reference surface is usually the mean plane of the scale-limited surface.

3.3.1.3
course line
curve separating adjacent *hills* (3.3.1.1)

Note 1 to entry: See Figure 8.

3.3.2
pit
point on the surface which is lower than all other points within a neighbourhood of that point

Note 1 to entry: There is a theoretical possibility of a plateau. In practice, this can be avoided by the use of an infinitesimal tilt.

Note 2 to entry: See Figure 9.

3.3.2.1
dale
<watershed segmentation> region around a *pit* (3.3.2) such that all maximal downward paths end at the pit

Note 1 to entry: This definition is used for feature parameters.

Note 2 to entry: See Figure 9.

3.3.2.2
dale
<reference plane> inwardly directed (from surrounding medium to material) contiguous portion of the *scale-limited surface* (3.1.9) below the *reference surface* (3.1.10)

Note 1 to entry: This definition is used for field parameters.

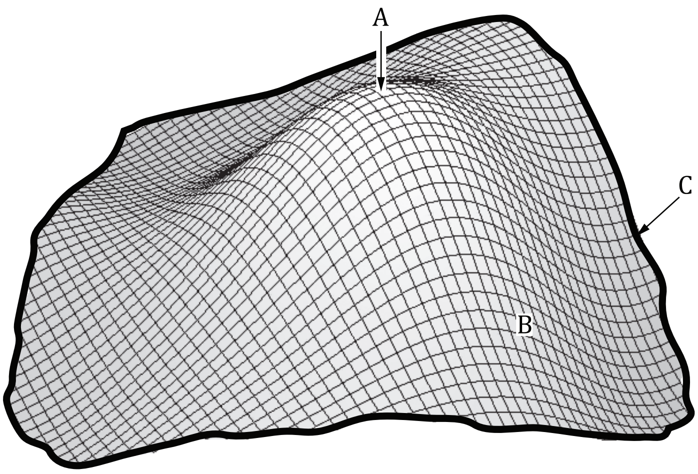
Note 2 to entry: The reference surface is usually the mean plane of the scale-limited surface.

3.3.2.3
ridge line
curve separating adjacent *dales* (3.3.2.1)

Note 1 to entry: See Figure 9.

3.3.3
saddle
point or set of points on the *scale-limited surface* (3.1.9) where *ridge lines* (3.3.2.3) and *course lines* (3.3.1.3) cross

3.3.3.1
saddle point
saddle (3.3.3) consisting of one point



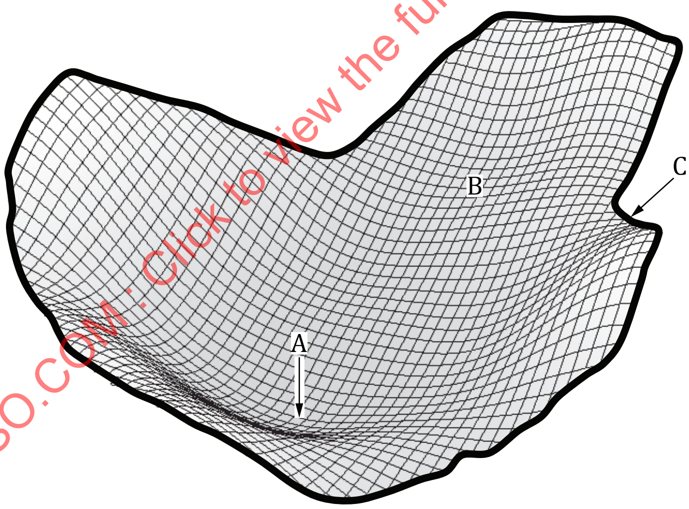
Key

A peak

B hill

C course line

Figure 8 — Representation of a hill in the context of watershed segmentation with the peak and the course line



Key

A pit

B dale

C ridge line

Figure 9 — Representation of a dale in the context of watershed segmentation with the pit and the ridge line

3.3.4
motif
hill (3.3.1.1) or *dale* (3.3.2.1) defined with watershed segmentation

Note 1 to entry: The term motif is used to designate an areal feature obtained by segmentation.

Note 2 to entry: The term motif as defined on a profile in ISO 12085 is a cross-section of a dale.

3.3.5
topographic feature
areal feature, line feature or point feature on a *scale-limited surface* (3.1.9)

3.3.5.1
areal feature
hill (3.3.1.1) or *dale* (3.3.2.1)

3.3.5.2
line feature
course line (3.3.1.3) or *ridge line* (3.3.2.3)

3.3.5.3
point feature
peak (3.3.1), *pit* (3.3.2) or *saddle point* (3.3.3.1)

3.3.6
contour line
line on the surface consisting of adjacent points of equal height

3.3.7
segmentation
method which partitions a *scale-limited surface* (3.1.9) into distinct features

3.3.7.1
segmentation function
function which splits a set of "events" into two distinct sets called the significant events and the insignificant events and which satisfies the three segmentation properties

Note 1 to entry: Examples of events include ordinate values and point features.

Note 2 to entry: A full mathematical description of the segmentation function and the three segmentation properties can be found in Reference [26] and ISO 16610-85.

3.3.8
change tree
graph where each *contour line* (3.3.6) is plotted as a point against height in such a way that adjacent contour lines are adjacent points on the graph

Note 1 to entry: Peaks and pits are represented on a change tree by the end of lines. Saddle points are represented on a change tree by joining lines. See ISO 16610-85 and Annex A for more details concerning change trees.

3.3.8.1
pruning
method to simplify a *change tree* (3.3.8) in which lines from *peaks* (3.3.1) [or *pits* (3.3.2)] to their nearest connected *saddle points* (3.3.3.1) are removed

3.3.8.2
hill local height
difference between the height of a *peak* (3.3.1) and the height of the nearest connected *saddle point* (3.3.3.1) on the *change tree* (3.3.8)

3.3.8.3
dale local depth
difference between the height of the nearest connected *saddle point* (3.3.3.1) on the *change tree* (3.3.8) and the height of a *pit* (3.3.2)

3.3.8.4
Wolf pruning
pruning where lines in the *change tree* (3.3.8) are removed, starting from the *peak* (3.3.1) [*pit* (3.3.2)] with the smallest *hill local height* (3.3.8.2) [*dale local depth* (3.3.8.3)] up to the peak (pit) with a specified hill *local height* (3.3.8.2) [*dale local depth* (3.3.8.3)]

Note 1 to entry: The peak local heights and pit local depths change during Wolf pruning as removing lines from a change tree also removes the associated saddle point.

3.3.9
height discrimination
minimum *hill local height* (3.3.8.2) or *dale local depth* (3.3.8.3) of the *scale-limited surface* (3.1.9) which should be considered during *Wolf pruning* (3.3.8.4)

Note 1 to entry: The height discrimination is specified by default as a percentage of Sz (4.2.7).

4 Field parameters

4.1 General

The symbol $\tilde{A}$ represents the domain (of integration or of definition of the parameters), and the symbol A represents the value of the evaluation area, in micrometres squared (μm^2) or millimetres squared (mm^2).

A summary of all S-parameters and V-parameters is given in Annex F.

4.2 Height parameters

4.2.1 General

All height parameters are defined over the evaluation area $\tilde{A}$.

4.2.2 Root mean square height

Sq

The root mean square height parameter is the square root of the mean square of the ordinate values of the scale-limited surface. It is sometimes referred to as the RMS height. It is calculated according to Formula (10).

$$S_q = \sqrt{\frac{1}{A}\iint_{\tilde{A}} z^2(x,y)dxdy} \tag{10}$$

4.2.3 Skewness

Ssk

The skewness parameter is the quotient of the mean cube value of the ordinate values of the scale-limited surface and the cube of Sq. It is calculated according to Formula (11).

$$S_{sk} = \frac{1}{AS_q^3}\iint_{\tilde{A}} z^3(x,y)dxdy \tag{11}$$

4.2.4 Kurtosis

Sku

The kurtosis parameter is the quotient of the mean quartic value of the ordinate values of the scale-limited surface and the fourth power of Sq. It is calculated according to Formula (12).

$$S_{\mathrm{ku}} = \frac{1}{A S_{\mathrm{q}}^4} \iint_{\tilde{A}} z^4(x,y)dxdy \qquad (12)$$

4.2.5 Maximum peak height

Sp

The maximum peak height parameter is the largest peak height value of the scale-limited surface.

4.2.6 Maximum pit depth

Sv

The maximum pit depth parameter is the largest pit depth value of the scale-limited surface. Sv is always a positive quantity, as the reference surface is always higher to the deepest pit.

4.2.7 Maximum height

Sz

The maximum height parameter is the sum of the maximum peak height value and the maximum pit depth value of the scale-limited surface.

4.2.8 Arithmetic mean height

Sa

The arithmetic mean height parameter is the mean of the absolute of the ordinate values of the scale-limited surface. It is calculated according to Formula (13).

$$S_{\mathrm{a}} = \frac{1}{A} \iint_{\tilde{A}} |z(x,y)|dxdy \qquad (13)$$

4.3 Spatial parameters

4.3.1 General

All spatial parameters are defined over the evaluation area $\tilde{A}$.

4.3.2 Autocorrelation length

Sal

The autocorrelation length parameter is the horizontal distance of the $f_{\mathrm{ACF}}(t_x,t_y)$ which has the fastest decay to a specified value *s*, with $0 \leq s < 1$. It is calculated according to Formula (14) or (15).

$$S_{\mathrm{al}} = \min_{t_{\mathrm{x}},t_{\mathrm{y}} \in R} \sqrt{t_{\mathrm{x}}^2 + t_{\mathrm{y}}^2} \qquad (14)$$

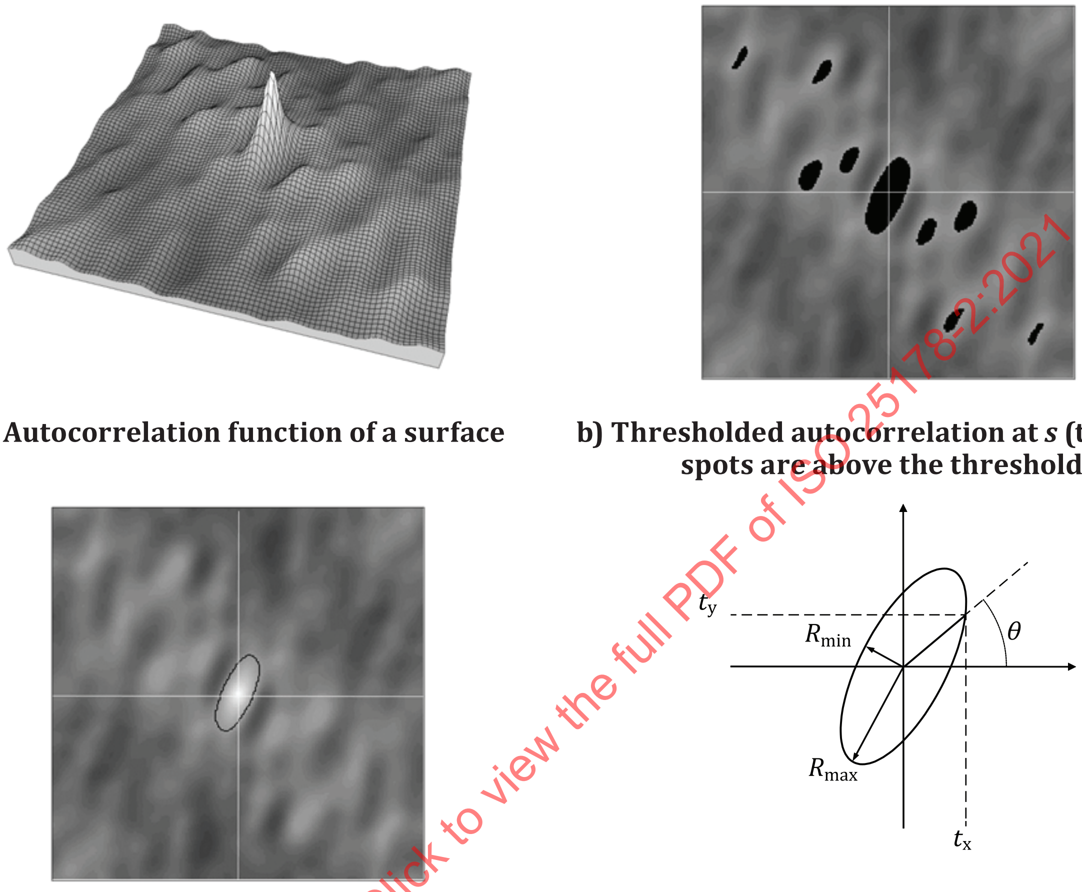
where

$$R = \left\{ (t_{\mathrm{x}},t_{\mathrm{y}}) : f_{ACF}(t_{\mathrm{x}},t_{\mathrm{y}}) \leq s \right\}$$

NOTE 1 If not otherwise specified, the default value of *s* is found in ISO 25178-3.

