INTERNATIONAL STANDARD

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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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 25178-2 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

ISO 25178 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Surface texture: Areal*:

⎯ *Part 2: Terms, definitions and surface texture parameters*

⎯ *Part 3: Specification operators*

⎯ *Part 6: Classification of methods for measuring surface texture*

⎯ *Part 70: Physical measurement standards*

⎯ *Part 71: Software measurement standards*

⎯ *Part 601: Nominal characteristics of contact (stylus) instruments*

⎯ *Part 602: Nominal characteristics of non-contact (confocal chromatic probe) instruments*

⎯ *Part 604: Nominal characteristics of non-contact (coherence scanning interferometry) instruments*

⎯ *Part 605: Nominal characteristics of non-contact (point autofocus probe) instruments*

⎯ *Part 701: Calibration and measurement standards for contact (stylus) instruments*

The following parts are under preparation:

⎯ *Part 1: Indication of surface texture*

⎯ *Part 603: Nominal characteristics of non-contact (phase-shifting interferometric microscopy) instruments*

Introduction

This part of ISO 25178 is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences chain link 2 of the chains of standards on areal surface texture.

The ISO/GPS Masterplan given in ISO/TR 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 specifications made in accordance with this document, unless otherwise indicated.

For more detailed information of the relation of this standard to the GPS matrix model, see Annex E.

This part of ISO 25178 develops the terminology, concepts and parameters for areal surface texture.

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

Part 2:
Terms, definitions and surface texture parameters

1   Scope

This part of ISO 25178 specifies terms, definitions and parameters for the determination of surface texture by areal methods.

2   Normative references

The following referenced documents are indispensable for the application 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/TS 16610-1:2006, *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*

ISO 25178-3:—[1]), *Geometrical product specifications (GPS) — Surface texture: Areal — Part 3: Specification operators*

3   Terms and definitions

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

3.1   General terms

3.1.1
non-ideal surface model
skin model
<of a workpiece> model of the physical interface of the workpiece with its environment

[ISO 17450-1:2011, 3.2.2]

---

1)   To be published.

3.1.1.1
mechanical surface
boundary of the erosion, by a spherical ball of radius r, of the locus of the centre of an ideal tactile sphere, also with radius r, rolled over the skin model of a workpiece

[ISO 14406:2010, 3.1.1]

3.1.1.2
electromagnetic surface
surface obtained by the electromagnetic interaction with the skin model of a workpiece

[ISO 14406:2010, 3.1.2]

3.1.2
specification coordinate system
system of coordinates in which surface texture parameters are specified

NOTE   If the nominal 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 part of ISO 25178.

3.1.3
primary surface
surface portion obtained when a surface portion is represented as a specified primary mathematical model with specified nesting index

[ISO/TS 16610-1:2006, 3.3]

NOTE   In this part of ISO 25178, an S-filter is used to derive the primary surface.

3.1.3.1
primary extracted surface
finite set of data points sampled from the primary surface

[ISO 14406:2010, 3.7]

3.1.4
surface filter
filtration operator applied to a surface

NOTE   In practice, the filter operator will apply to a primary extracted surface.

3.1.4.1
S-filter
surface filter which removes small scale lateral components from the surface resulting in the primary surface

3.1.4.2
L-filter
surface filter which removes large scale lateral components from the primary surface or S-F surface

3.1.4.3
F-operation
operation which removes form from the primary surface

NOTE 1   Some F-operations (such as association operations) 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 hence the fuzzy line for the action of the F-operation in Figure 1.

NOTE 2   Many L-filters are sensitive to form and require an F-operation first as a prefilter before being applied.

3.1.5
S-F surface
surface derived from the primary surface by removing the form using an F-operation

NOTE   Figure 1 illustrates the relationship between the S-F surface and the S-filter and F-operation.

3.1.6
S-L surface
surface derived from the S-F surface by removing the large scale components using an L-filter

NOTE   Figure 1 illustrates the relationship between the S-L surface and the S-filter and L-filter.

a	Small scale.
b	Large scale.
c	Scale axis.
d	F-operation.
e	S-filter.
f	L-filter.
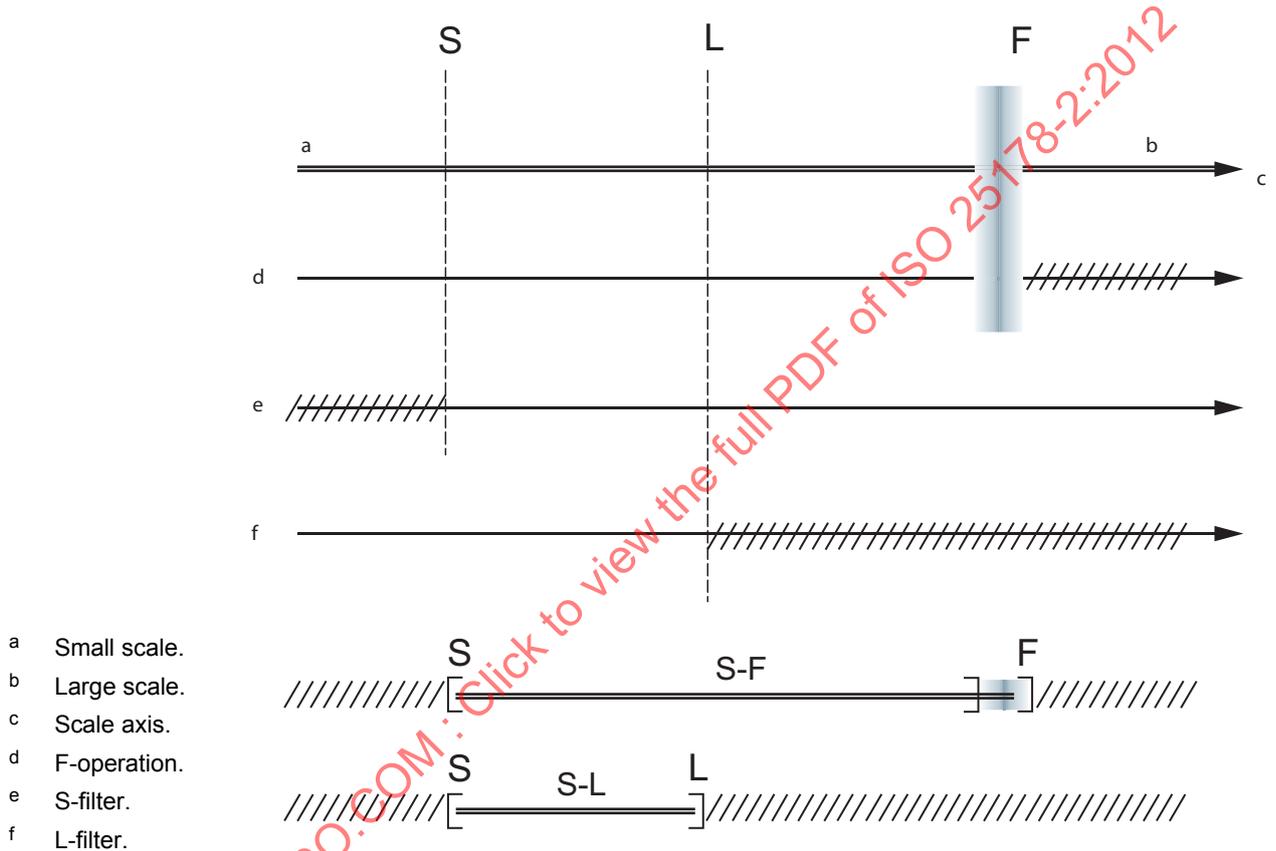
Figure 1 — Relationships between the S-filter, L-filter, F-operation and S-F and S-L surfaces

3.1.7
scale-limited surface
S-F surface or a S-L surface

3.1.8
reference surface
surface associated to the scale-limited surface according to a criterion

NOTE 1   The result is used as a reference surface for surface texture parameters.

NOTE 2   Examples of reference surfaces include plane, cylinder and sphere.

3.1.9
evaluation area
portion of the scale-limited surface for specifying the area under evaluation

NOTE   See ISO 25178-3 for more information.

3.1.10
definition area
portion of the evaluation area for defining the parameters characterizing the scale-limited surface

3.2   Geometrical parameter terms

3.2.1
field parameter
parameter defined from all the points on a scale-limited surface

NOTE   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

NOTE   Feature parameters are defined in Clause 5.

3.2.3
V-parameter
material volume or void volume field or feature parameter

3.2.4
S-parameter
field or feature parameter that is not a V-parameter

3.2.5
height
signed normal distance from the reference surface to the scale-limited surface

NOTE 1   The distance is defined normal to the reference surface.

NOTE 2   The height is negative, if from the reference surface the point lies in the direction of the material.

3.2.6
ordinate value
$z(x,y)$
height of the scale-limited surface at position x,y

NOTE   The coordinate system is based on the reference surface.

3.2.7
local gradient vector
$$\left(\frac{\partial z}{\partial x}, \frac{\partial z}{\partial y} \right)$$
gradient of the scale-limited surface at position x,y

NOTE   For specific implementation, see ISO 25178-3.

3.2.8
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)

$$f_{\mathrm{ACF}}\left(t_x, t_y\right) = \frac{\iint\limits_{A} z(x,y)z(x-t_x, y-t_y)\mathrm{d}x\mathrm{d}y}{\iint\limits_{A} z(x,y)z(x,y)\mathrm{d}x\mathrm{d}y}$$

with A being the definition area

3.2.9
Fourier transformation
$F(p,q)$
operator which transforms the scale-limited surface into Fourier space

$$F(p,q) = \iint\limits_{A} z(x,y)\mathrm{e}^{-(ipx+iqy)}\mathrm{d}x\mathrm{d}y$$

with A being the definition area

3.2.9.1
angular spectrum
$f_{\mathrm{APS}}(s)$
power spectrum for a given direction, with respect to a specified direction θ in the plane of the definition area

$$f_{\mathrm{APS}}(s) = \int\limits_{R_2}^{R_1} r\left| F\left[r\sin(s-\theta), r\cos(s-\theta)\right]\right|^2 \mathrm{d}r$$

where R_1 to R_2 is the range of integration in the radial direction and s the specified direction

NOTE 1   The positive x-axis is defined as the zero angle.

NOTE 2   The angle is positive in an anticlockwise direction from the x-axis.

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   For discrete data, a triangulization of the surface is necessary.

NOTE 2   There is a theoretical possibility of a plateau. In practice, this can be avoided by the use of an infinitesimal tilt.

NOTE 3   For specific implementation, see ISO 25178-3.

3.3.1.1
hill
region around a peak such that all maximal upward paths end at the peak

3.3.1.2
course line
curve separating adjacent hills

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

NOTE 1   For discrete data, a triangulization of the surface is necessary.

NOTE 2   There is a theoretical possibility of a plateau. In practice, this can be avoided by the use of an infinitesimal tilt.

NOTE 3   For specific implementation, see ISO 25178-3.

3.3.2.1
dale
region around a pit such that all maximal downward paths end at the pit

NOTE   An areal motif is a dale; see ISO 12085.

3.3.2.2
ridge line
curve separating adjacent dales

3.3.3
saddle
set of points on the scale-limited surface where ridge lines and course lines cross

3.3.3.1
saddle point
saddle consisting of one point

3.3.4
topographic feature
areal, line or point feature on a scale-limited surface

3.3.4.1
areal feature
hill or dale

3.3.4.2
line feature
course line or ridge line

3.3.4.3
point feature
peak, pit or saddle point

3.3.5
contour line
line on the surface consisting of points of equal height

3.3.6
segmentation
method which partitions a scale-limited surface into distinct regions

3.3.6.1
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   Examples of events are: ordinate values, point features, etc.

NOTE 2   A full mathematical description of the segmentation function and the three segmentation properties can be found in Scott (2004) (see Reference [16]).

NOTE 3   The mathematical treatment of the segmentation function and segmentation properties will be transferred to a future ISO 16610 series document on segmentation.

3.3.6.2
first segmentation property
P1
property where each event is allocated to the set of significant events or the set of insignificant events but not both

$$\text{P1}: \ \forall A \subseteq E, \ \Psi(A) \cup \Phi(A) = A \ \wedge \ \Psi(A) \cap \Phi(A) = \varnothing$$

where

E is the set of all events;

$\Psi(.)$ maps events onto the set of significant events;

$\Phi(.)$ maps events onto the set of insignificant events

3.3.6.3
second segmentation property
P2
property where if a significant event is removed from the set of events then the remaining significant events are contained in the new set of significant events

$$\text{P2}: \ \forall A \subseteq B \subseteq E, \quad \Phi(A) \subseteq \Phi(B)$$

where

E is the set of all events;

$\Phi(.)$ maps events onto the set of insignificant events

3.3.6.4
third segmentation property
P3
property where if an insignificant event is removed from the set of events then the same set of significant events is obtained

$$\text{P3}: \ \forall A \subseteq B \subseteq E, \quad \Psi(B) \subseteq A \Rightarrow \Psi(A) = \Psi(B)$$

where

E is the set of all events;

$\Psi(.)$ maps events onto the set of significant events

3.3.7
change tree
graph where each contour line is plotted as a point against height in such a way that adjacent contour lines are adjacent points on the graph

NOTE   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 Annex A for more details concerning change trees.

3.3.7.1
pruning
method to simplify a change tree in which lines from peaks (or pits) to their nearest connected saddle points are removed

3.3.7.2
local peak height
difference between the height of a peak and the height of the nearest connected saddle on the change tree

3.3.7.3
local pit height
difference between the height of the nearest connected saddle on the change tree and the height of a pit

3.3.7.4
Wolf pruning
pruning where lines are removed in order from the peak/pit with the smallest local peak/pit height up to the peak/pit with a specified local peak/pit height

NOTE   The local peak/pit heights will change during Wolf pruning as removing lines from a change tree will also remove the associated saddle point.

3.3.8
Wolf peak height
minimum threshold at which a peak is pruned using Wolf pruning

3.3.9
Wolf pit height
minimum threshold at which a pit is pruned using Wolf pruning

3.3.10
peak height
height of the peak

3.3.11
pit height
height of the pit

3.3.12
height discrimination
minimum Wolf peak height or Wolf pit height of the scale-limited surface which should be taken into account

NOTE   The height discrimination is usually specified as a percentage of Sz (4.1.6).

4   Field parameter definitions

In the terminological entries below, each term is followed by its parameter (abbreviated term), then its symbol. Whereas abbreviated terms can contain multiple letters, symbols consist only of a single letter with subscripts as needed. Symbols are used in the equations shown in this document. The reason for this differentiation is to avoid misinterpretation of compound letters as an indication of multiplication between quantities in equations. The parameters (abbreviated terms) are used in product documentation, drawings and data sheets.

4.1   Height parameters

All height parameters are defined over the definition area.

4.1.1
root mean square height of the scale-limited surface
Sq
S_q
root mean square value of the ordinate values within a definition area (A)

$$S_q = \sqrt{\frac{1}{A} \iint\limits_A z^2(x,y)\,\mathrm{d}x\mathrm{d}y}$$

4.1.2
skewness of the scale-limited surface
Ssk
S_{sk}

quotient of the mean cube value of the ordinate values and the cube of Sq within a definition area (A)

$$S_{sk} = \frac{1}{S_q^3}\left[\frac{1}{A} \iint\limits_A z^3(x,y)\,\mathrm{d}x\mathrm{d}y\right]$$

4.1.3
kurtosis of the scale-limited surface
Sku
S_{ku}

quotient of the mean quartic value of the ordinate values and the fourth power of Sq within a definition area (A)

$$S_{ku} = \frac{1}{S_q^4}\left[\frac{1}{A} \iint\limits_A z^4(x,y)\,\mathrm{d}x\mathrm{d}y\right]$$

4.1.4
maximum peak height of the scale limited surface
Sp
S_p

largest peak height value within a definition area

4.1.5
maximum pit height of the scale limited surface
Sv
S_v

minus the smallest pit height value within a definition area

4.1.6
maximum height of the scale-limited surface
Sz
S_z

sum of the maximum peak height value and the maximum pit height value within a definition area

4.1.7
arithmetical mean height of the scale limited surface
Sa
S_a

arithmetic mean of the absolute of the ordinate values within a definition area (A)

$$S_a = \frac{1}{A} \iint\limits_A |z(x,y)|\ \mathrm{d}x\mathrm{d}y$$

4.2 Spatial parameters

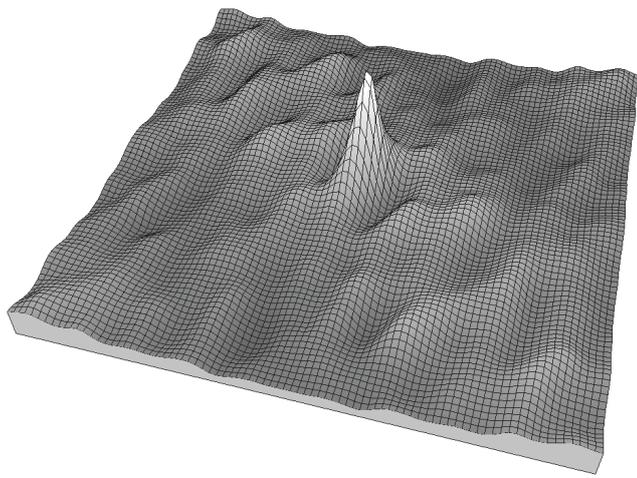All spatial parameters are defined over the definition area.

4.2.1
autocorrelation length
Sal
S_{al}
horizontal distance of the $f_{ACF}(t_x, t_y)$ which has the fastest decay to a specified value s, with $0 \le s < 1$

$$S_{al} = \min_{t_x, t_y \in R} \sqrt{t_x^2 + t_y^2} \quad \text{where } R = \left\{ (t_x, t_y) : f_{ACF}(t_x, t_y) \le s \right\}$$

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 2.

a)   **Autocorrelation function of the surface**   b)   **Threshold autocorrelation at s (the black spots are above the threshold)**
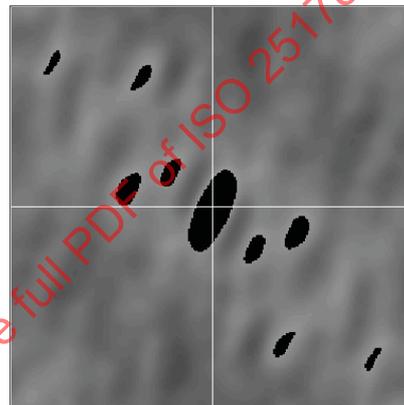
$$S_{al} = R_{min}$$
$$S_{tr} = R_{min} / R_{max}$$

c)   **Threshold boundary of the central threshold portion**   d)   **Polar coordinates leading to the autocorrelation lengths in different directions**
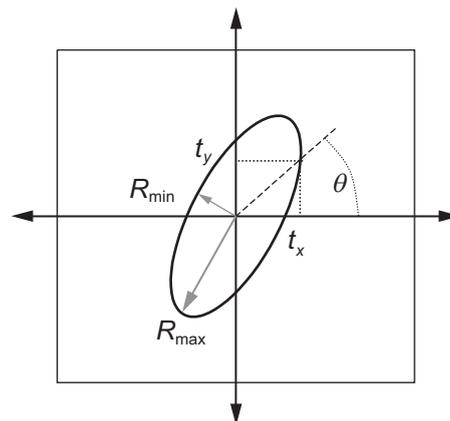
Figure 2 — Procedure to calculate Sal and Str

4.2.2
texture aspect ratio
Str
S_{tr}

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 $0 \le s < 1$

$$S_{tr} = \frac{\min\limits_{t_x,t_y \in R} \sqrt{t_x^2 + t_y^2}}{\max\limits_{t_x,t_y \in Q} \sqrt{t_x^2 + t_y^2}} \quad \text{where} \quad \begin{aligned} R &= \left\{ (t_x,t_y) : f_{ACF}(t_x,t_y) \le s \right\} \\ Q &= \left\{ (t_x,t_y) : f_{ACF}(t_x,t_y) \ge s \text{ and } ** \right\} \end{aligned}$$

where ** is the property that the $f_{ACF} \ge s$ on the straight line connecting the point (t_x,t_y) to the origin

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 2.

4.3   Hybrid parameters

4.3.1
root mean square gradient of the scale-limited surface
Sdq
S_{dq}

root mean square of the surface gradient within the definition area (A) of a scale-limited surface

$$S_{dq} = \sqrt{\frac{1}{A} \iint_A \left[\left(\frac{\partial z(x,y)}{\partial x} \right)^2 + \left(\frac{\partial z(x,y)}{\partial y} \right)^2 \right] dx dy}$$

4.3.2
developed interfacial area ratio of the scale-limited surface
Sdr
S_{dr}

ratio of the increment of the interfacial area of the scale-limited surface within the definition area (A) over the definition area

$$S_{dr} = \frac{1}{A} \left[\iint_A \left(\sqrt{\left[1 + \left(\frac{\partial z(x,y)}{\partial x} \right)^2 + \left(\frac{\partial z(x,y)}{\partial y} \right)^2 \right]} - 1 \right) dx dy \right]$$

NOTE   For a practical implementation of this parameter, see Reference [10].

4.4   Functions and related parameters

4.4.1
areal material ratio function of the scale-limited surface
function representing the areal material ratio of the scale-limited surface as a function of height

NOTE   This function can be interpreted as the sample cumulative probability function of the ordinates $z(x,y)$ within the evaluation area.

4.4.2
areal material ratio of the scale-limited surface
Smr(c)
$S_{mr}(c)$
ratio of the area of the material at a specified height c to the evaluation area

NOTE 1   Smr(c) is usually expressed as a percentage.

NOTE 2   Height is taken from the reference plane. See Figure 3.

NOTE 3   This function is related to the sample cumulative probability function of the ordinates.

Key
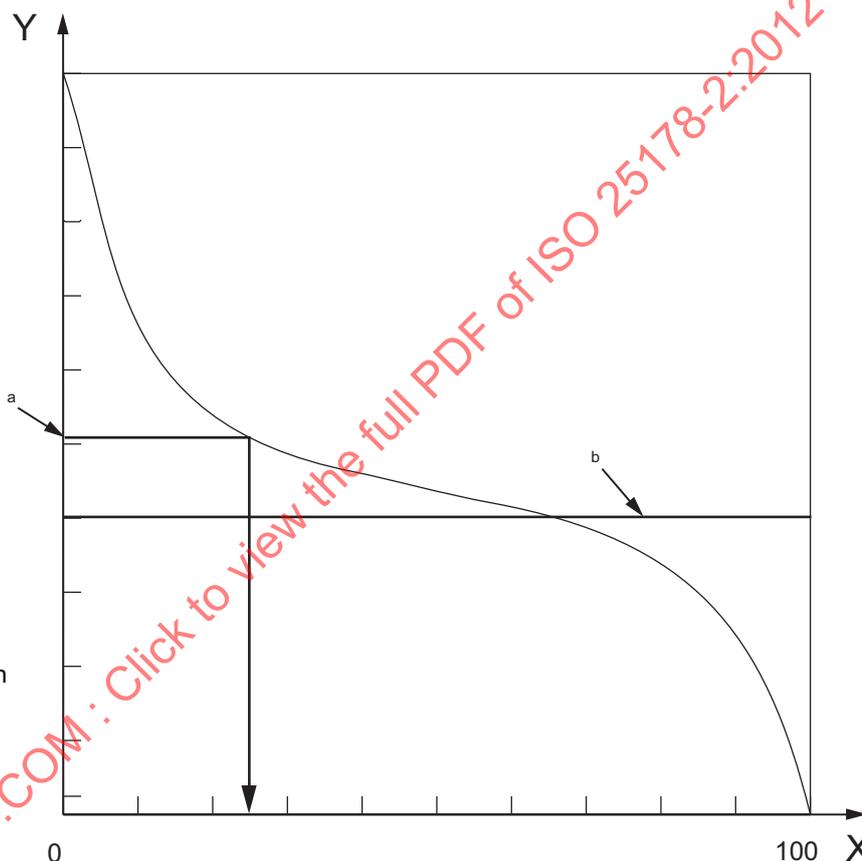
X   areal material ratio Smr(c), in percent

Y   height

a   Specified height, c.

b   Reference plane.