NOTE 2 A graphical representation of the procedure to calculate Sal is given in Figure 10.

$$S_{al} = R_{min} \quad (15)$$



a) Autocorrelation function of a surface

b) Thresholded autocorrelation at *s* (the black spots are above the threshold)

c) Threshold boundary of the central threshold portion

d) Polar coordinates leading to the autocorrelation lengths in different directions

NOTE The central lobe of the thresholded autocorrelation may be of any shape and is not always an ellipse.

Figure 10 — Procedure to calculate Sal and Str

4.3.3 Texture aspect ratio

Str

The texture aspect ratio parameter is the ratio of the horizontal distance of the $f_{ACF}(t_x, t_y)$ which has the fastest decay to a specified value s to the horizontal distance of the $f_{ACF}(t_x, t_y)$ which has the slowest decay to s, with $0 \le s < 1$. It is calculated according to Formula (16) or (17).

$$S_{tr} = \frac{R_{min}}{R_{max}} \quad (16)$$

$$S_{tr} = \frac{\min\limits_{t_x, t_y \in R} \sqrt{t_x^2 + t_y^2}}{\max\limits_{t_x, t_y \in Q} \sqrt{t_x^2 + t_y^2}} \quad (17)$$

where

$R = \{ (t_x, t_y) : f_{ACF}(t_x, t_y) \leq s \}$

$Q = \{ (t_x, t_y) : f_{ACF}(t_x, t_y) \geq s \}$

NOTE 1 If not otherwise specified, the default value of s is found in ISO 25178-3.

NOTE 2 A graphical representation of the procedure to calculate Str is given in Figure 10.

4.3.4 Texture direction

Std

The texture direction parameter is the angle of the absolute maximum value of the angular amplitude density, with respect to a reference direction θ_{ref}.

NOTE Setting $\theta = S_{td}$ maximizes the absolute value of the $f_{AAD}(\theta)$ function.

4.3.5 Dominant spatial wavelength

Ssw

The dominant spatial wavelength parameter is the wavelength which corresponds to the largest absolute value of the Fourier transformation of the ordinate values.

NOTE 1 This parameter might not be applicable to surfaces lacking significant periodicity.

NOTE 2 It is also possible to use the areal power spectral density to find the dominant spatial wavelength.

NOTE 3 This parameter is adapted from ISO 21920-2.

4.4 Hybrid parameters

4.4.1 General

All hybrid parameters are defined over the evaluation area $\tilde{A}$.

4.4.2 Root mean square gradient

Sdq

The root mean square gradient parameter is the square root of the mean square of the surface gradient of the scale-limited surface. It is calculated according to Formula (18).

$$S_{dq} = \sqrt{\frac{1}{A}\iint_{\tilde{A}} \left[\left(\frac{\partial z(x,y)}{\partial x} \right)^2 + \left(\frac{\partial z(x,y)}{\partial y} \right)^2 \right] dxdy} \tag{18}$$

NOTE See Annex D for implementation details.

4.4.3 Developed interfacial area ratio

Sdr

The developed interfacial area ratio parameter is the ratio of the increment of the interfacial area of the scale-limited surface over the evaluation area. It is calculated according to Formula (19).

$$S_{dr} = \frac{1}{A}\iint_{\tilde{A}} \left(\sqrt{\left[1 + \left(\frac{\partial z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial z(x,y)}{\partial y}\right)^2\right]} - 1 \right) dxdy \tag{19}$$

NOTE See Annex D for implementation details.

4.5 Material ratio functions and related parameters

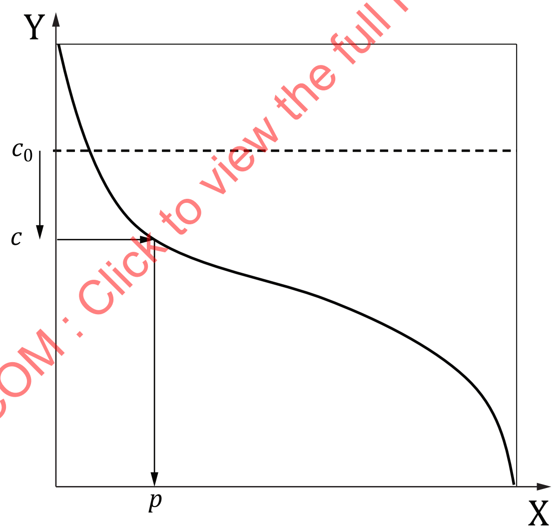
4.5.1 Areal material ratio

Smr(*c*)

The areal material ratio parameter is the material ratio *p* of the area of the material at a specified height *c* to the evaluation area. The height *c* is taken from the reference height c_0. See Figure 11. The reference height is defined by default at the highest point but may be set to other heights by stating it explicitly (see ISO 25178-1).

NOTE 1 Smr is usually expressed as a percentage.

NOTE 2 The reference height c_0 is specified either in height or through a material ratio *q* (in that case, c_0 = Smc(*q*)).



Key

X areal material ratio

Y height

c cutting height

p material ratio at cutting height *c*

c_0 reference height

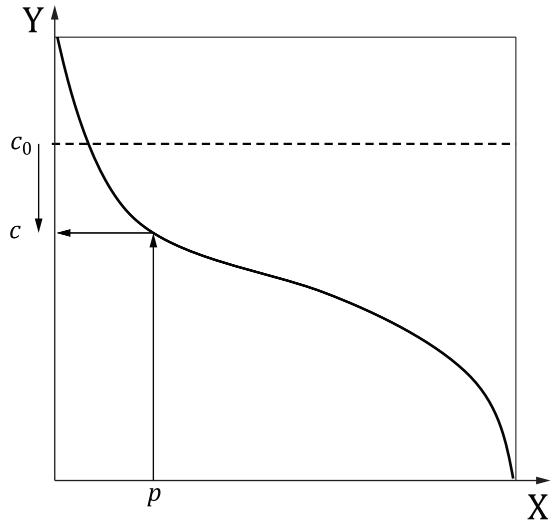
Figure 11 — Areal material ratio

4.5.2 Inverse areal material ratio

Smc(*p*)

The inverse areal material ratio parameter is the height c at which a given areal material ratio p is satisfied.

NOTE The height c is taken from the reference height c_0. See Figure 12.



Key

X areal material ratio

Y height

c cutting height at material ratio p

p material ratio

c_0 reference height

Figure 12 — Inverse areal material ratio

4.5.3 Material ratio height difference

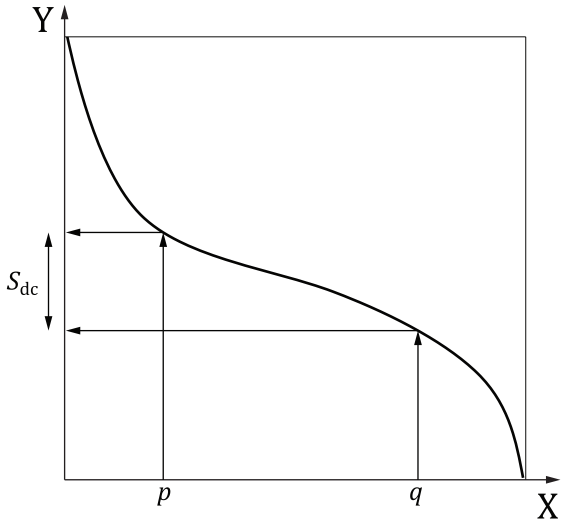
Sdc

The material ratio height difference parameter is the difference in height between the p and q material ratio. It is calculated according to Formula (20).

$$S_{dc} = S_{mc}(p) - S_{mc}(q) \tag{20}$$

where $p < q$.

NOTE The default values of p and q are found in ISO 25178-3. See Figure 13.



Key

X areal material ratio

Y height

p material ratio

q material ratio

S_{dc} material ratio height difference

Figure 13 — Material ratio height difference

4.5.4 Areal parameter for stratified surfaces

4.5.4.1 General

The following parameters are calculated on scale-limited stratified functional surfaces. See Annex B for details on the graphical calculation on the Abbott curve.

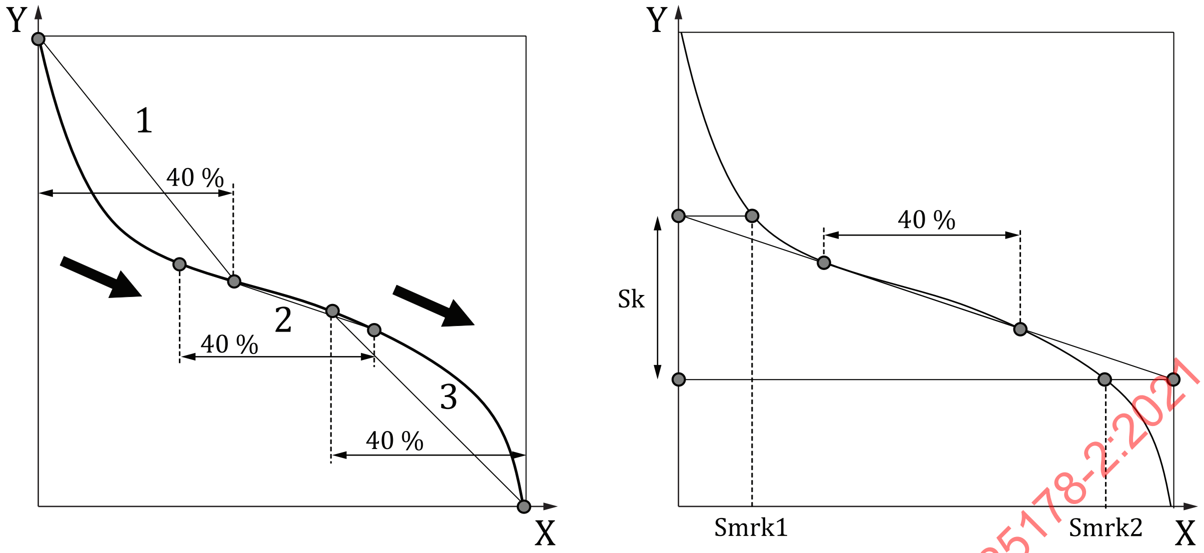
NOTE See Reference [48] for the definition of stratified surface.