Figure 3 — Areal material ratio

4.4.3
inverse areal material ratio of the scale-limited surface
Smc(mr)
$S_{mc}(mr)$
height c at which a given areal material ratio (mr) is satisfied

NOTE   Height is taken from the reference plane. See Figure 4.
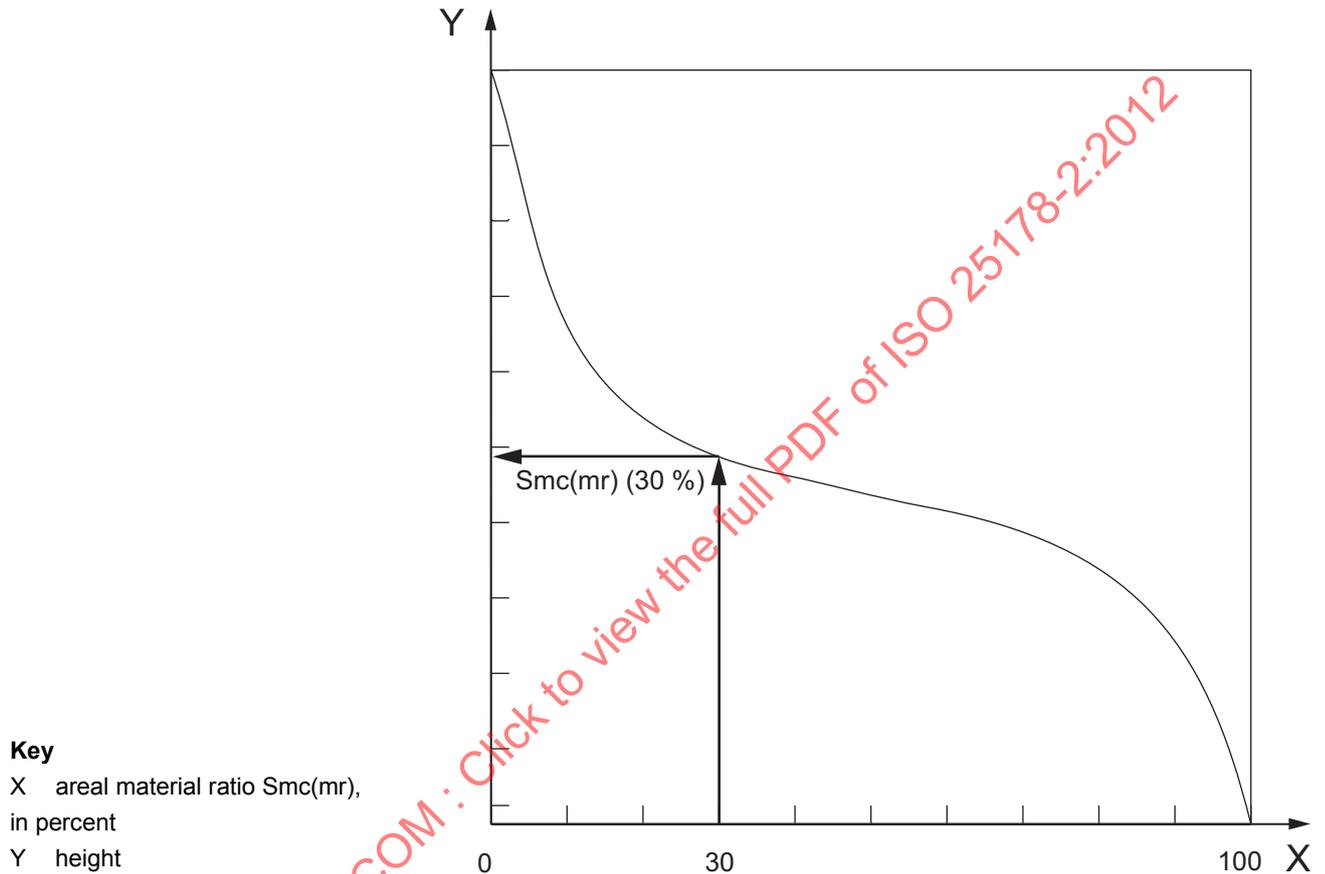
Figure 4 — Inverse areal material ratio

Key
X   areal material ratio Smc(mr),
in percent
Y   height

4.4.4
areal parameter for scale-limited stratified functional surfaces
parameter representing the areal material ratio of the scale-limited stratified functional surface as a function of height

4.4.4.1
core surface
scale-limited surface excluding core-protruding hills and dales

See Figure 5.

4.4.4.2
core height
Sk
S_k
distance between the highest and lowest level of the core surface

See Figure 5.

Key
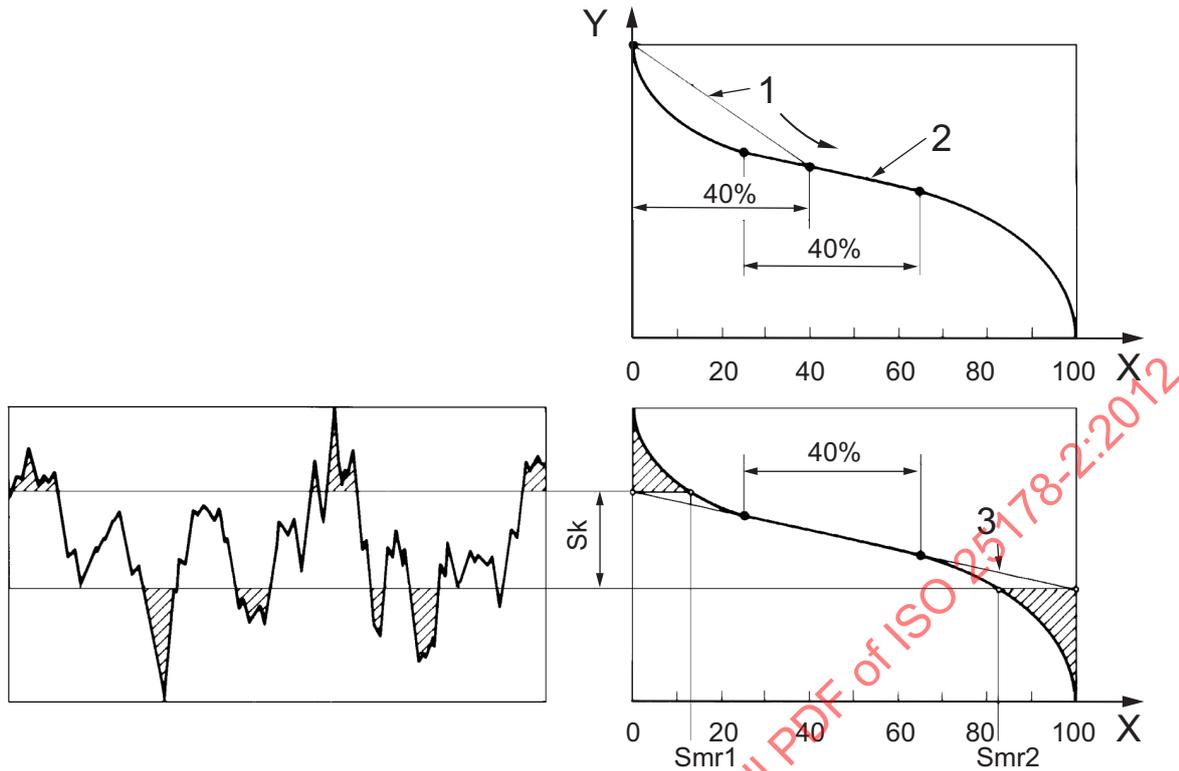
X	areal material ratio
Y	intersection line position
1	secant
2	secant with smallest gradient
3	equivalent straight line
Sk	core height
Smr1, Smr2	material ratios

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

Figure 5 — Calculation of Sk, Smr1 and Smr2

4.4.4.3
reduced peak height
Spk
S_{pk}
average height of the protruding peaks above the core surface

NOTE   The averaging process in Clause 5 reduces the effect of outlier values on this parameter.

4.4.4.4
reduced dale height
Svk
S_{vk}
average height of the protruding dales below the core surface

NOTE   The averaging process in Clause 5 reduces the effect of outlier values on this parameter.

4.4.4.5
material ratio
Smr1
S_{mr1}
⟨peaks⟩ ratio of the area of the material at the intersection line which separates the protruding hills from the core surface to the evaluation area

NOTE   The ratio is expressed in percent.

4.4.4.6
material ratio
Smr2
S_{mr2}
⟨dales⟩ ratio of the area of the material at the intersection line which separates the protruding dales from the core surface to the evaluation area

NOTE   The ratio is expressed in percent.

4.4.4.7
areal material probability curve
representation of the areal material ratio curve in which the areal material area ratio is expressed as a Gaussian probability in standard deviation values, plotted linearly on the horizontal axis

NOTE   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 1 and 2 in Figure 6).
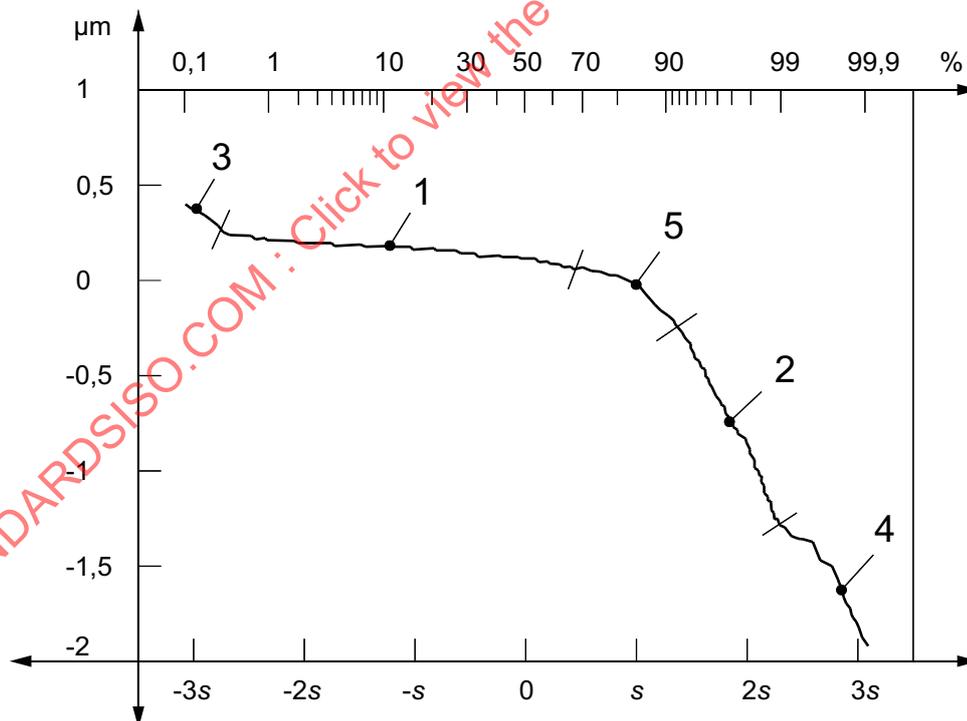
Key

1   plateau region

2   dale region

3   debris or outlying peaks in the data (scale-limited surface)

4   deep scratches or outlying dales in the data (scale-limited surface)

5   unstable region (curvature) introduced at the plateau-to-dale transition point based on the combination of two distributions

Figure 6 — Areal material probability curve

4.4.4.8
dale root mean square deviation
Svq
S_{vq}
slope of a linear regression performed through the dale region

See Figure 7.

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

4.4.4.9
plateau root mean square deviation
Spq
S_{pq}
slope of a linear regression performed through the plateau region

See Figure 7.

NOTE   Spq can thus be interpreted as the Sp-value, in micrometres, of the random process that generated the plateau component of the surface.

4.4.4.10
material ratio
Smq
S_{mq}
⟨plateau-to-dale⟩ areal material ratio at the plateau-to-dale intersection

See Figure 7.

NOTE   The ratio is expressed in percent.

4.4.5
void volume
Vv(p)
$V_v(p)$
volume of the voids per unit area at a given material ratio calculated from the areal material ratio curve

$$V_v(p) = \frac{K}{100\%} \int_p^{100\%} \left[S_{mc}(p) - S_{mc}(q) \right] \mathrm{d}q$$

where K is a constant to convert to millilitres per metres squared

4.4.5.1
dale void volume of the scale-limited surface
Vvv
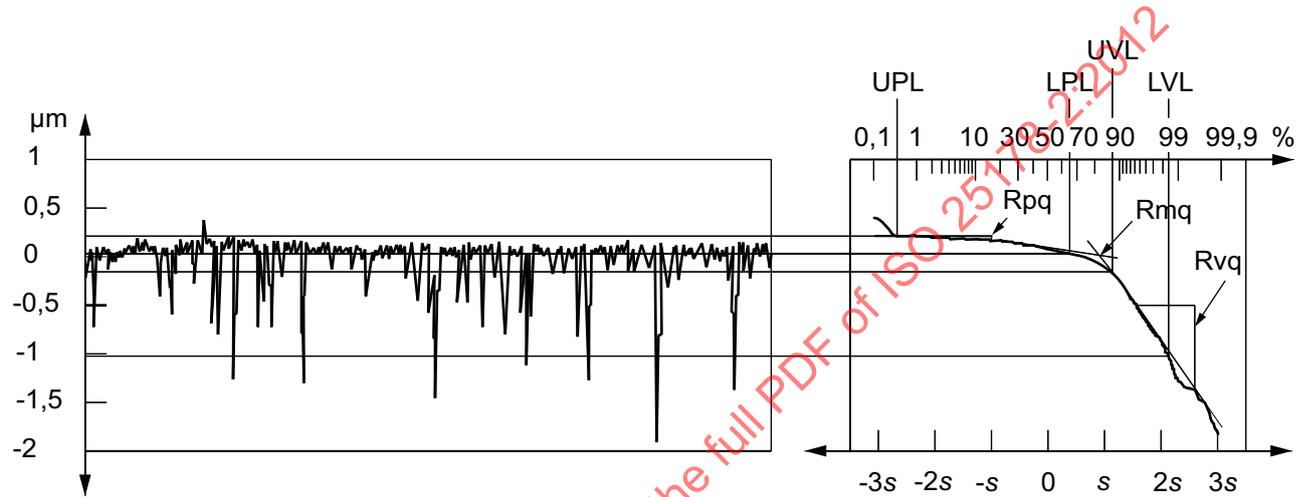V_{vv}
dale volume at p material ratio

$$V_{vv} = V_v(p)$$

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

4.4.5.2
core void volume of the scale-limited surface
Vvc
V_{vc}
difference in void volume between p and q material ratio

$$V_{\text{vc}} = V_{\text{v}}(p) - V_{\text{v}}(q)$$

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

Key

LPL   lower plateau limit

LVL   lower dale limit

UPL   upper plateau limit

UVL   upper dale limit

Rmq   relative material ratio at the plateau to dale intersection

Rpq   slope of a linear regression performed through the plateau region

Rvq   slope of a linear regression performed through the dale region

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

Figure 7 — Scale-limited surface with its corresponding areal material probability curve and the regions used in the definitions of the parameters Spq, Svq and Smq

4.4.6
material volume
Vm(p)
$V_{\text{m}}(p)$
volume of the material per unit area at a given material ratio calculated from the areal material ratio curve

$$V_{\text{m}}(p) = \frac{K}{100\,\%} \int_{0}^{p} S_{\text{mc}}(q) - S_{\text{dc}}(p)\,\mathrm{d}q$$

where K is a constant to convert to millilitres per metres squared

NOTE   See Figure 8.

Key
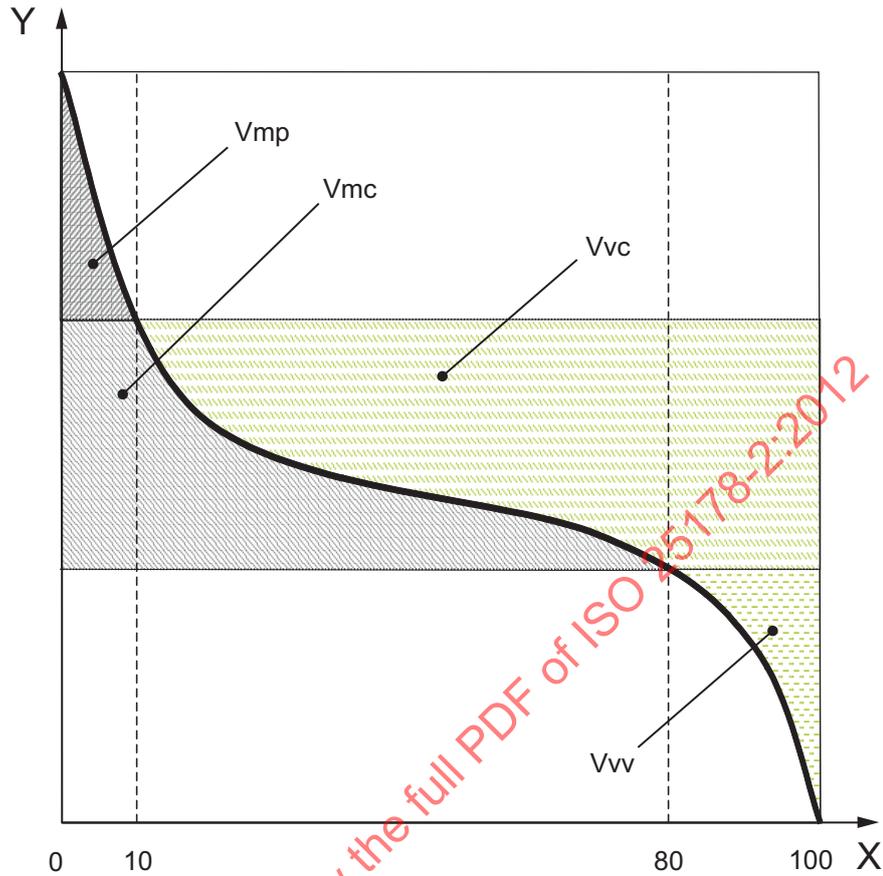
X   areal material ratio, in percent

Y   height

Figure 8 — Void volume and material volume parameters

4.4.6.1
peak material volume of the scale-limited surface
Vmp
V_{mp}
material volume at p

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

4.4.6.2
core material volume of the scale-limited surface
Vmc
V_{mc}
difference in material volume between the p and q material ratio

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

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

4.4.7
peak extreme height
Sxp
S_{xp}
difference in height between the p and q material ratio

$$S_{xp} = S_{mc}(p) - S_{mc}(q)$$

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

4.4.8
gradient density function
density function calculated from the scale-limited surface showing the relative frequencies against the angle of the steepest gradient $\alpha(x,y)$ and direction of the steepest gradient $\beta(x,y)$ anticlockwise from the x-axis (Figure 9)

$$\alpha(x,y) = \arctan\sqrt{\left.\frac{\partial z}{\partial y}^2 + \frac{\partial z}{\partial x}^2\right|_{(x,y)}} \quad \wedge \quad \beta(x,y) = \arctan\left[\left.\frac{\frac{\partial z}{\partial y}}{\frac{\partial z}{\partial x}}\right]\right|_{(x,y)}$$

NOTE 1   See Figure 9 for an example of the gradient density function.

NOTE 2   See Figure 10 for the steepest gradient, α, and the direction of the steepest gradient, β.
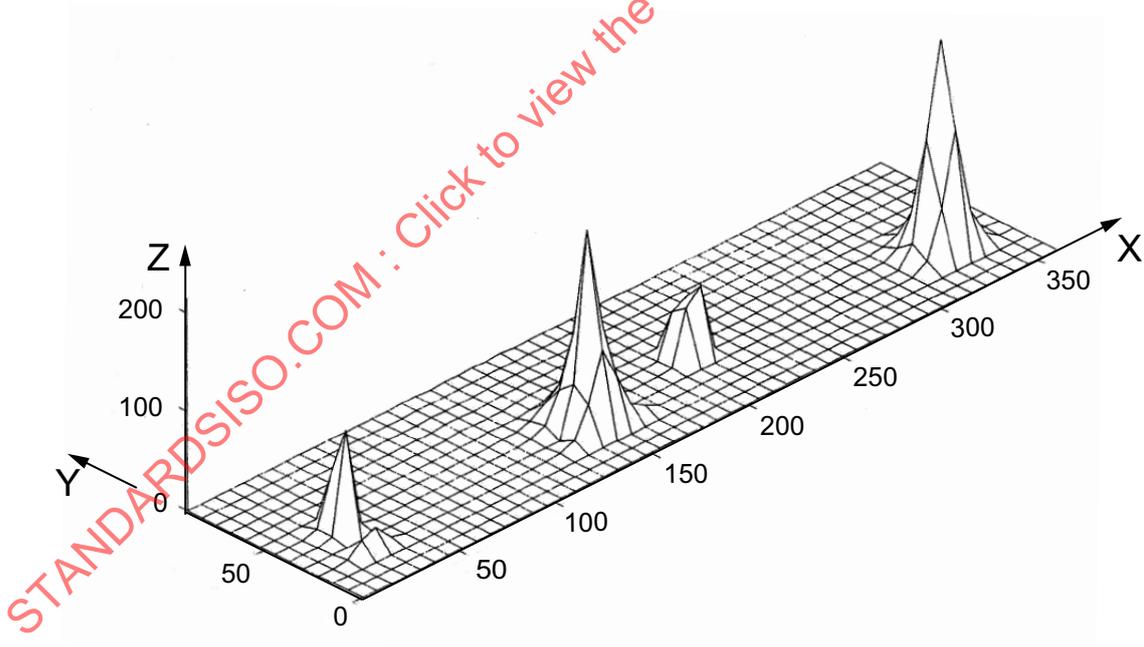
Key

X   direction of steepest gradient, β, in degrees

Y   steepest gradient, α, in degrees

Z   frequency of the occurrences

Figure 9 — Example of gradient density function
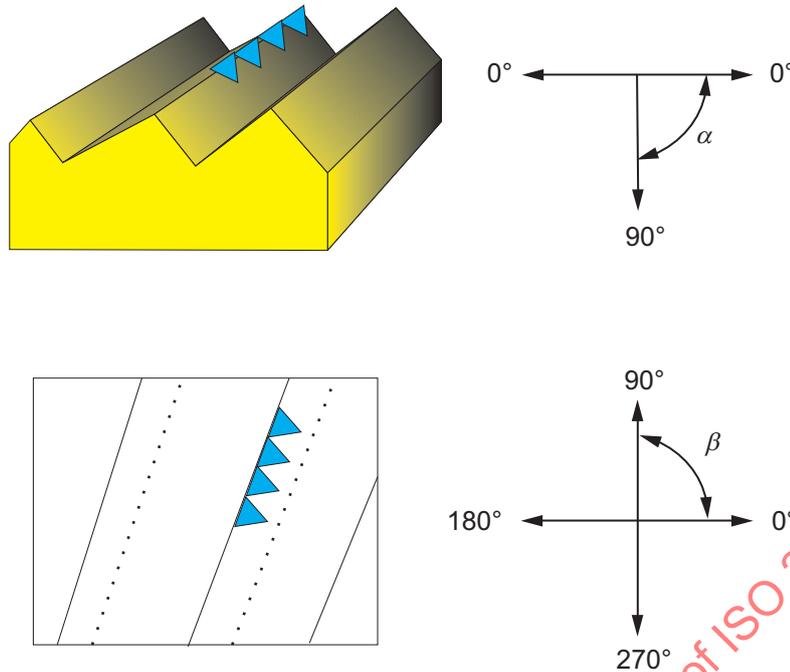
Figure 10 — Steepest gradient, α, and direction of steepest gradient, β

4.4.9 Fractal methods

4.4.9.1
volume-scale function
Svs(c)
$S_{vs}(c)$

volume between a morphological closing and opening of the scale-limited surface using a square horizontal flat as a structuring element as a function of the size of the structuring element

NOTE   The volume-scale function is usually plotted with log-log scales.