4.5.4.2 Core height

Sk

The core height parameter is the distance between the highest and lowest level of the core surface.

NOTE See Figure 14 and Annex B.1 for explanations on the procedure of defining the position of the equivalent straight line.



Key

X	areal material ratio
Y	intersection line position
1, 3	secants
2	secant with smallest gradient
Sk	core height
Smrk1, Smrk2	material ratios

Figure 14 — Calculation of Sk, Smrk1 and Smrk2

4.5.4.3 Reduced peak height

Spk

The reduced peak height parameter is the height of the protruding peaks above the core surface after the reduction process.

NOTE The reduction process described in Annex B reduces the effect of outlier values on this parameter.

4.5.4.4 Maximum peak height

Spkx

The maximum peak height parameter is the height of the protruding peaks above the core surface before the reduction process.

4.5.4.5 Reduced pit depth

Svk

The reduced pit height parameter is the depth of the protruding pits below the core surface after the reduction process.

NOTE The reduction process described in Annex B reduces the effect of outlier values on this parameter.

4.5.4.6 Maximum pit depth

Svkx

The maximum pit depth parameter is the depth of the protruding pits below the core surface before the reduction process.

4.5.4.7 Material ratio of the hills

Smrk1

The material ratio of the hills parameter is the material ratio at the intersection line which separates the protruding hills from the core surface.

NOTE The ratio is expressed in per cent.

4.5.4.8 Material ratio of the dales

Smrk2

The material ratio of the dales parameter is the material ratio at the intersection line which separates the protruding dales from the core surface.

NOTE The ratio is expressed in per cent.

4.5.4.9 Area of the hills

Sak1

The area of the hills parameter is the area of the triangle obtained during the reduction process of the protruding hills. The height of the triangle is Spk and its base is Smrk1.

4.5.4.10 Area of the dales

Sak2

The area of the dales parameter is the area of the triangle obtained during the reduction process of the protruding dales. The depth of the triangle is Svk and its base is 100 % - Smrk2.

4.5.5 Areal material probability parameters

4.5.5.1 Dale root mean square deviation

Svq

The dale root mean square deviation parameter is the slope of a linear regression performed through the dale region.

NOTE Svq can thus be interpreted as the Sq-value, in micrometres, of the random process that generated the dale component of the surface. See H in Figure 15.

4.5.5.2 Plateau root mean square deviation

Spq

The plateau root mean square deviation parameter is the slope of a linear regression performed through the plateau region.

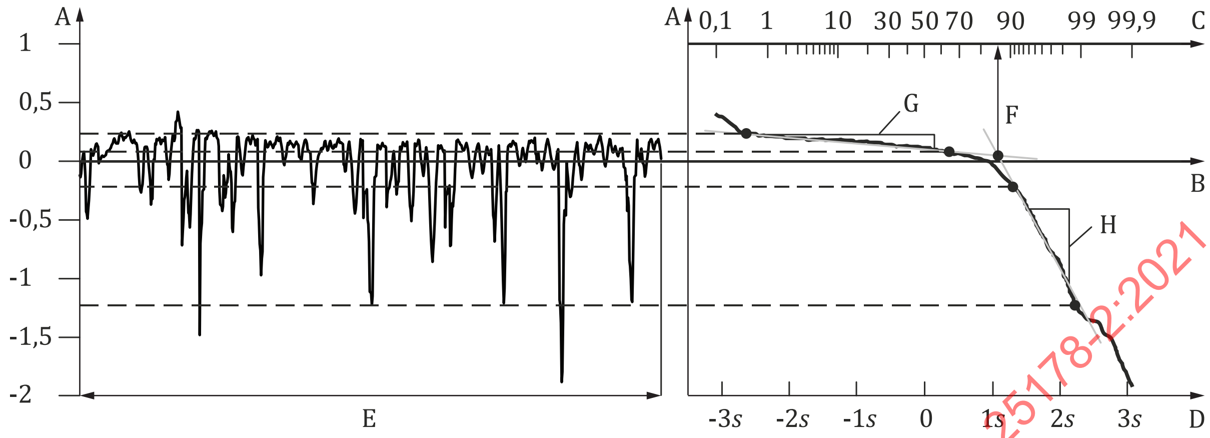
NOTE Spq can thus be interpreted as the Sq-value, in micrometres, of the random process that generated the plateau component of the surface. See G in Figure 15.

4.5.5.3 Plateau-to-dale material ratio

Smq

The plateau-to-dale material ratio parameter is the areal material ratio at the plateau-to-dale intersection.

NOTE The ratio is expressed in per cent. See F in Figure 15.



Key

A height

B reference line

C material ratio expressed as a Gaussian probability

D material ratio expressed as a Gaussian probability in standard deviation

E evaluation length

F Smq, relative material ratio at the plateau-to-dale intersection

G Spq, slope of a linear regression performed through the plateau region

H Svq, slope of a linear regression performed through the dale region

NOTE This figure shows a profile instead of a surface area for ease of illustration. The principle is the same for a surface area.

Figure 15 — Scale-limited surface with its corresponding areal material probability curve and the regions used in the definitions of the parameters Spq, Svq and Smq

4.5.6 Void volume

4.5.6.1 Void volume parameter

Vv(p)

The void volume parameter is the volume of the voids per unit area at a given material ratio p calculated from the areal material ratio curve. It is calculated according to Formula (21). See Figure 16.

$$V_v(p) = \frac{K}{100\ \%} \int_{p}^{100\ \%} \left(S_{mc}(p) - S_{mc}(q) \right) dq \qquad (21)$$

where

$p < q$

K is a constant to convert to millilitres per square metre or to micrometres cubed per square millimetre or equivalent.

4.5.6.2 Dale void volume

Vvv

The dale void volume parameter is the dale volume at p material ratio. It is calculated according to Formula (22). See Figure 16.

$$V_{vv} = V_v(p) \tag{22}$$

NOTE The default values of p can be found in ISO 25178-3.

4.5.6.3 Core void volume

Vvc

The core void volume parameter is the difference in void volume between the p and q material ratio. It is calculated according to Formula (23). See Figure 16.

$$V_{vc} = V_v(p) - V_v(q) \tag{23}$$

where $p < q$.

NOTE The default values of p and q are found in ISO 25178-3.

4.5.7 Material volume

4.5.7.1 Material volume parameter

Vm(p)

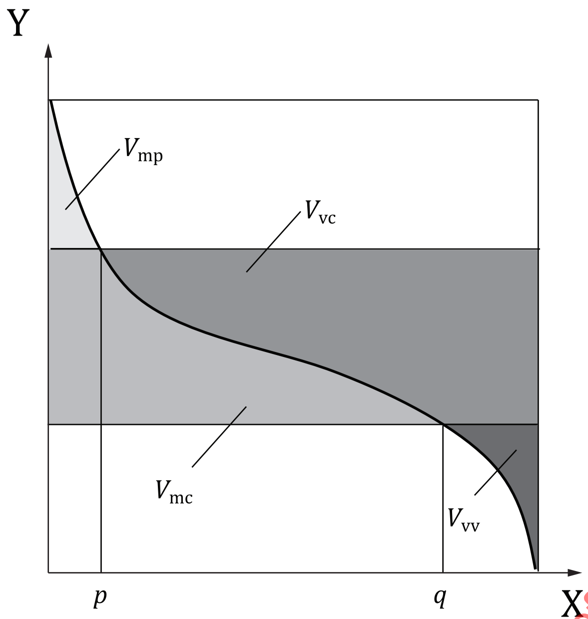
The material volume parameter is the volume of the material per unit area at a given material ratio p calculated from the areal material ratio curve. It is calculated according to Formula (24). See Figure 16.

$$V_m(p) = \frac{K}{100\ \%}\int_0^p [S_{mc}(q) - S_{mc}(p)]dq \tag{24}$$

where

$p < q$

K is a constant to convert to millilitres per square metre or to micrometre cube per square millimetre or equivalent.



Key

X areal material ratio

Y height

Figure 16 — Void volume and material volume parameters

4.5.7.2 Peak material volume

Vmp

The peak material volume parameter is the material volume at p material ratio. It is calculated according to Formula (25). See Figure 16.

$$V_{mp} = V_m(p) \tag{25}$$

NOTE The default value of p is found in ISO 25178-3.

4.5.7.3 Core material volume

Vmc

The core material volume parameter is the difference in material volume between the p and q material ratio. It is calculated according to Formula (26). See Figure 16.

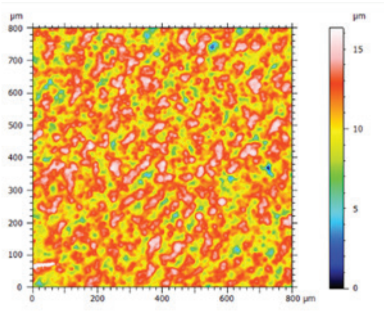
$$V_{mc} = V_m(q) - V_m(p) \tag{26}$$

where $p < q$.

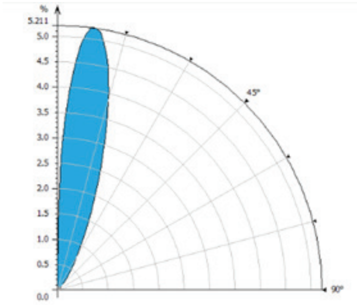
NOTE The default values of p and q are found in ISO 25178-3.

4.6 Gradient distribution

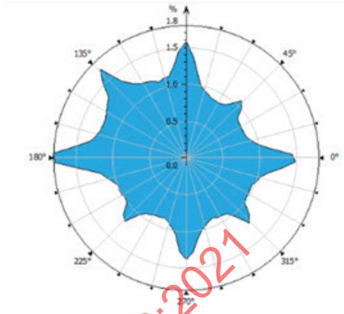
The gradient distribution is the density function calculated from the scale-limited surface showing the relative frequencies against the angle of the steepest gradient α (x, y) with respect to the z-axis and direction of the steepest gradient β (x, y) anticlockwise from the x-axis. It is sometimes called slope distribution. See Figure 17 for an example of the gradient distribution. See Figure 18 for the calculation of the steepest gradient α, and the direction of the steepest gradient β.



a) Example surface used in b) and c)

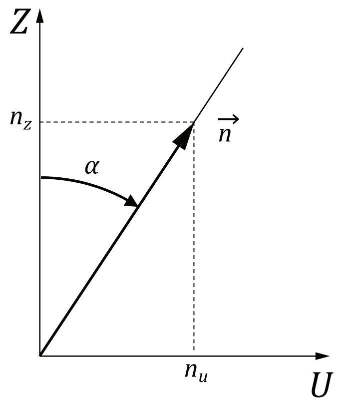


b) Polar graph of the steepest gradient, α, in degrees



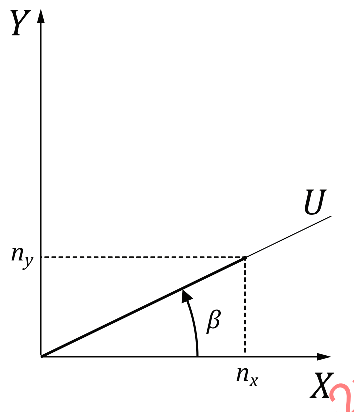
c) Polar graph of the direction of the steepest gradient, β, in degrees