4.4.9.2
relative area function
Srel(c)
$S_{rel}(c)$

ratio of the area calculated by triangular tiling of the surface at a particular length scale to the definition area as a function of the length scale

NOTE   The relative area function is usually plotted with log-log scales.

4.4.9.3
length scale of observation
length scale at which the calculations for volume-scale or relative area functions are made

4.4.9.4
volume fractal complexity
Svfc
S_{vfc}

complexity parameter derived from the volume-scale function, equal to 1 000 times the slope of a log-log plot of the volume versus length scale of observation

4.4.9.5
areal fractal complexity
Safc
S_{afc}

complexity parameter derived from the relative area function, equal to −1 000 times the slope of a log-log plot of the relative area versus the length scale of observation

4.4.9.6
crossover scale
length scale of observation at which there is a change in the slope of relative area or volume-scale functions

NOTE   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.

4.4.9.7
smooth-rough crossover scale
fSRC
f_{SRC}

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

NOTE   The fSRC 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 SRC in length-scale and relative area analyses (see Annex B).

4.4.9.8
threshold
Th
T_h

value of relative area or volume used to determine the smooth-rough crossover scale

NOTE 1   Starting from the largest scales, working towards the smallest, the first relative area or volume to exceed the threshold is used to determine the SRC.

NOTE 2   A value of relative area or volume can be specified for the threshold, or the threshold can be selected as some percent, P, of the largest relative area or volume function, F, in the following manner:

$$T_h = 1 + (P)(F - 1)$$

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

4.5   Miscellaneous parameters

4.5.1
texture direction of the scale-limited surface
Std
S_{td}

angle, with respect to a specified direction θ, of the absolute maximum value of the angular spectrum

NOTE   Setting $s = S_{td}$ maximizes the absolute value of $f_{APS}(s - \theta)$.

5 Determination of areal parameters for stratified functional surfaces of scale-limited surfaces

5.1 Calculating the parameters Sk, Smr1 and Smr2

The equivalent straight line, calculated according to 5.2, intersects the 0 % and 100 % lines on the Smr axis (see Figure 5). 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 Smr1 and Smr2.

5.2 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 5). This is determined by moving the secant line for $\Delta M_r = 40$ % along the areal material ratio curve, starting at the $\Delta M_r = 0$ % position as in Figure 5. The secant line for $\Delta M_r = 40$ % 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.

5.3 Calculating the parameters Spk and Svk

The areas above and below the region of the areal material ratio curve which delimits the core height S_k are shown hatched in Figure 5. These correspond to the cross-sectional area of the surface hills and dales which protrude out of the core surface.

The parameters Spk and Svk are each calculated as the height of the right-angle triangle which is constructed to have the same area as the "hill area" or "dale area", respectively (see Figure 11). The right-angle triangle corresponding to the "hill area A1" has Smr1 as its base, and that corresponding to "dale area A2" has the difference between 100 % and Smr2 as its base.

The parameters Sk, Spk, Svk, Smr1 and Smr2 should only be calculated if the areal material ratio curve is "S" shaped as shown in Figures 5 and 11, and thus has only one single point of inflection. Experience has shown that this is always the case of lapped, ground or honed surfaces.

5.4 Calculating the parameters Spq, Svq and Smq

Three non-linear effects can be present in the areal material probability curve shown in Figure 6 for measured surface data from a two-process 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 6, the non-linear effects originate from

— debris or outlying hills in the data (scale-limited surface) (labelled 3),

— deep scratches or outlying dales in the data (scale-limited surface) (labelled 4), and

— an unstable region (curvature) introduced at the plateau-to-dale transition point based on the combination of two distributions (labelled 5).

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

Figure 7 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 7 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. Figure 7 shows a profile instead of a surface area for ease of illustration. The principle is the same for a surface area.

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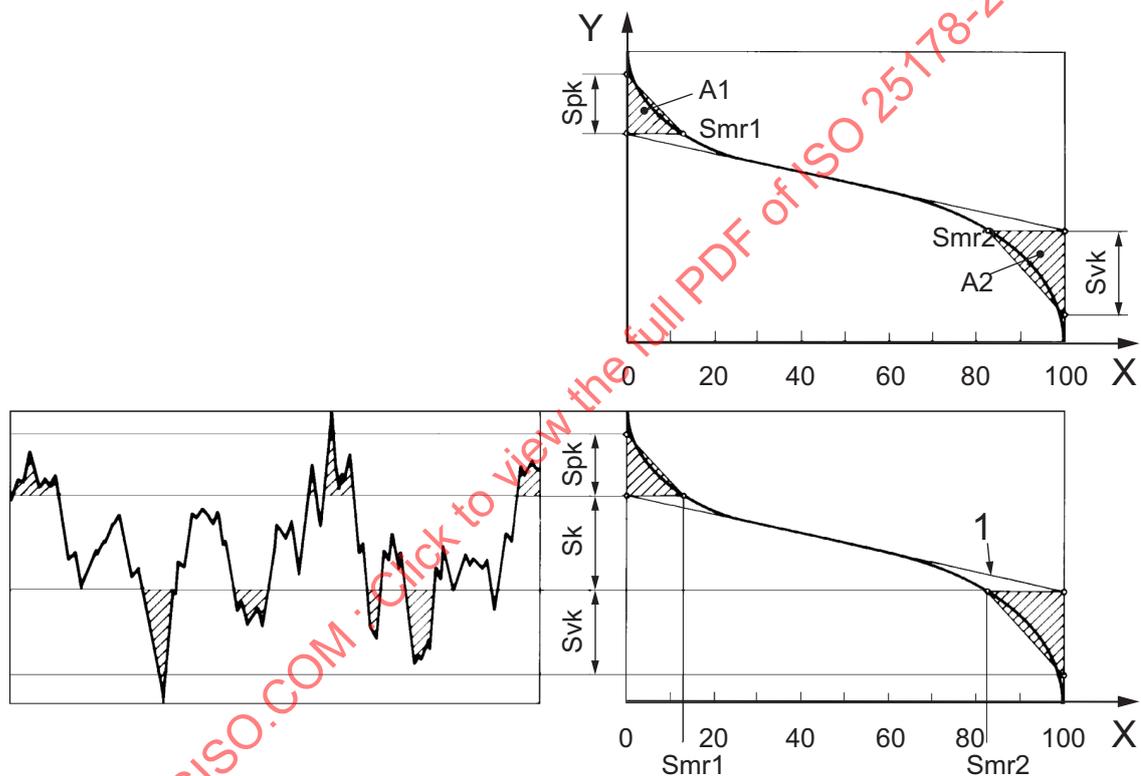
Key

X	material ratio
Y	intersection line position
1	equivalent straight line
A1	hill area
A2	dale area
Smr1, Smr2	material ratios
Sk	relative material ratio at the plateau to dale intersection
Spk	slope of a linear regression performed through the plateau region
Svk	slope of a linear regression performed through the dale region

Conversion of "hill area" and "dale area" into equivalent right-angle triangle.

Figure 11 — Calculation of Spk and Svk based on that for Rpk and Rvk

6 Feature characterization

6.1 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;

— segmentation;

— determining significant features;

— selection of feature attributes;

— quantification of feature attribute statistics.

The surface depicted in Figure 12 is used as an illustrative example throughout this clause.
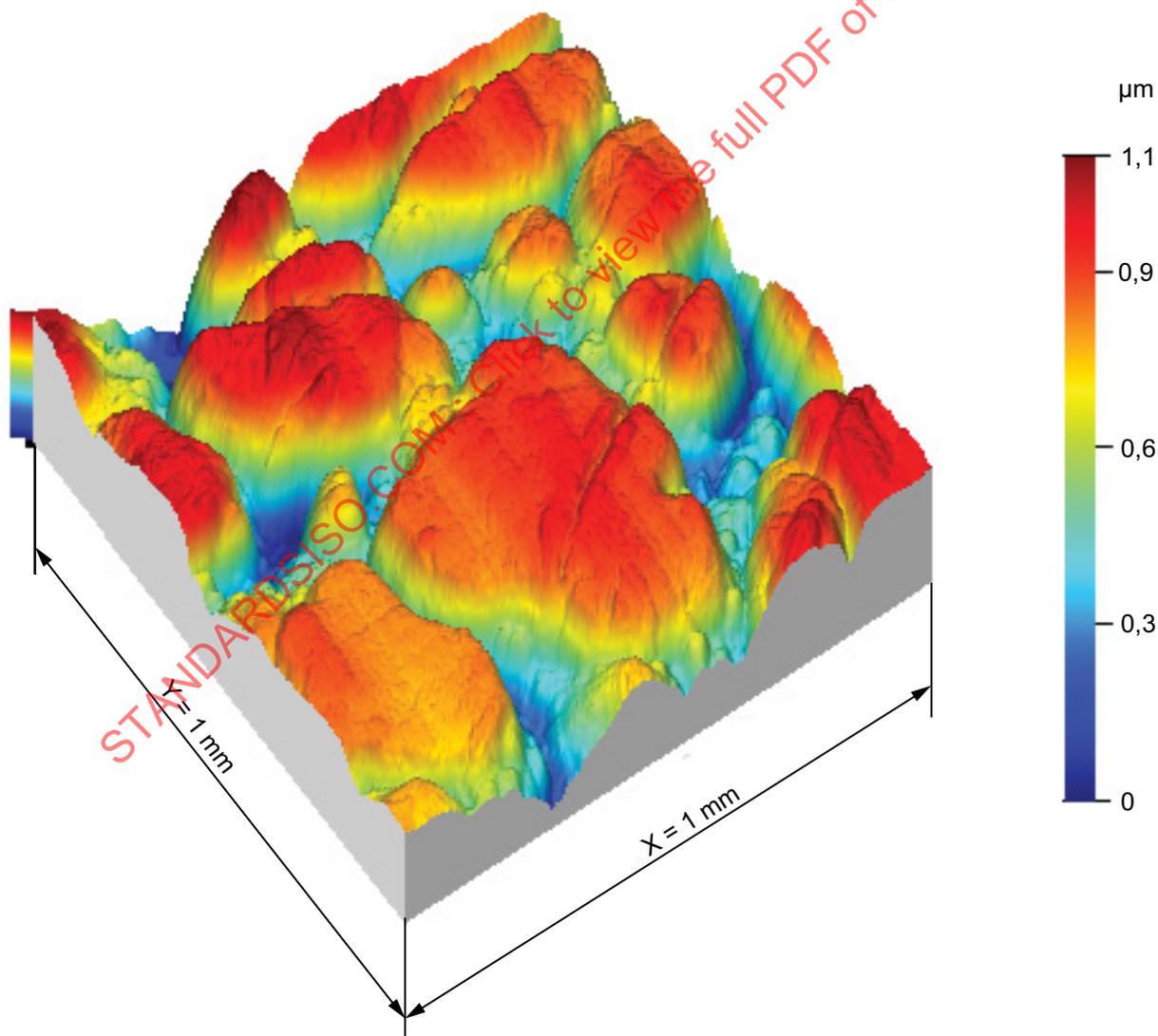

Figure 12 — Example of an illustrative surface

6.2   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 scale-limited features

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

6.3   Segmentation

Segmentation is used to determine regions of the scale-limited surface which define the scale-limited 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, using the surface illustrated in Figure 12, of Hills defined from Wolf pruning using 10 % of S_z is given in Figure 13.

Table 2 — Criteria of size for segmentation

Criteria of size	Designation	Threshold
Local peak/pit height (Wolf pruning), see Figure 13	Wolfprune	% of Sz
Volume of hill/dale (at height of connected saddle on change tree)	VolS	Specified volume
Area of hill/dale	Area	% of definition area
Circumference of hill/dale	Circ	Specified length

6.4   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 non-functionally significant. For each particular surface function, there needs to be defined a segmentation function which identifies the significant and non-significant 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.
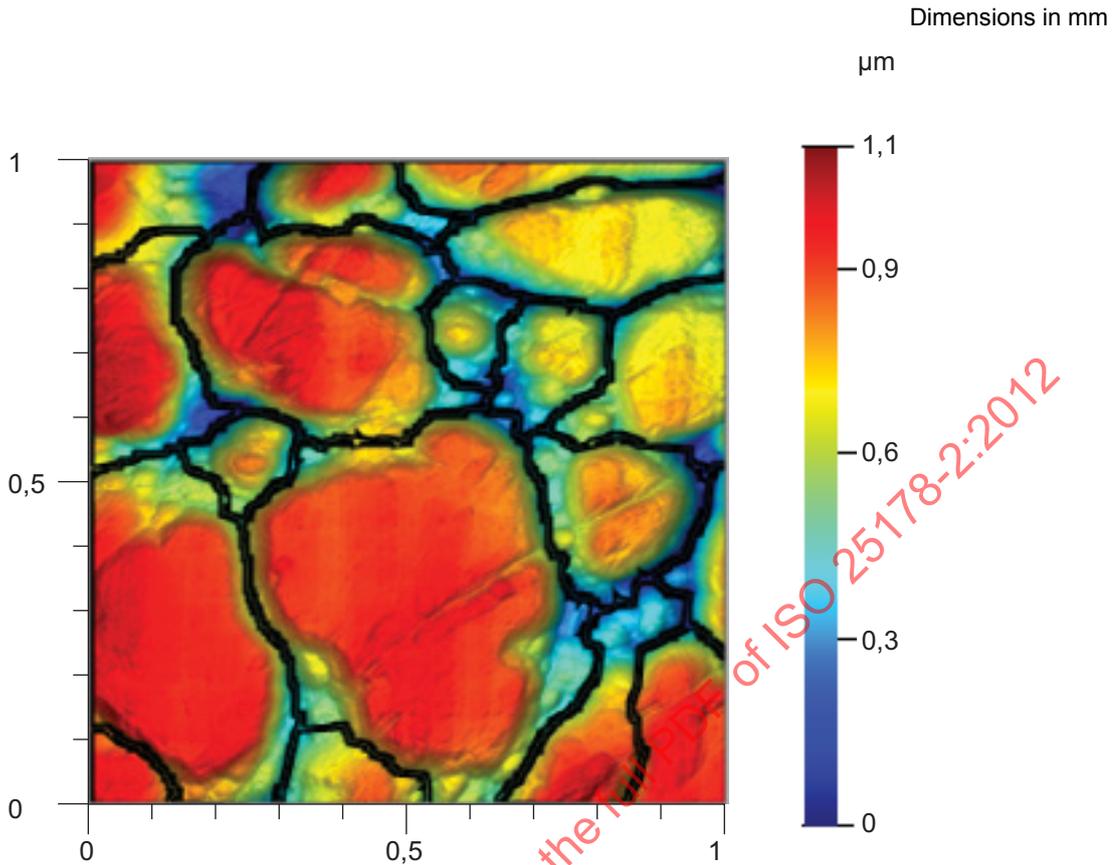
Dimensions in mm

μm

**Figure 13 — Hills defined from Wolf pruning using 10 % of Sz**

Table 3 — Methods of determining significant features

Class of feature	Method of determining significant features	Designation	Parameter units
Areal	Areal feature is significant if not connected to the edge at a given height (see Figure 14, feature A)	Closed	Height is given as a material ratio
	Areal feature is significant if it is connected to the edge at a given height (see Figure 14, feature B)	Open	Height is given as a material ratio
Point	A peak is significant if it has one of the top N Wolf peak heights	Top	N is an integer
	A pit is significant if it has one of the top N Wolf pit heights	Bot	N is an integer
Areal, line, point	Use all of the features	All	—

NOTE 1   In future additions of this part of ISO 25178, it is anticipated other standardized methods of determining segmentation functions for particular functions will be given.

NOTE 2   An example, using the surface illustrated in Figure 12, of closed hills, open hills and open dales is given in Figure 14.

NOTE 3   The definitions of closed hills, open hills and open dales require more research to make them fully stable (due to the "connection/no connection" to the edge). It is anticipated that in future additions of this part of ISO 25178 stable versions of these concepts will be defined.
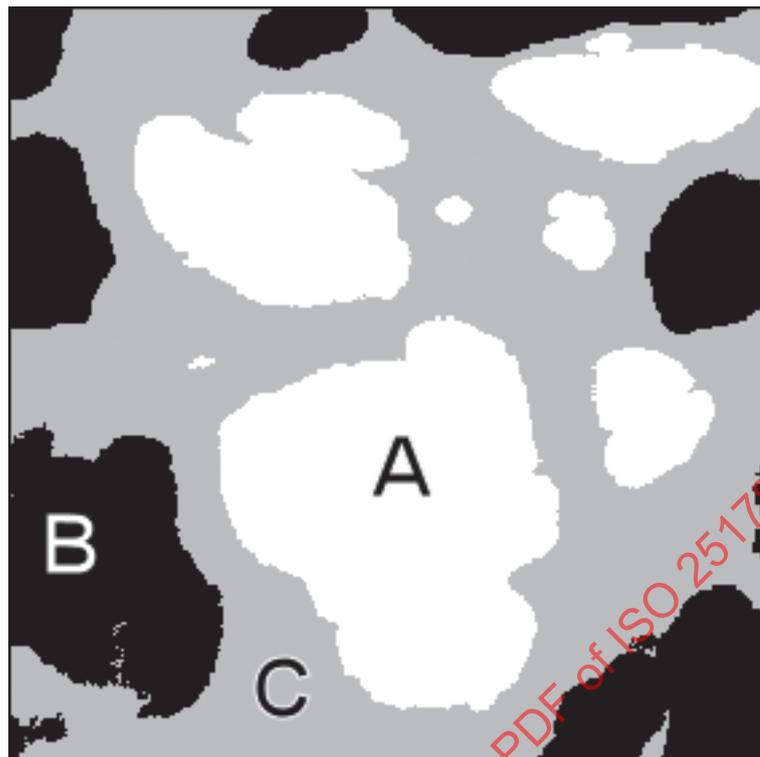
Key

A   example of a closed hill, i.e. not connected to edge (white)

B   example of an open hill, i.e. connected to edge (black)

C   example of an open dale, i.e. connected to edge (grey)

Figure 14 — Hills above height threshold (50 % material ratio) showing those connected to edge (black) and those not connected to edge (white)

6.5   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, e.g. length, area or volume of a feature. Some feature attributes are given in Table 4.

Table 4 — Feature attributes

Feature class	Feature attributes	Designation
Areal	Local peak/pit height	Lpvh
	Volume of areal feature (at height of connected saddle on change tree)	VolS
	Volume of areal feature (at height of connection to edge)	VolE
	Area of areal feature	AreaE
	Circumference of areal feature	Cleng
Line	Length of line	Leng
Point	Local peak/pit height	Lpvh
	Local curvature at critical point	Curvature
Areal, line, point	Attribute takes value of one	Count

NOTE   In future additions of this part of ISO 25178, it is anticipated that standardized methods of determining feature attributes for particular functions will be given.

6.6   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	—
RMS attribute value	RMS	—
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 definition area	Density	—

NOTE   In future additions of this part of ISO 25178, it is anticipated that standardized methods of naming particular attribute statistics will be given.

6.7   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 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 the symbol ":" to delimit within a stage.

—   If a tool is not specified in this part of ISO 25178, then a reference to the tool definition can be used instead.

EXAMPLE   FC;D;Wolfprune:5%;Edge:60%;AreaE;Hist

6.8   Named feature parameters

In the terminological entries below, each term is followed by its parameter (abbreviated term), then its symbol. Whereas abbreviated terms can contain multiple letters, symbols consist only of a single letter with subscripts as needed. Symbols are used in the equations shown in this document. The reason for this differentiation is to avoid misinterpretation of compound letters as an indication of multiplication between quantities in equations. The parameters (abbreviated terms) are used in product documentation, drawings and data sheets.

6.8.1
density of peaks
Spd
S_{pd}
number of peaks per unit area

$$S_{pd} = \text{FC;H;Wolfprune:X\%;All;Count;Density}$$

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.

6.8.2
arithmetic mean peak curvature
Spc
S_{pc}
arithmetic mean of the principal curvatures of peaks within a definition area

$$S_{pc} = \text{FC;P;Wolfprune:X\%;All;Curvature;Mean}$$

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.

6.8.3
ten-point height of surface
S10z
S_{10z}
average value of the heights of the five peaks with largest global peak height added to the average value of the heights of the five pits with largest global pit height, within the definition area

$$S_{10z} = S_{5p} + S_{5v}$$

6.8.3.1
five-point peak height
S5p
S_{5p}
average value of the heights of the five peaks with largest global peak height, within the definition area

$$S_{5p} = \text{FC;H;Wolfprune:X\%;Top:5;Lpvh;Mean}$$

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.

6.8.3.2
five-point pit height
S5v
S_{5v}
average value of the heights of the five pits with largest global pit height, within the definition area

$$S_{5v} = \text{FC;D;Wolfprune:X\%;Bot:5;Lpvh;Mean}$$

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.

6.8.4
mean dale area
Sda(c)
$S_{da}(c)$
$S_{da}(c) = FC;D;Wolfprune:X\%;Open:c/Closed:c;AreaE;Mean$

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.

6.8.5
mean hill area
Sha(c)
$S_{ha}(c)$
$S_{ha}(c) = FC;H;Wolfprune:X\%;Open:c/Closed:c;AreaE;Mean$

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.

6.8.6
mean dale volume
Sdv(c)
$S_{dv}(c)$
$S_{dv}(c) = FC;D;Wolfprune:X\%;Open:c/Closed:c;VolE;Mean$

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.

6.8.7
mean hill volume
Shv(c)
$S_{hv}(c)$
$S_{hv}(c) = FC;H;Wolfprune:X\%;Open:c/Closed:c;VolE;Mean$

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.

Annex A
(informative)

Segmentation

A.1 Surface segmentation

More than a hundred years ago Maxwell[12] proposed dividing a landscape into regions consisting of hills and regions consisting of dales. A Maxwellian hill is an area from which maximum uphill paths lead to one particular peak, and a Maxwellian dale is an area from which maximum downhill paths lead to one particular pit. By definition, the boundaries between hills are course lines (watercourses), and the boundaries between dales are ridge lines (watershed lines). Maxwell was able to demonstrate that ridge and course lines are maximum uphill and downhill paths emanating from saddle points and terminating at peaks and pits. Recently, the Maxwellian dale (watershed lines) has emerged as the primary tool of mathematical morphology of image segmentation as preparation for pattern recognition.