Figure 17 — Example of gradient distribution



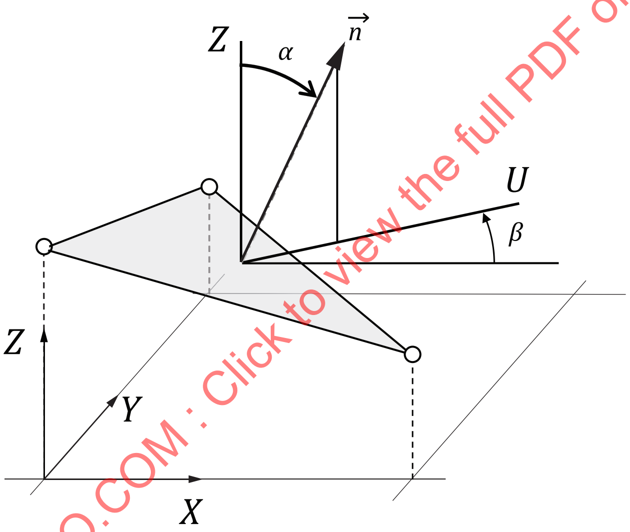
$$\alpha = \arctan\left(\frac{n_u}{n_z}\right) = \arctan\left(\frac{\sqrt{n_x^2 + n_y^2}}{n_z}\right)$$

a) Calculation of *α*



$$\beta = \arctan\left(\frac{n_y}{n_x}\right)$$

b) Calculation of *β*



c) Three-dimensional view

Key

$\vec{n}$ normal vector to the facet

U projection of $\vec{n}$ on the horizontal plane

Figure 18 — Gradient *α* calculated vertically with respect to the *z*-axis and gradient *β* calculated horizontally with respect to the *x*-axis

4.7 Multiscale geometric (fractal) methods

4.7.1 Morphological volume-scale function

Smvs(c)

This function plots the volume between a morphological upper envelope (closing) and lower envelope (opening) using a square horizontal flat as a structuring element, as a function of scales c representing the size of the structuring element. The volume-scale function is usually plotted as log(volume) in function of log(scale). The volume may be multiplied by a constant *K* to convert it to micrometres cubed per square millimetre. See Annex A.3 for further explanations.

4.7.2 Relative area

4.7.2.1 General

The relative area is the ratio of the area calculated by triangular tiling of fixed area *c* to the evaluation area. See Annex A.4 for the details on the area-scale tiling method.

4.7.2.2 Area-scale function

Sas(*c*)

This function plots the relative area as a function of scales *c*. It is usually plotted as log(relative area) in function of log(scale). The scale *c* represents the area of the triangular tiles and is expressed in units of lateral length squared.

4.7.3 Relative length

4.7.3.1 General

The relative area is the ratio of the length calculated by tiling of line segments of length *c* to the projected length *L*. The projected length *L* is usually smaller than the side of the surface. Length-scale can be calculated on each line or each column of a surface. It is then provided as the average of values calculated on lines or columns. See Annex A.5 for details of the length-scale tiling method.

4.7.3.2 Length-scale function

Sls(*c*)

This function plots the length-scale as a function of scales *c*. The length-scale function is usually plotted as log(relative length) in function of log(scale). The scale *c* represents the length of the line segment and is expressed in units of lateral length.

4.7.4 Scale of observation

The scale of observation is the size of the structuring element of the volume-scale function or area of the triangular tiles of the area-scale function or length of the line segment of the length-scale function.

4.7.5 Volume-scale fractal complexity

Svsfc

The volume-scale fractal complexity parameter is calculated by 1 000 times the slope of the volume-scale function, within a defined domain of scale of observation. The factor 1 000 is introduced to avoid too many zeros in the decimal value.

4.7.6 Area-scale fractal complexity

Sasfc

The area-scale complexity parameter is calculated by –1 000 times the slope of the area-scale function, within a defined domain of scale of observation. The factor 1 000 is introduced to avoid too many zeros in the decimal value.

4.7.7 Length-scale fractal complexity

Slsfc

The length-scale fractal complexity parameter is calculated by −1 000 times the slope of the length-scale function, within a defined domain of scale of observation. The factor 1 000 is introduced to avoid too many zeros in the decimal value.

4.7.8 Crossover scale

4.7.8.1 General

The crossover scale is the scale of observation at which there is a change in the slope of area-scale or volume-scale functions. Since the change in slope is not necessarily abrupt with respect to scale, a procedure is necessary for determining the scale at which the change takes place.

NOTE As a scale, it is given in unit of scale.

4.7.8.2 Smooth-rough crossover scale — Area-scale, length-scale

Ssrc(t)

The smooth-rough crossover scale parameter is the first crossover scale encountered going from relatively larger scales where the surface appears to be smooth to finer scales where the surface appears to be rough.

Starting from the largest scales, working towards the smallest, the first relative area or relative length to exceed the threshold t is used to determine the value of Ssrc. Ssrc is the scale above which the fractal dimension is approximately equal to the Euclidean dimension, and below which it is significantly greater than the Euclidean dimension. A threshold in relative area is used to determine the crossover in area-scale analyses (see Annex A).

The threshold t can be selected as a percentage p of the maximum value m of the area-scale or volume-scale function, as described in Formula (27).

$$t = 1 + p(m - 1) \tag{27}$$

NOTE The default value of the threshold is found in ISO 25178-3.

4.7.8.3 Smooth-rough crossover scale — Morphological volume-scale

Ssrc(t)

The smooth-rough crossover scale parameter is the first crossover scale encountered going from relatively smaller scales where the surface appears to be rough to larger scales where the surface appears to be smooth.

5 Feature parameters

5.1 General

Feature characterization does not have specific feature parameters defined but has instead a toolbox of pattern recognition techniques that can be used to characterize specified features on a scale-limited surface.

The feature characterization process is in five stages:

— selection of the type of texture feature (see Table 1);

— segmentation (see Table 2 for selection of criteria of size);

— determining significant features (see Table 3);

— selection of feature attributes (see Table 4);

— quantification of feature attribute statistics (see Table 5).

The surface depicted in Figure 19 is used as an illustrative example throughout this clause.

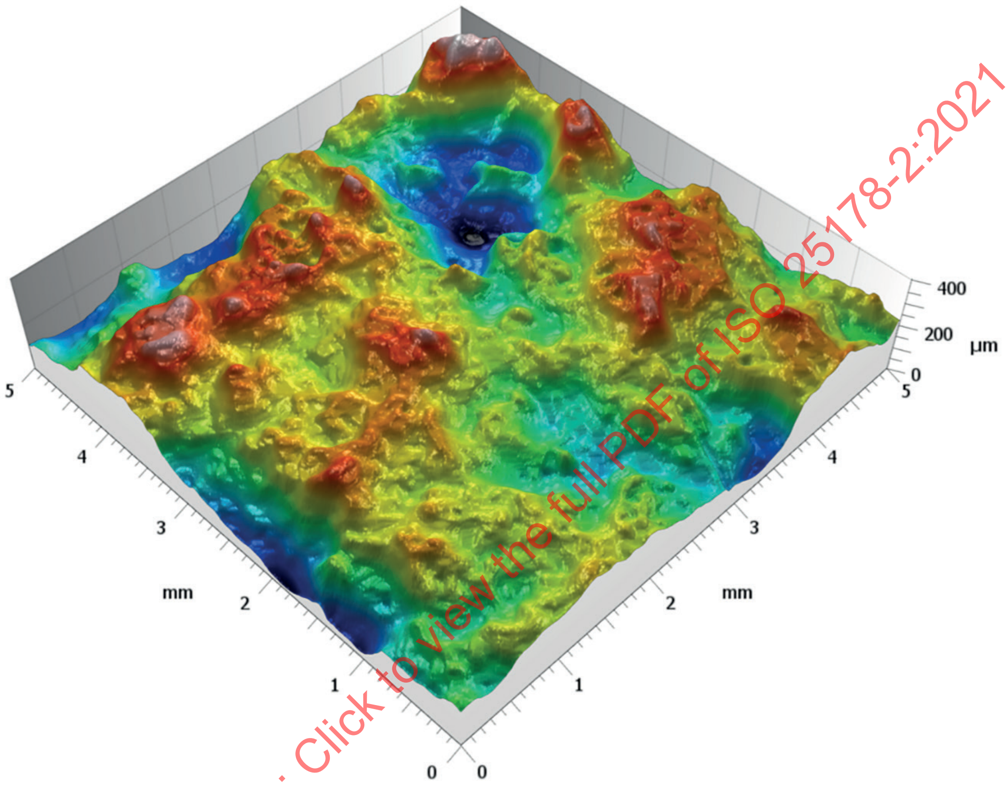


Figure 19 — Example of an illustrative surface

5.2 Type of texture feature

The three main types of texture features are areal features (hills and dales), line features (course and ridge lines) and point features (peaks, pits and saddle points); see Table 1. It is important to select the appropriate type of texture feature for the function of the surface under inspection.

Table 1 — Types of texture features

Class of feature	Type of texture feature	Designation
Areal	Hill	H
	Dale	D
Line	Course line	C
	Ridge line	R
Point	Peak	P
	Pit	V
	Saddle point	S

5.3 Segmentation

Segmentation is used to determine regions of the scale-limited surface which define the features. The segmentation process consists of first finding all of the hills and dales on the scale-limited surface. This usually results in over-segmentation of the surface and so the "smaller" segments are pruned out to leave a suitable segmentation of the scale-limited surface. Some criteria of size are given in Table 2, which can be used to define a threshold to define "small" segments to prune out.

An example of hills defined from Wolf pruning using 1 % or 5 % of Sz, using the surface illustrated in Figure 19, is given in Figure 20.

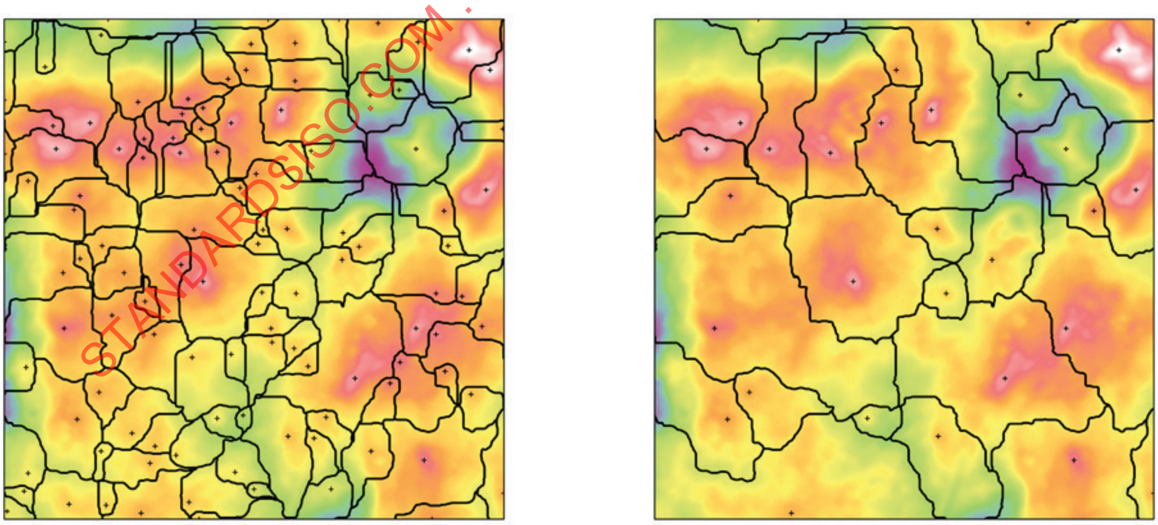
Table 2 — Criteria of size for segmentation

Criteria of size	Designation	Threshold
Hill local height/dale local depth (Wolf pruning)	Wolfprune	Specified height/depth or % of Sz
Volume of hill/dale	VolS	Specified volume
Area of hill/dale	AreaS	Specified area or % of evaluation area
Perimeter of hill/dale	PerS	Specified length

By default, a height discrimination is applied, but other pruning criteria, such as volume, area or even form factor or orientation, can also be used.

5.4 Determining significant features

"Function" does not interact with all features in the same way; different features interact differently. It is thus essential to distinguish those features that are functionally significant from those that are functionally insignificant. For each particular surface function, there needs to be a defined segmentation function which identifies the significant and insignificant features defined by the segmentation. It is the set of significant features that is used for characterization. Methods of determining significant features are given in Table 3. These are all segmentation functions.



a) 1 % of Sz

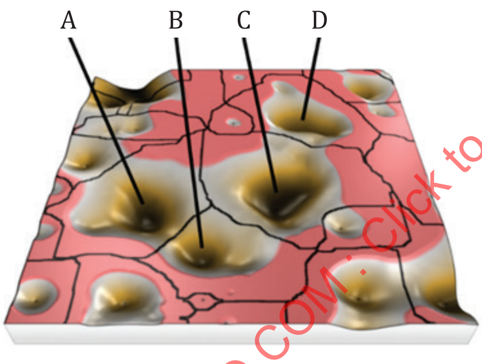
b) 5 % of Sz

Figure 20 — Hills defined from Wolf pruning

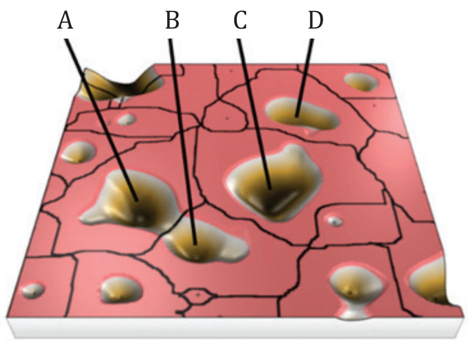
Table 3 — Methods of determining significant features

Class of feature	Method of determining significant features	Designation	Parameter units
Areal	Hill is significant if its course line is entirely below a horizontal plane at a given height, as if it was an island surrounded by water level[a]	Closed c	Height is defined from a material ratio or an absolute height
	Dale is significant if its ridge line is entirely above a horizontal plane at a given height, so fluid inside the dale cannot escape to an adjacent dale[a] [see Figure 21 b), features C and D]	Closed c	Height is defined from a material ratio or an absolute height
	Hill is significant if its highest saddle point is above a horizontal plane at a given height, as if two adjacent hills are connected above the water level[a]	Open c	Height is defined from a material ratio or an absolute height
	Dale is significant if its lowest saddle point is below a horizontal plane at a given height, so fluid inside the dale can circulate to an adjacent dale[a] [see Figure 21 a), features A and B]	Open c	Height is defined from a material ratio or an absolute height
Point	A peak is significant if it is one of the top N peak heights	Top	N is an integer
	A pit is significant if it is one of the top N pit depths	Bot	N is an integer
Areal, line, point	Use all of the features	All	—

[a] See Reference [47] and Figure 21.



a)



b)

NOTE 1 The thresholding plane is represented in rose colour. Its height is defined from a material ratio. Figure 21 a) and b) use a different threshold value.

NOTE 2 In Figure 21 a), A, B, C and D are open dales as they are connected by saddle points that are below the threshold.

NOTE 3 In Figure 21 b), A and B are still open, but C and D are closed dales.

Figure 21 — Open and closed dales

5.5 Section of feature attributes

Once the set of significant features has been determined, it is necessary to determine suitable feature attributes for characterization. Most attributes are a measure of size of the feature, for example length, area or volume of a feature. Some feature attributes are given in Table 4.

Table 4 — Feature attributes

Class of feature	Feature attributes	Designation
Areal	Local hill height/local dale depth	Hh/Dd
	Area of hill or dale	Ah/Ad
	Volume of hill or dale	Vh/Vd
	Open/closed local void volume of dale at penetration threshold c[a]	Vlvv
	Open/closed local material volume of hills at penetration threshold c[a]	Vlmv
	Roundness of hill or dale[b]	Mrn
	Form factor of hill or dale[b]	Mff
	Equivalent diameter of hill or dale[b]	Med
	Aspect ratio of hill or dale[b]	Mar
Line	Length of course line or ridge line	Lcr
Point	Peak height	Hp
	Pit depth	Hv
	Saddle point height	Hs
	Local mean curvature at critical point	Curvature
Areal, line, point	Attribute takes value of one	Count

[a] See Reference [31].

[b] These morphological features are explained in Reference [22]. They can be used on structured or textured surfaces to characterize the shape of printed motifs.

5.6 Attribute statistics

Calculation of a suitable statistic of the attributes of the significant features, a feature parameter or, alternatively, a histogram of attribute values is the final part of feature characterization. Some attribute statistics are given in Table 5.

Table 5 — Attribute statistics

Attribute statistic	Designation	Threshold
Arithmetic mean of attribute values	Mean	—
Maximum attribute value	Max	—
Minimum attribute value	Min	—
Standard deviation of attribute values	StdDev	—
Percentage above a specified value	Perc	Value of threshold in units of attribute
Histogram	Hist	—
Sum of attribute values	Sum	—
Sum of all the attribute values divided by the evaluation area	Density	—

NOTE In future editions of this document, it is anticipated that standardized methods of naming particular attribute statistics will be given.

5.7 Feature characterization convention

To record the feature characterization, it is necessary to indicate the particular tools used in each of the five steps. This can be achieved by using the following convention:

— Start with the letters FC (feature characterization) to indicate that this is a feature characterization.

— For each stage, in turn, use the designation from the appropriate table to indicate the tool required.

— Some stage tools require further values for completeness. Use the symbol “;” to delimit between each stage and a space to delimit within a stage.

— If a tool is not specified in this document, then a reference to the tool definition can be used instead.

EXAMPLE FC; D; Wolfprune 5 %; Open c 60 %; Ad; Hist.

NOTE See Tables 1 to 5 for explanations of the designations.

5.8 Named feature parameters

5.8.1 General

Each of the following subclauses contains a parameter (abbreviated term) and a symbol. Whereas abbreviated terms can contain multiple letters, symbols consist only of a single letter with subscripts as needed. Symbols are used in the formulae shown in this document. The reason for this differentiation is to avoid misinterpretation of compound letters as an indication of multiplication between quantities in formulae. The parameters (abbreviated terms) are used in product documentation, drawings and data sheets.

5.8.2 Density of peaks

Spd

The density of peaks parameter is the number of peaks per unit area. It corresponds to the following feature specification:

Spd = FC; P; Wolfprune X%; All; Count; Density

NOTE 1 See Tables 1 to 5 for explanations of the designations.

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

5.8.3 Density of pits

Svd

The density of pits parameter is the number of pits per unit area. It corresponds to the following feature specification:

Svd = FC; V; Wolfprune X%; All; Count; Density

NOTE 1 See Tables 1 to 5 for explanations of the designations.

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

5.8.4 Arithmetic mean peak curvature

Spc

The arithmetic mean peak curvature parameter is the mean of the local mean curvature of peaks. It corresponds to the following feature specification:

Spc = FC; P; Wolfprune X%; All; Curvature; Mean

NOTE 1 See Tables 1 to 5 for explanations of the designations.

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

5.8.5 Arithmetic mean pit curvature

Svc

The arithmetic mean pit curvature is the mean of the local mean curvature of pits. It corresponds to the following feature specification:

Svc = FC; V; Wolfprune X%; All; Curvature; Mean

NOTE 1 See Tables 1 to 5 for explanations of the designations.

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

5.8.6 Five-point peak height

S5p

The five-point peak height parameter is the mean of the five largest peak heights. It corresponds to the following feature specification:

S5p = FC; P; Wolfprune X%; Top 5; Hp; Mean

NOTE 1 See Tables 1 to 5 for explanations of the designations.

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

NOTE 3 If less than five significant peaks are found, then the average is done on the available significant peaks.

5.8.7 Five-point pit depth

S5v

The five-point pit depth parameter is the mean of the five largest pit depths. It corresponds to the following feature specification:

S5v = FC; V; Wolfprune X%; Bot 5; Hv; Mean

NOTE 1 See Tables 1 to 5 for explanations of the designations.

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

NOTE 3 If less than five significant pits are found, then the average is done on the available significant pits.

5.8.8 Ten-point height

S10z

The 10-point height parameter is the sum of the five-point peak height and the five-point pit depth, as shown in Formula (28).

$$S_{10z} = S_{5p} + S_{5v} \tag{28}$$

5.9 Additional feature parameters

5.9.1 General

Table 4 defines many characteristics that can be combined with statistical attributes defined in Table 5. This leads to many parameters that can be specified using the FC specification line. However, for simplicity, Table 6 provides a set of parameters that can be used directly in specification.

Table 6 — Named features parameters

Type of texture feature	Attribute statistics	Local height/ local depth (Hh/Hd)	Area (Ah/Ad)	Volume (Vh/Vd)	Count
Hill	mean	Shh	**Sha**	**Shv**	Shn
	max	Shhx	Shax	Shvx	
	StdDev	Shhq	Shaq	Shvq	
Dale	mean	Sdd	**Sda**	**Sdv**	Sdn
	max	Sddx	Sdax	Sdvx	
	StdDev	Sddq	Sdaq	Sdvq	

Naming rules: parameters start with an upper-case S, followed by *h* for hills or *d* for dales, followed by *h* for height, *d* for depth, *a* for area, *v* for volume or *n* for count.

Parameters shown in bold font in Table 6 correspond to names parameters in the previous version of this document (ISO 25178-2:2012).

Shn and Sdn give the number of hills or dales. The other parameters are calculated as arithmetic means of the characteristic on all motifs, except when the name finishes with an *x*, which stands for "max" (maximum of the characteristic), or with a *q*, which stands for standard deviation. For example, Sda is the mean area of dales and corresponds to the following feature specification line:

Sda(*c*) = FC; D; Wolfprune X%; Open *c*/Closed *c*; Ad; Mean

Shhx is the maximum local height of all hills and corresponds to the following feature specification line:

Shhx(*c*) = FC; H; Wolfprune X%; Open *c*/Closed *c*; Hh; Max

NOTE 1 See Tables 1 to 5 for explanations of the designations. "Open:*c*/Closed:*c*" provides the user with a choice of either "open at height *c*" or "closed at height *c*".

NOTE 2 If not otherwise specified, the default value of X% is found in ISO 25178-3.

NOTE 3 If not otherwise specified, the default value of Open/Closed is found in ISO 25178-3.

5.9.2 Shape parameters

5.9.2.1

Additional parameters can be calculated in the horizontal plane to characterize the shape of the texture motif (See Table 7).

Table 7 — Named shape parameters

Type of texture feature	Attribute statistics	Roundness	Form factor	Equivalent diameter	Aspect ratio
Hill	mean	Shrn	Shff	Shed	Shar
	max	Shrnx	Shffx	Shedx	Sharx
	StdDev	Shrnq	Shffq	Shedq	Sharq
Dale	mean	Sdrn	Sdff	Sded	Sdar
	max	Sdrnx	Sdffx	Sdedx	Sdarx
	StdDev	Sdrnq	Sdffq	Sdedq	Sdarq

5.9.2.2 Motif roundness

The roundness parameter is calculated by the ratio of the motif horizontal area A_m to the area of a circle with a diameter equal to the maximum diameter. A round object will give a value of 1 and an oblong object will give a value less than 1. The M_{RN} parameter is given by Formula (29).

$$M_{RN} = \frac{4A_m}{\pi D_{max}^2} \tag{29}$$

where

A_m is the motif horizontal area;

D_{max} is the maximum diameter.