Unfortunately, segmenting a surface or image into Maxwellian dales is often disappointing as the surface/image is over-segmented into a large number of insignificant tiny, shallow dales rather than a few significant large deep dales. What is required is to merge the insignificant dales into larger significant dales.

It is proposed to extend Maxwell's definitions and to define a dale as consisting of a single dominant pit surrounded by a ring of ridge lines connecting peaks and saddle points and to define a hill as consisting of a single dominant peak surrounded by a ring of course lines connecting pits and saddle points. Within a dale or hill, there may be other pits/peaks, but they will all be insignificant compared to the dominant pit/peak.

The dale is the areal equivalent of the profile motif (see ISO 12085). The hill is also a useful complementary concept. Like the profile motif, several types of surface specific points and lines characterize hills and dales. These include the critical points (peaks, pits and saddle points) and the critical lines (ridge lines and course lines). (See Figure A.1.)

It is also important to consider edge effects. Ockham's Razor (*non sunt multiplicanda entia praeter necessitatem* – entities are not to be multiplied beyond necessity) is used to extend contour lines outside the area of interest in such a way that a minimum number of new critical points are created. Ockham's Razor leads to two possible solutions called the "virtual pit" and the "virtual peak", each being the dual of the other. The concept of the virtual pit is adopted[13]. A virtual pit is assumed to be a point of height minus infinity to which all the boundary points are connected. (A virtual peak is assumed to be a point of infinite height to which all the boundary points are connected.)

A.2 Combining segments

A.2.1 Change tree

A useful way to organize the relationships between critical points in hills and dales and still retain relevant information is a change tree. Kweon and Kanade[14] introduced the concept of a scale-limited change tree to describe the connectability of a surface. The change tree represents the relationships between contour lines from a surface and is one example of a more general topological object called a Reeb graph[13]. The vertical direction on the change tree represents height. At a given height, all individual contour lines are represented by a point which is part of a line representing that contour line continuously varying with height. Saddle points are represented by the merging of two or more of these lines into one; peaks and pits are represented by the termination of a line.
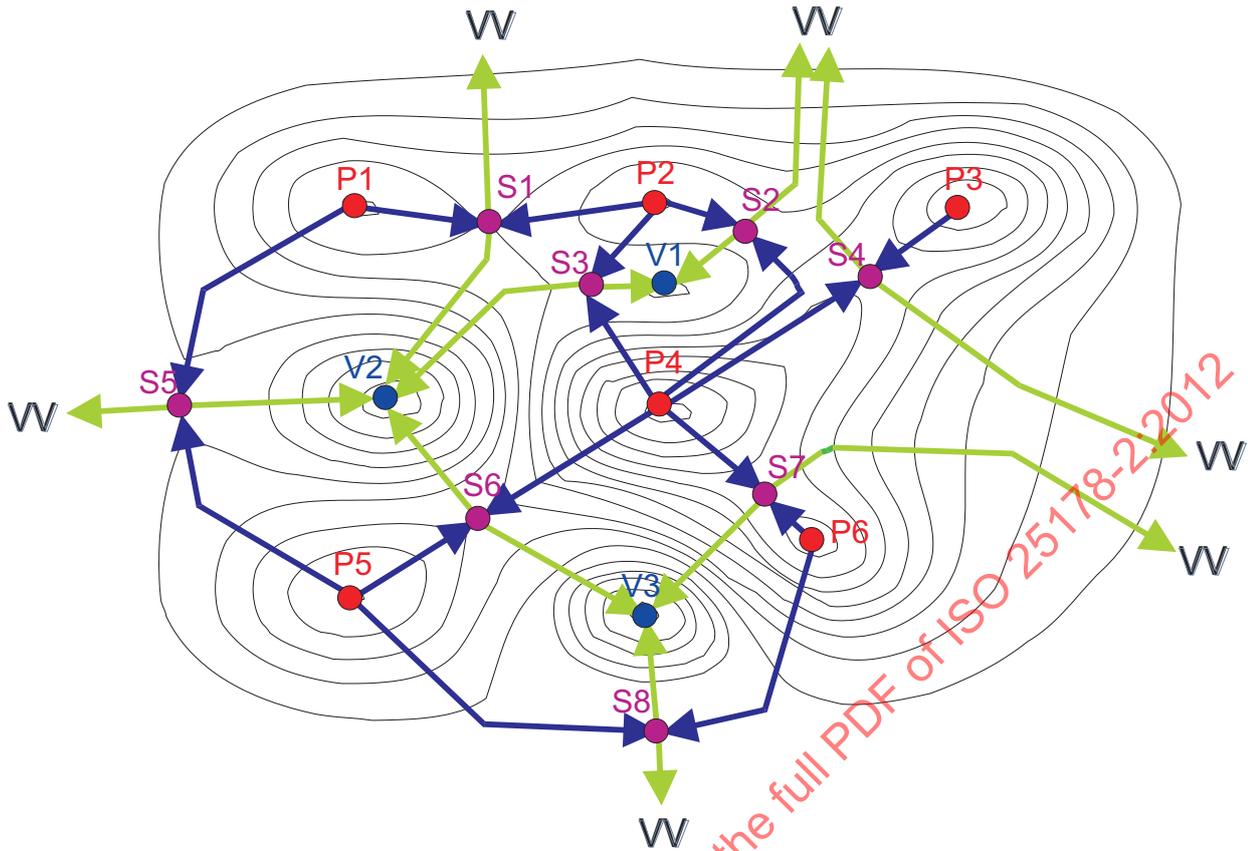
Key

P   peaks
V   pits
S   saddle points
VV   virtual pit

Figure A.1 — Contour map showing critical lines and points

Consider filling a dale gradually with water. The point where the water first flows out of the dale is a saddle point. The pit in the dale is connected to this saddle point in the change tree. Continuing to fill the new lake, the next point where the water flows out of the lake is also a saddle point. Again the line on the change tree, representing the contour of the lake shoreline, will be connected to this saddle point in the change tree. This process can be continued and establishes the connection between the pits, saddle points and the change tree. By inverting the landscape so peaks become pits, etc., a similar process will establish the connection between peaks, saddle points and the change tree.

There are at least three types of change tree:

⎯   the *full change tree* which represents the relationships between critical points in hills and dales (Figure A.2);

⎯   the *dale change tree* which represents the relationships between pits and saddle points (Figure A.3);

⎯   the *hill change tree* which represents the relationships between peaks and saddle points (Figure A.4).

Key
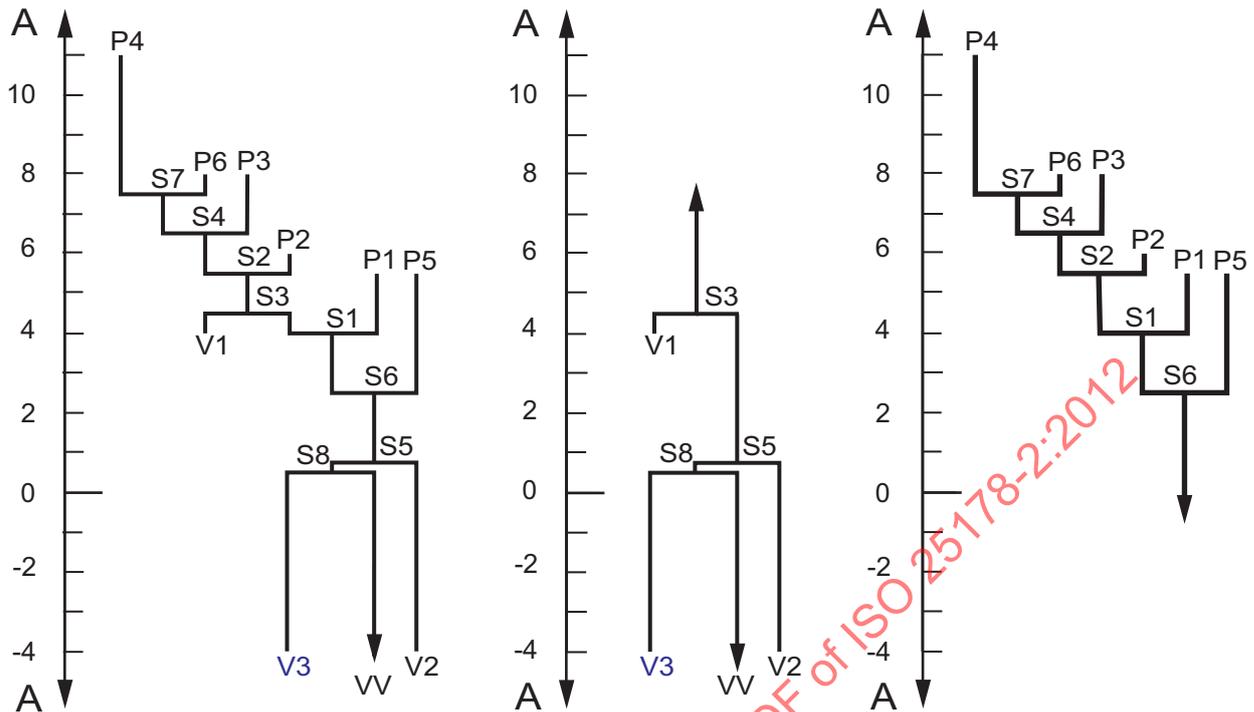
A   height, µm

P   peaks

V   pits

S   saddle points

VV virtual pit

Figure A.2 — Full change tree   Figure A.3 — Dale change tree   Figure A.4 — Hill change tree

It should be noted that the dale and hill change trees can be calculated from the full change tree. In the rest of this annex, "change tree" implies the full change tree.

A.2.2 Areal combination

In practice, change trees can be dominated by very short contour lines, due to noise, etc., which hinders interpretation (over-segmentation of the surface/image by Maxwellian hills and dales). A mechanism is required to prune the change tree, which reduces the noise, but retains relevant information. An areal combination is such a mechanism; it leaves the change tree simplified but still containing relevant information.

A.2.3 Rules for areal combination

The following is an outline of the areal combination algorithm for the full change tree. This algorithm can easily be modified for dale or hill combinations so these cases will not be discussed here. The simplified algorithm presented here assumes that the virtual pit condition has been applied.

Step 1   Assuming the virtual pit condition, find all the Maxwellian hills and dales and generate the full change tree.

Step 2   Classify all peaks, pits, edge peaks and edge pits significant or non-significant according to the function of the surface.

Step 3 Combine non-significant peaks and pits with the adjacent saddle point they are connected to in the change tree.

The resulting change tree will indicate the significant peaks, pits, edge peaks and pits and the relationships between them. Hence, the change tree has been pruned, reducing the noise, but retaining relevant information.

A.2.4 Which segments to combine

A segmentation function consists of splitting a set of "events" into two distinct sets called "significant events" and "insignificant events". For the segmentation function to give unique and stable results, the segmentation function must satisfy the following three properties[20].

⸺ P1: Each event is allocated to one and only one of these two sets (i.e. the set of significant events and the set of insignificant events).

⸺ P2: If a significant event is removed from the set of events then the remaining significant events are contained in the new set of significant events.

⸺ P3: If an insignificant event is removed from the set of events, then the same set of significant events is obtained.

It can be shown[16] that all segmentation functions that satisfy these three properties can be mapped one-to-one onto a certain subset of morphological closing filters. Morphological closing filters are widely used in image analysis. They are set functions with the following three defining properties[17]:

a) all sets are subsets of their own closings;

b) a closing of a closing of a set is the closing of the original set;

c) a closing of a subset is a subset of the closing of the original set.

The particular subset of the closing filters that the segmentation functions map onto are the closings with the following properties.

If two sets of events give the same closing, then their intersection also gives the same closing.

Any closing that satisfies this property can be mapped one-to-one onto a particular segmentation function as follows.

For any set of events, consider the smallest subset of this set that gives the same closing as the original set of events. It can be shown that this particular subset is unique and well defined and corresponds to the set of significant events and its complement, with respect to the set of events, corresponds to the set of insignificant events. The inverse mapping is also well defined. Proofs of these results can be found in Reference [16].

This is a powerful result since it allows one to construct all possible segmentation combination functions from the morphological closing filters whose properties are very well known, including how to generate all possible finite closing filters[17].

A.3 Change tree pruning

A.3.1 General

In the literature, there are now several publicized references to methods that are analogous to pruning a change tree (see References [18], [19] and [20]).

Wolf[18] presents a method which is equivalent to pruning a change tree. This is discussed in A.3.2.

Very recently methods to merge watersheds (Maxwellian dales) have appeared in the literature[19][20]. Watershed merging is equivalent to change tree pruning only if the triangulization of the lattice is assumed to be a continuous surface (i.e. triangular facets).

All of the above pruning methods can be shown to satisfy the three properties given in A.2.4.

A.3.2 Wolf pruning

One first calculates for each peak and pit the height difference between the peak or pit and the adjacent saddle point they are connected to on the change tree. Wolf's pruning method consists of finding the peak or pit with the smallest height difference and combining it with the adjacent saddle point on the change tree. The other peak or pit also connected to this saddle point is now connected to another saddle and so its height difference is adjusted to reflect this. The process is then repeated with that peak or pit with the smallest height difference to its adjacent saddle point on the change tree being eliminated until some threshold is reached. This threshold could be when all remaining height differences are above a fixed value or alterative when a fixed number of peaks or pits are left. It can easily be proved that both criteria lead to a segmentation function that satisfies the three required properties given in A.2.4. Using the change tree given in Figure A.2, P6 to S7, P2 to S2 and V1 to S3 all take the value of the smallest height difference, i.e. of 0,5. Pruning these leads to the change tree given in Figure A.5.

Using Wolf pruning until five peaks and five pits are left on a surface gives a stable definition of the ten-point height parameter. These peaks/pits may not be the highest/lowest, but they will be the tallest.

NOTE   Mount Everest may be the highest mountain on earth, but it is not the tallest (base to peak) – that distinction belongs to Mauna Kea on Hawaii.
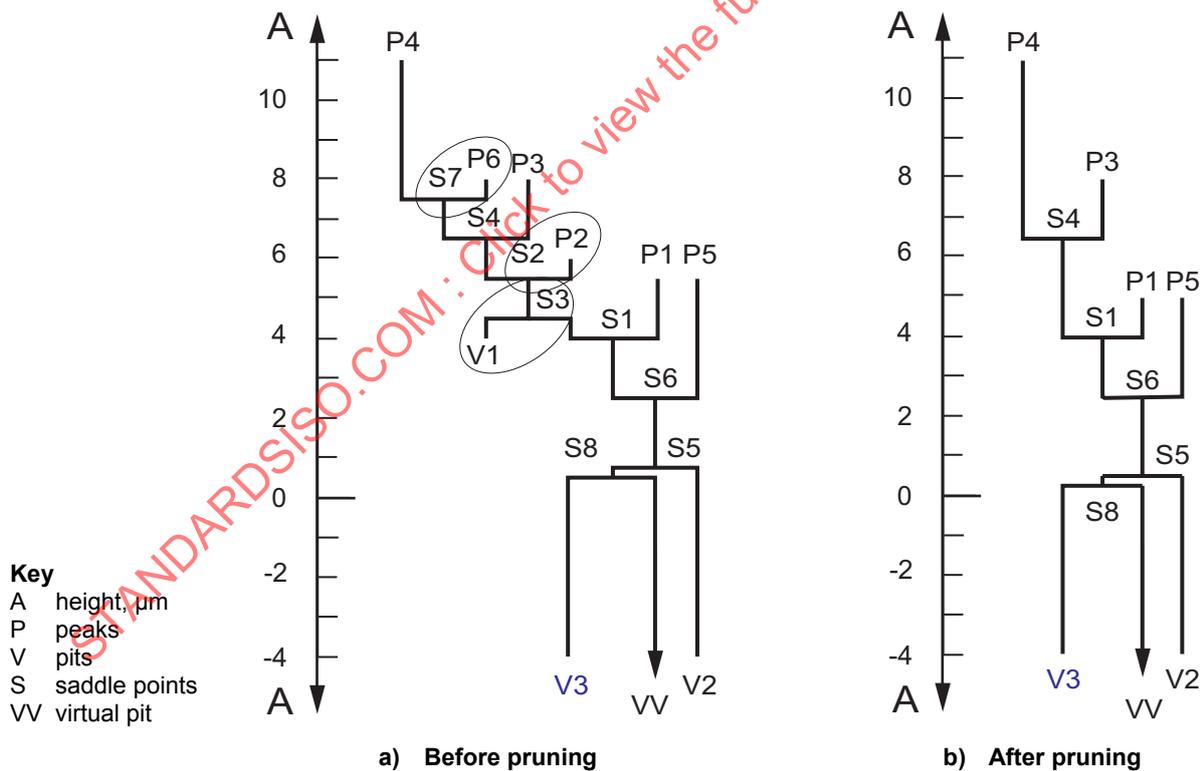

Key
A   height, µm
P   peaks
V   pits
S   saddle points
VV virtual pit

a)   **Before pruning**   b)   **After pruning**

Figure A.5 — Wolf pruning of Figure A.2

Annex B
(informative)

Fractal methods

B.1 What is a fractal?

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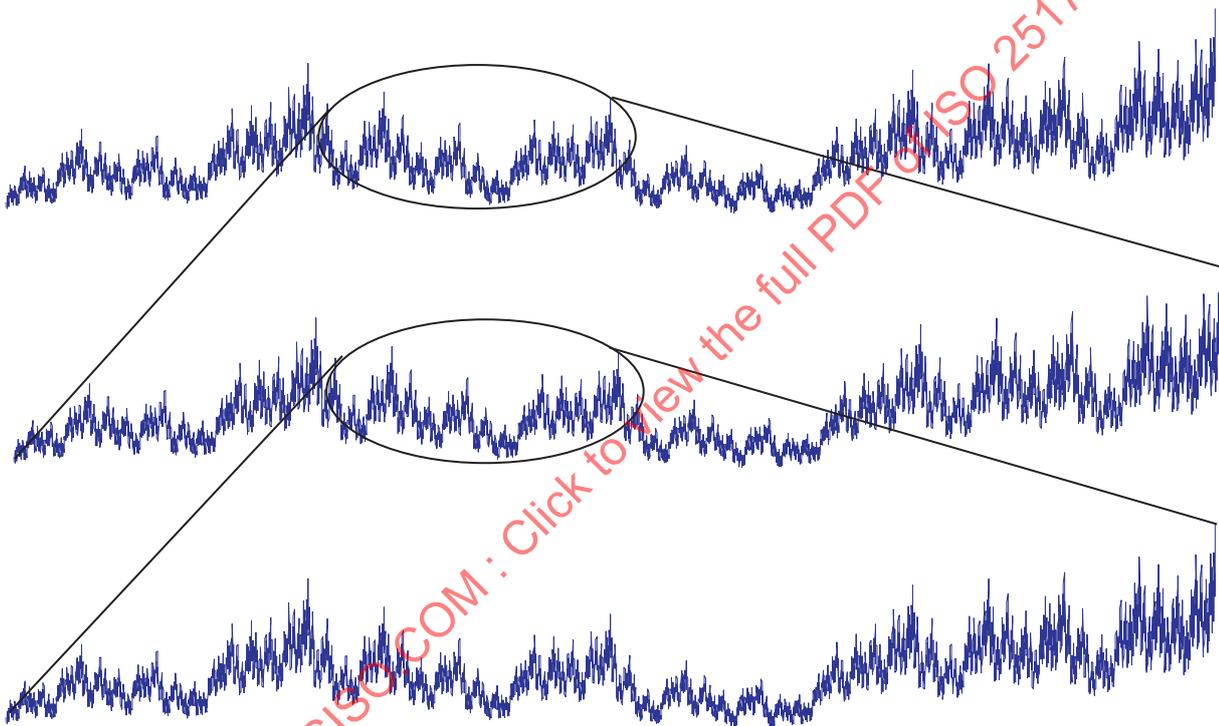
Figure B.1 — Fractal profile showing the same structures at all scales

In general, a "fractal dimension" can be calculated from a fractal surface using several methods [21][22] including the variation method [23] and relative area analysis [24]. The latter has shown to be capable of providing parameters that support strong functional correlations with adhesion [25], electrochemical impedance [26], friction [27], gloss [28], good differentiation of dental microwear [29], grinding conditions [30], mass transfer during heat treatment [31], and powder compacts [32].

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 some 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.

B.2 Variation methods

Let $F(s)$ be 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 s (s by s).

Then, providing the limit exists,

$$D_V = \lim_{s \to +0} \left\{ 3 - \frac{d\left(\log_e\left[F(s)\right]\right)}{d\left[\log_e\left(s\right)\right]} \right\}$$

The fractal dimension calculated using the variation method is equivalent to the Minkowski-Bouligand dimension. It has been shown [23] that the variational 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.

B.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 B.2, is very useful in capturing some of these behaviours over the observable range of scales.

The volume-scale plot Svs(s) 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 scale, in micrometres
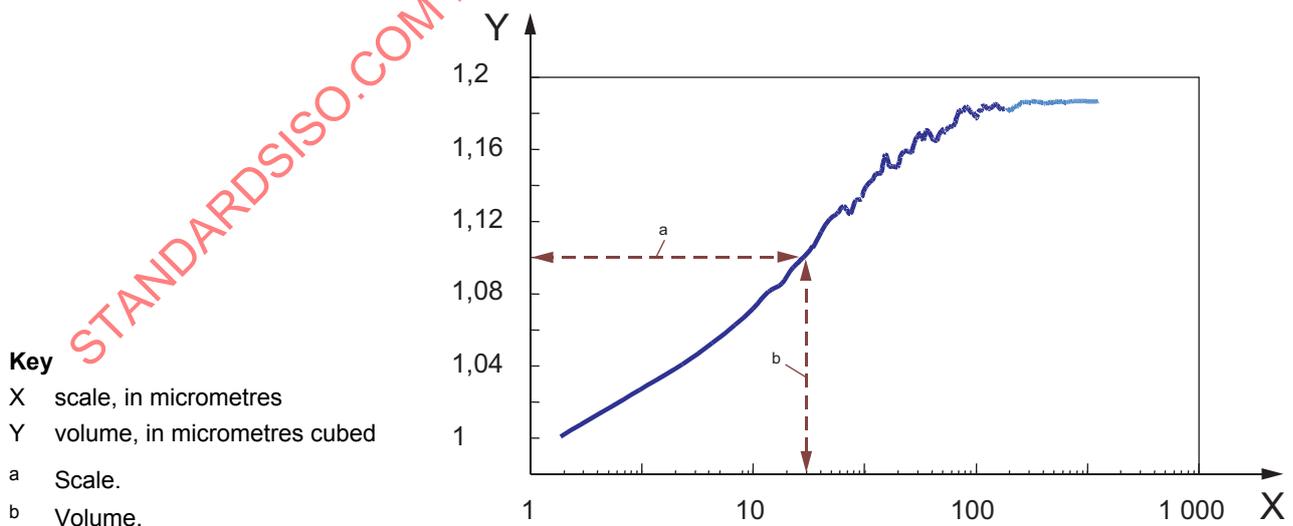
Y volume, in micrometres cubed

a Scale.

b Volume.

Figure B.2 — Volume-scale plot of a scale-limited surface