NOTE M_{RN} has no units.

5.9.2.3 Motif form factor

The form factor M_{FF} evaluates the compacity of the shape (the filled volume fraction). An elongated object will give a value close to zero while a compact object will give a value close to 1. The M_{FF} parameter is given by Formula (30).

$$M_{FF} = \frac{4\pi A_m}{\Pi^2} \tag{30}$$

where

A_m is the motif horizontal area;

Π is the perimeter.

NOTE M_{FF} has no units.

5.9.2.4 Motif equivalent diameter

The equivalent diameter M_{ED} is the diameter of the circle of the same area as the motif, given by Formula (31).

$$M_{ED} = \sqrt{\frac{4A_m}{\pi}} \tag{31}$$

where

A_m is the motif horizontal area.

NOTE M_{ED} is given in units of length (mm or µm).

5.9.2.5 Motif aspect ratio

The aspect ratio M_{AR} is the ratio of the maximum diameter to the minimum diameter, as given by Formula (32). It discriminates between compact and oblong motifs. For example, in the case of a disc, $M_{AR} = 1$. In the case of an oblong motif, its value is greater than 1.

$$M_{AR} = \frac{D_{max}}{D_{min}} \tag{32}$$

where

D_{max} is the maximum diameter;

D_{min} is the minimum diameter.

NOTE M_{AR} has no units.

Annex A
(informative)

Multiscale geometric (fractal) methods

A.1 What is a fractal?

A fractal is an object that looks approximately the same over a range of scales or magnification, i.e. the object should be statistically self-similar, see Figure A.1. The object need not exhibit exactly the same structure at all scales, but the same "type" of structures appear over a range of scales.

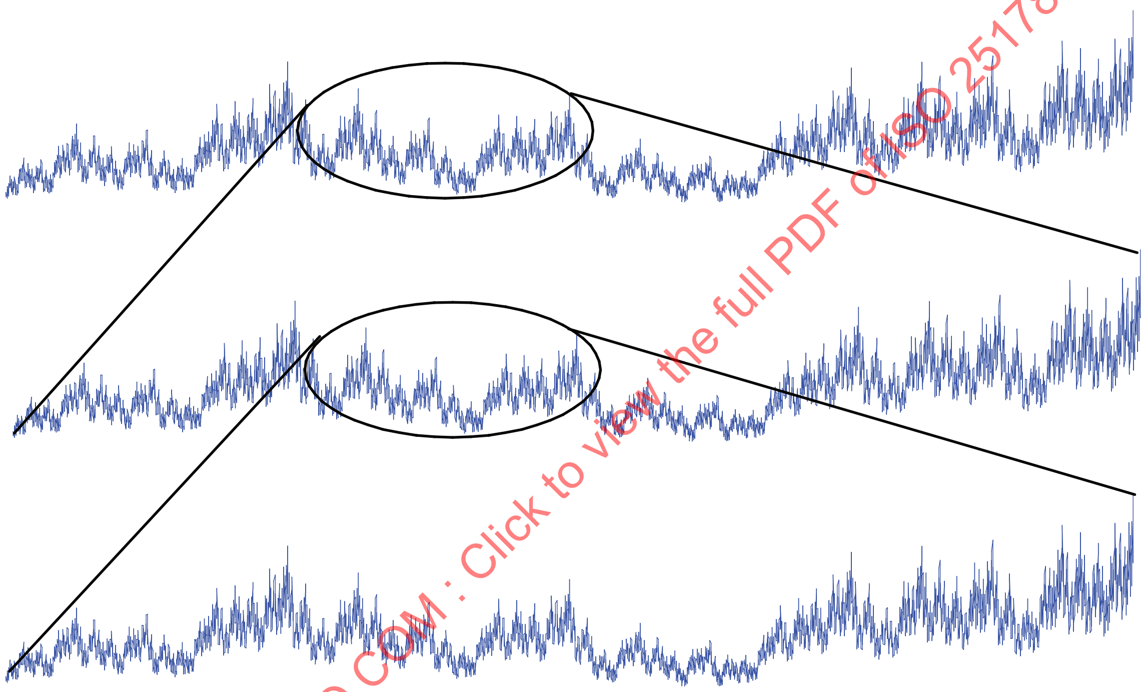


Figure A.1 — Fractal profile showing the same structures at all scales

In general, a "fractal dimension" can be calculated from a fractal surface using several methods[32][33], including the variation method[34] and relative area analysis[35]. The latter has proved to be capable of providing parameters that support strong functional correlations with adhesion[36], electrochemical impedance[37], friction[38], gloss[39], good differentiation of dental microwear[40], grinding conditions[41], mass transfer during heat treatment[42] and powder compacts[43].

The fractal dimension is a measure of the geometric complexity or intricacy components of a fractal or partially fractal surface. The fractal dimension increases with increasing complexity. The fractal dimension is greater than or equal to the Euclidian dimension, i.e. greater than or equal to one and less than two for a profile, and greater than or equal to two and less than three for a surface.

Real surfaces are partially fractal, in that they can be characterized, approximated or modelled as having irregular geometric components over a range of scales of observations. Ideal fractal surfaces are mathematical models that have irregular components at all scales of observation.

Periodic and quasi-periodic geometric components of a surface do not exclude that surface from having fractal components or from being advantageously characterized by fractal analysis.

A.2 Variation methods

Let $F(c)$ be, for example, the volume between a morphological closing envelope and a morphological opening envelope of the fractal surface by a square horizontal flat structuring element with scale c (c by c).

Then, providing the limit exists, the fractal dimension D_v can be defined for the morphological volume-scale method as in Formula (A.1):

$$D_\mathrm{v} = \lim_{c \to +0} \left\{ 3 - \frac{d\left[log_e\left(F(c)\right)\right]}{d\left[log_e(c)\right]} \right\} \tag{A.1}$$

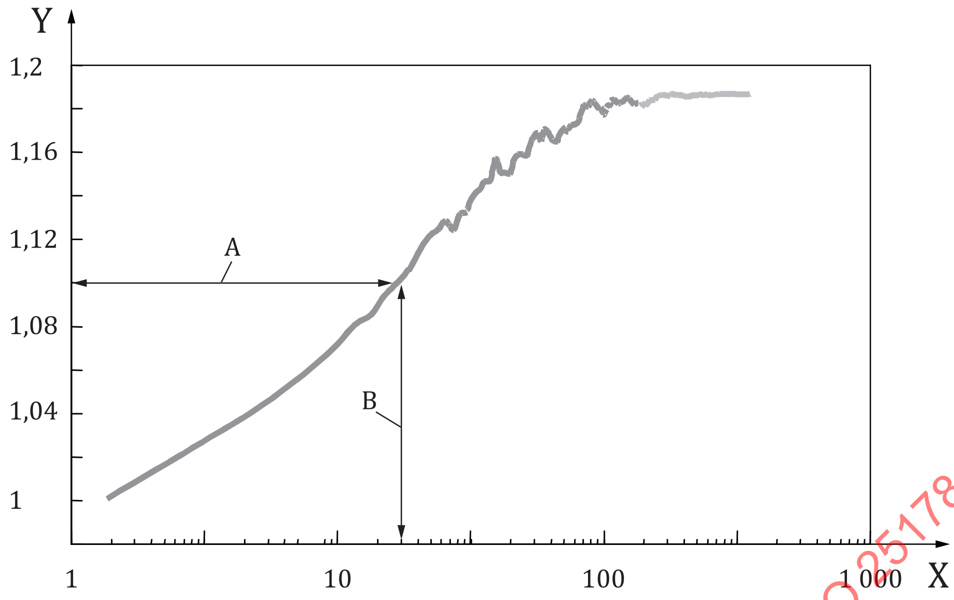
The fractal dimension calculated using the variation method is equivalent to the Minkowski-Bouligand dimension. It has been shown[34] that the variation method has the lowest uncertainty of all current methods to calculate a fractal dimension. The fractal dimension of a surface is greater than or equal to two and is an indication of how complex a fractal surface is. The higher the fractal dimension, the more complicated or irregular the fractal surface is.

Similar reasoning can be applied with other methods and quantities calculated in function of scale.

A.3 Variational method applied to scale-limited surfaces

In a strict mathematical sense, scale-limited surfaces are not true fractal surfaces since they have been deliberately smoothed at some defined scale and so do not contain “the same type of structures *at all scales*”. Scale-limited surfaces may, however, display “fractal-type behaviours” over a range of scales. The volume-scale plot, see Figure A.2, is very useful in capturing some of these behaviours over the observable range of scales.

A graph is set to represent the log of the calculated quantity, in function of the log of the scale. Figure A.2 shows an example with the morphological volume-scale plot Smvs(c), which is a plot of the log of the volume between a morphological closing envelope and a morphological opening envelope of the scale-limited surface using a square horizontal flat as a structuring element against log-scale of the structuring element.



Key

X log(scale)
Y log(volume)
A scale
B volume

Figure A.2 — Morphological volume-scale plot of a scale-limited surface

Most plots of scale-limited surfaces will display several regions where the curve is approximately a straight line. In each of these particular regions, the relationship between the scale *c* and the calculated quantity takes the form of a power law.

For example, for the morphological volume-scale function, Smvs is calculated at scale *c* according to Formula (A.2):

$$S_{\mathrm{mvs}}(c) = k \cdot c^{d} \tag{A.2}$$

This is a power law because the volume $S_{mvs}(c)$ changes as if it were a power of scale *c*. The slope of the straight line, on the volume-scale plot, is just the exponent *d* and its volume-intercept is *log(k)*.

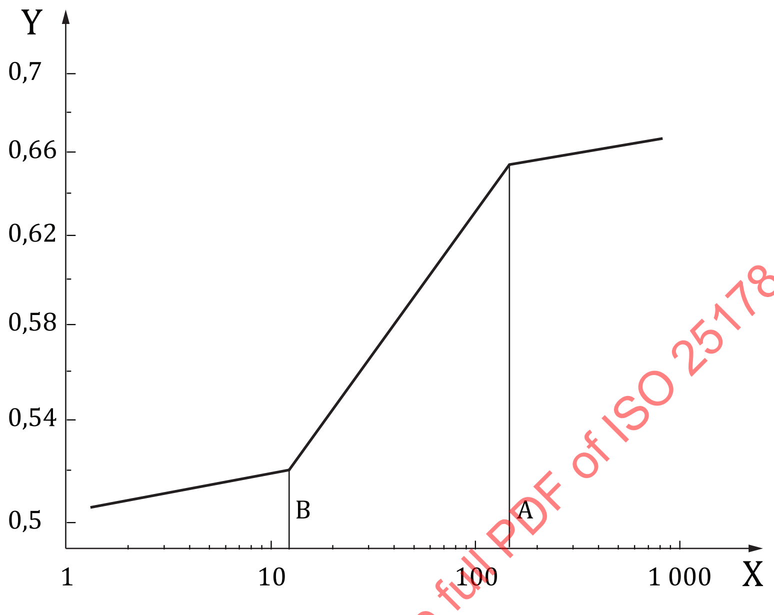
For another example, the relative area-scale Sas is calculated at scale *c* according to Formula (A.3):

$$S_{\mathrm{as}}(c) = k' \cdot c^{-d'} \tag{A.3}$$

which shows a negative slope, meaning that the graph is decreasing in function of scale.

Over those ranges of scales where a particular power law is valid (i.e. over the corresponding region of the plot where the curve is approximately a straight line), the scale-limited surface will display self-similarity (i.e. portions of the surface when enlarged by a suitable amount will look like the original surface). Hence, the scale-limited surface, over these particular ranges of scales, is approximately a fractal surface with an associated fractal dimension. Thus, the steeper the slope of the plot, the more complicated the surface is for that particular range of scales.

As mentioned previously, most plots will display several regions where the curve is approximately a straight line. The scale where there is a change in slope from one region approximated by a straight line to another is called a “crossover scale”. In practice, this can be a gradual change and so a procedure is necessary for determining the scale at which this change takes place. The identification of crossover scales is important because they indicate a change in the dominant mechanism affecting the scale-limited surface and/or measurement procedure. An example is shown in Figure A.3. Going from relative larger scales, where the slope is near zero, to smaller scales, where the slope is steeper, the first crossover scale indicates a change from a relative smooth surface at larger scales to a rougher surface at smaller scales. Hence, above this first crossover scale, this particular scale-limited surface can be considered smooth.



Key

X log(scale)

Y log(volume)

A smooth-rough crossover scale

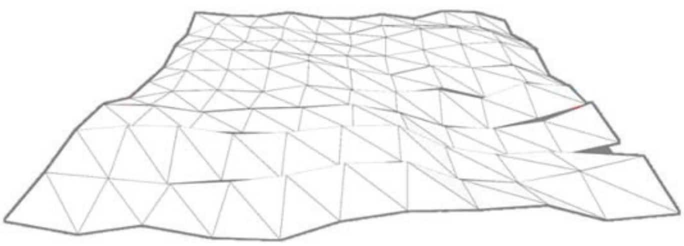
B second crossover scale

Figure A.3 — Idealized morphological volume-scale plot showing crossover scales

A.4 Area-scale analysis

The area-scale analysis consists in covering the surface with tiles of a given scale (its area) and calculating the ratio of the total area of the tiles to their projected area.

The observed area of a measured surface is calculated as a function of scale by a series of virtual tiling exercises covering the measured surface in a patchwork fashion[35][45]. The areas of the tiles, or patches, represent the areal scales of observation. The tiling exercises are repeated with tiles of progressively smaller areas to determine the observed areas as a function of the areal scales of observation (Figure A.4)[45].



Scale = 5 000 μm^2

Number of tiles = 180

Observed area = 899 995 μm^2

Relative area Sas = 1,034 9

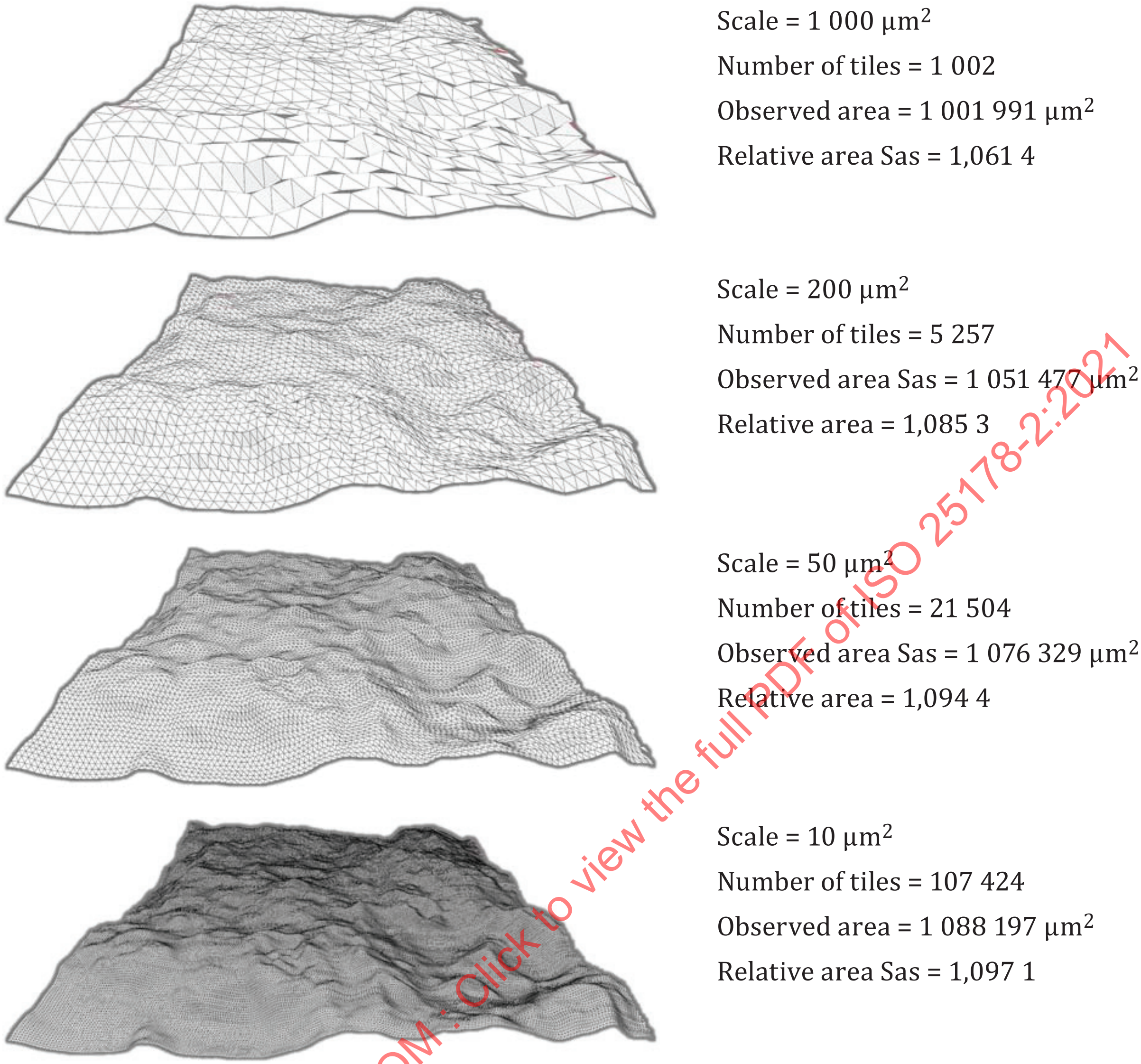


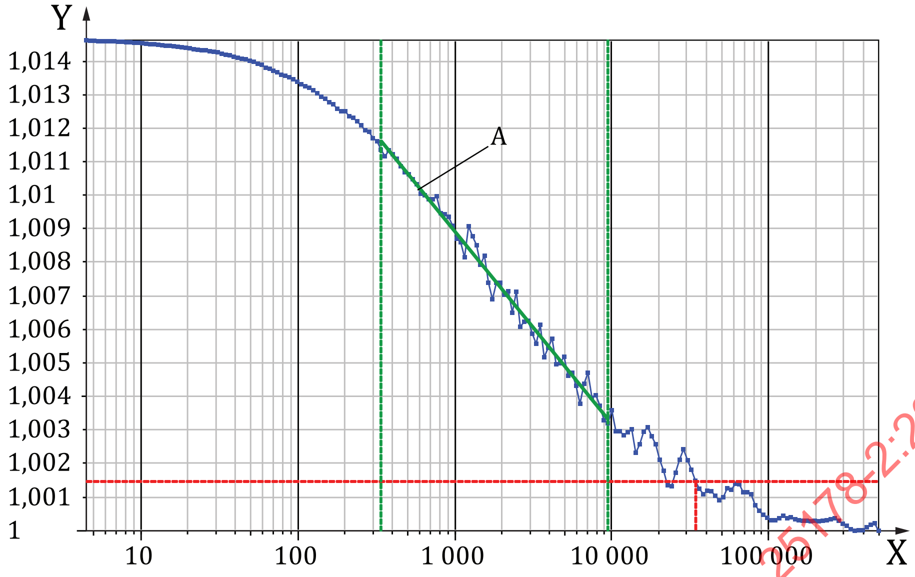
Figure A.4 — Five tiling exercises from a relative area analysis

The observed area is the number of tiles, or patches, for one virtual tiling exercise times the area of the tile or patch (scale of observation). For example, at scale 5 000 µm^2, the observed area is 180 tiles × 5 000 µm^2 = 900 000 µm^2 (in fact here 899 995 due to rounding errors). The observed area is the apparent area at a particular scale of observation and is referenced to that scale, as the observed area changes with the scale of observation. The nominal area is the area of an individual tiling exercise projected onto the nominal surface, i.e. the area on the nominal surface covered by the tiling exercise. The least squares plane or the measurement datum can be used for the nominal surface. The nominal area is usually lower than the horizontal area of the full surface, as there is missing space at the end of each line, when there is not enough space for a tile. The relative area Sas is the observed area at a particular scale divided by the nominal area[36][45]. Consequently, the minimum relative area is 1,0.

An area-scale plot Sas(c) is a log-log plot of the relative area in function of areal scales of observation (Figure A.5). The fractal dimension, D_v, over some scale range can be calculated from the slope, a, of the relative area plot as:

$$D_v = 2 - 2a \tag{A.4}$$

which can be shown to be derivable from Formula (A.4).



Key

X scale *c* of observation on a log scale

Y relative area Sas(*c*) (on a log scale)

A slope

NOTE In the above example, the fractal dimension D_v is 2,005 and the slope *a* is −0,002 48.

Figure A.5 — Relative area plot including the results of the tiling series in Figure A.4

A.5 Length-scale analysis

When measuring the curvilinear length of a profile (or surface line) with a line-segment, this length depends on the size of the line-segment. The shorter the line-segment, the longer the length. If the length is divided by the horizontal length, it gives the relative length of the profile at a given scale (the size of the line-segment).

On a surface, the length-scale analysis is applied on all lines or on all columns. It is then provided as the average of relative length values calculated on lines or columns.

In Figure A.6, a first measure is done with a line segment of size 5 mm. Five segments are used over a horizontal length of 24,94 mm, leading to a relative length of 1,002 4. A second measure with a line-segment of size 2,5 mm allows 12 segments over a horizontal length of 25,06 mm, leading to a relative length of 1,197 1.

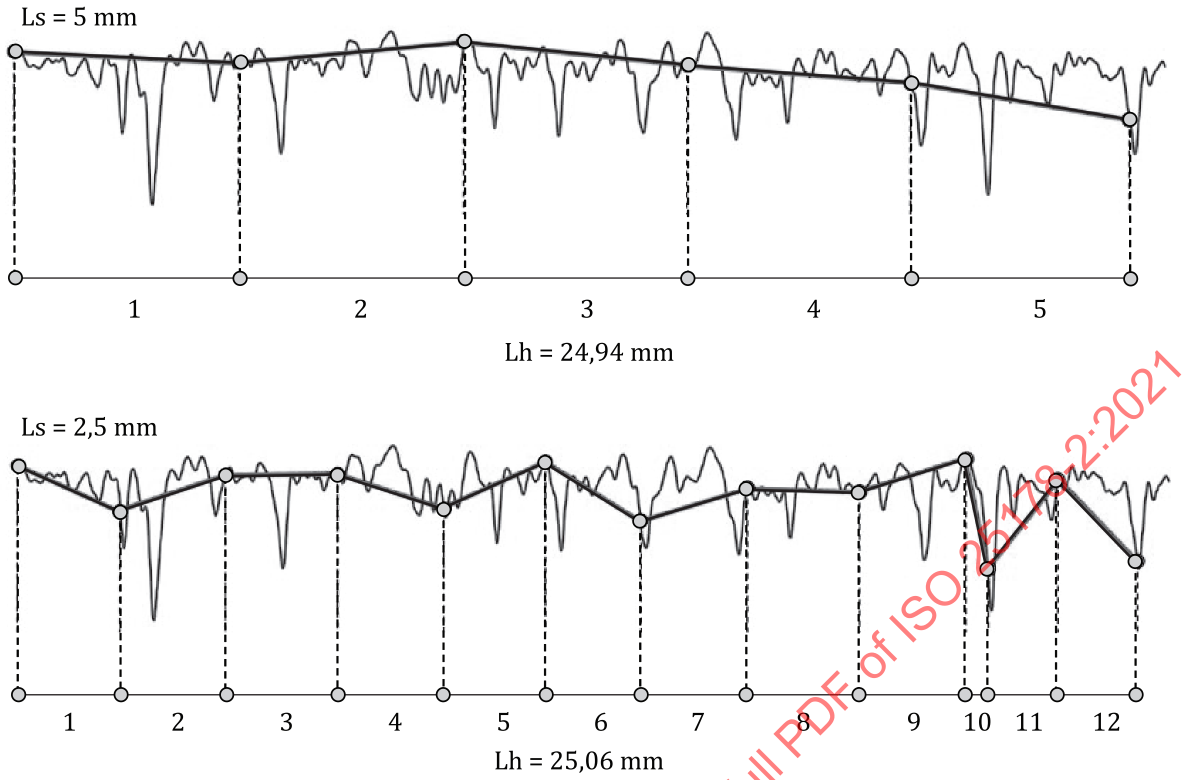


Figure A.6 — Calculation of relative length on a profile for two segment lengths

A plot of the log of the relative length Sls(c) as a function of the log of scale c is drawn, and similar parameters are calculated as in the area-scale case.

Annex B
(informative)

Determination of areal parameters for stratified functional surfaces

B.1 Calculating the equivalent straight line

The equivalent straight line is calculated for the central region of the areal material ratio curve which includes 40 % of the measured surface points. This "central region" lies where the secant of the areal material ratio curve over 40 % of the areal material ratio shows the smallest gradient (see Figure 14). This is determined by moving the secant line for ΔM_r = 40 % along the areal material ratio curve, starting at material ratio p = 0 % position as in Figure 14. The secant line for ΔM_r = 40 % which has the smallest gradient establishes the "central region" of the areal material ratio curve for the equivalence calculation. If there are multiple regions which have equivalent minimum gradients, then the region that is first encountered is the region of choice. A straight line is then calculated for this "central region" which gives the least square deviation in the direction of the surface ordinates.

To ensure the validity of the areal material ratio curve, the class widths of ordinates of the scale-limited surface should be selected to be small enough for at least 10 classes to fall within the "central region". With surfaces having an almost ideal geometrical plateau, such a fine classification may no longer be meaningful, because of the limited resolution of the measuring system. In this case, the number of classes used in the calculation of the equivalent straight line should be stated in the test results.

B.2 Calculating the parameters Sk, Smrk1 and Smrk2

The equivalent straight line intersects the 0 % and 100 % lines on the Smr axis (see Figure 14). From these points, two lines are plotted parallel to the x-axis; these determine the core surface by separating the protruding hills and dales.

The vertical distance between these intersection lines is the core height Sk. Their intersections with the areal material ratio curve define the material ratios Smrk1 and Smrk2.

B.3 Calculating the parameters Spk and Svk

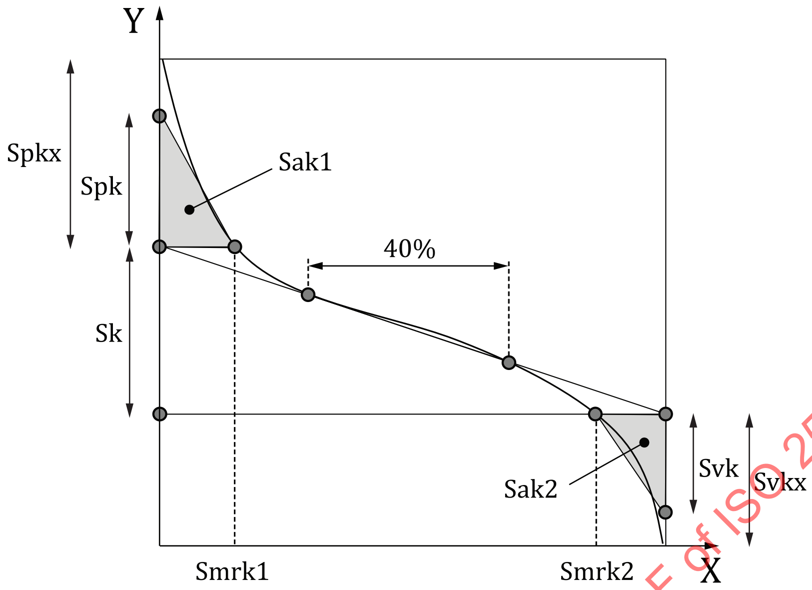
The areas above and below the central region which delimits the core height Sk are shown hatched in Figure B.1. These correspond to the cross-sectional area of the surface hills and dales which protrude out of the core surface.

The area enclosed between the material ratio curve and the ordinate axis on the left, above the left intersection point, is called Sak1. A right-angled triangle is constructed so that its area equals the hill area Sak1. Its horizontal base corresponds to Smrk1 and its height corresponds to Spk. The distance between the highest point and the left intersection point is called Spkx.

Symmetrically, the area enclosed between the material ratio curve and the ordinate axis on the right, below the right intersection point, is called Sak2. A right-angled triangle is constructed so that its area equals to the hill area Sak2. Its horizontal base corresponds to 100 % – Smrk2 and its height corresponds to Svk. The distance between the highest point and the left intersection point is called Svkx.

The process of creating a right-angled triangle to define Spk and Svk is not an averaging process but a height-reduction process (see Reference [48]).

These parameters (Sk, Spk, Svk, Smrk1, Smrk2, Sak1, Sak2, Spkx, Svkx) should only be calculated if the areal material ratio curve is “S” shaped as shown in Figure B.1, and thus has only one single point of inflection. Experience has shown that this is always the case for lapped, ground or honed surfaces.



Key

X	material ratio
Y	intersection line position
Smrk1, Smrk2	material ratios
Sak1, Sak2	areas
Sk	core height
Spk	reduced peak height
Svk	reduced pit depth
Spkx	maximum peak height
Svkx	maximum pit depth

Figure B.1 — Calculation of the parameters

B.4 Calculating the parameters Spq, Svq and Smq

Three nonlinear effects can be present in the areal material probability curve shown in Figure 7 for measured surface data from a stratified surface. These effects shall be eliminated by limiting the fitted portions of the areal material probability curve, using only the statistically sound, Gaussian portions of the areal material probability curve, excluding a number of influences.

In Figure 7, the nonlinear effects originate from:

— outlying hills, for example debris or dirt particles (Key G);

— outlying dales, for example deep scratches (Key H);

— an unstable region (curvature) introduced at the plateau-to-dale transition point based on the combination of two distributions (Key I).

These exclusions are intended to keep the parameters more stable for repeated measurements of a given surface.

Figure 15 shows a profile with its corresponding areal material probability curve and its plateau and dale regions and the parts of the surface that define the two regions. The profile has a hill that is outlying and the figure shows how it does not influence the parameters. Figure 15 also shows how the bottom parts of the deepest dales, which will vary significantly depending on where the measurements are made on a surface, are disregarded when determining the parameters.

The process for determining the limits of the linear regions is given in ISO 13565-3:1998, Annex A.

Annex C
(informative)

Basis for areal surface texture standards — Timetable of events

The timetable of events leading to the publication of the ISO 25178 series on areal surface texture is as follows:

April 1990 to April 1993	EU-funded project entitled *Development of Methods for the Characterization of Roughness in Three Dimensions* under the leadership of Birmingham University. Developed basic foundation for areal surface texture characterization. Project report[17] introduced the "Birmingham 14" areal surface texture parameters and investigated communication protocols which included data-file formats.
September 1993	"Blue book"[17] published containing the detailed results from the above EU project. This book became a de facto standard for areal surface texture characterization.
April 1998 to April 2001	AUTOSURF project under the leadership of Rover/Brunel University. This EU-funded project developed areal surface texture characterization methods for sheet materials for automotive applications. This includes characterization for oil retention during storage of the coils, pressing performance and paint performance. Used the feature toolbox to solve real surface texture problems.
May 1998 to May 2001	SURFSTAND project under the leadership of Huddersfield University. This EU-funded project laid the foundations for the standardization of areal surface texture analysis. Evaluated the functional usefulness of the "Birmingham 14" parameters through a series of case studies. Areal texture definitions were revisited, resulting in "tightening up" the definitions of the "Field" parameters and the introduction of a "Feature" toolbox. Development of robust and wavelet filter technologies. Finally, issues dealing with areal instrument calibration were investigated.
January 2002	SURFSTAND and AUTOSURF project presentations to ISO/TC 213 in Madrid, Spain.
June 2002	Surface texture taskforce set up by ISO/TC 213 to determine requirements for standardization of areal surface texture.
January 2003	ISO/TC 213 set up WG 16 to develop new surface texture system as part of next generation GPS.
May 2003	"Green book"[18] published containing the detailed results from the SURFSTAND project.
June 2003	ASME B46.1 published. Contains the basis for areal surface texture fractal methods and classification of surface texture instruments.
March 2012	ISO 25178-2 originally published by ISO.
2021	Publication of the first revision of ISO 25178-2 with numerous corrections (see Annex E).

Annex D
(informative)

Implementation details

D.1 Local gradient vector

The local gradient is usually approximated for the point *i* by Formula (D.1):

$$\frac{\partial z}{\partial x} \approx \frac{1}{60\Delta x}(z_{i+3} - 9z_{i+2} + 45z_{i+1} - 45z_{i-1} + 9z_{i-2} - z_{i-3}) \quad \text{(D.1)}$$

with 3 ≤ *i* ≤ *N*-4 (*N* being the number of points in *X*) and Δ*x* the spacing in *X* ($x_i = i\Delta x$).

The gradient in Y is calculated in the same way, using Δ*y* instead.

Formula (D.1) is adapted at the edges of the profile (line or column of the surface) with Formulae (D.2) to (D.7).

Derivatives for the left profile boundary:

i = 0

$$\left.\frac{\partial z(x,y)}{\partial x}\right|_{x=0} \approx \frac{1}{60\Delta x}(-147\, z_0 + 360\, z_1 - 450\, z_2 + 400\, z_3 - 225\, z_4 + 72\, z_5 - 10\, z_6) \quad \text{(D.2)}$$

i = 1

$$\left.\frac{\partial z(x,y)}{\partial x}\right|_{x=\Delta x} \approx \frac{1}{60\Delta x}(-10\, z_0 - 77\, z_1 + 150\, z_2 - 100\, z_3 + 50\, z_4 - 15\, z_5 + 2\, z_6) \quad \text{(D.3)}$$

i = 2

$$\left.\frac{\partial z(x,y)}{\partial x}\right|_{x=2\Delta x} \approx \frac{1}{60\Delta x}(2\, z_0 - 24\, z_1 - 35\, z_2 + 80\, z_3 - 30\, z_4 + 8\, z_5 - z_6) \quad \text{(D.4)}$$

Derivatives for the right profile boundary: