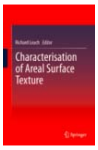
Areal Field Parameters

The first manufacturers of areal surface texture measurement instruments initially proposed characterization methods that were mainly based upon a simple extrapolation of 2D methods. In the absence of official documentation, the manufacturers made up solutions that were more or less felicitous, with surface parameters sometimes calculated as the simple mean of profile parameters evaluated for each line on the surface, or for radial profiles extracted from a circle with its origin at the centre of the image. The naming rules for the parameters were also derived from the 2D parameters (sRa, sWa...) and were calculated using proprietary algorithms leading to different values on different instruments. Nonetheless good practices were later disseminated, notably thanks to publications by **Pr. Stout** and his collaborators at **Birmingham**, and with the release of **DigiSurface** software on Macintosh in 1993, developed by Digital Surf and later adapted for Taylor Hobson's Form Talysurf under the name Talymap. Later, the **SurfStand** report and the release of **MountainsMap** in 1996, contributed to establish standard ways to calculate areal surface texture parameters. MountainsMap® version 5.0 was the first commercial package to offer, in 2007, the complete set of field parameters defined in the draft ISO 25178.



Details on how to calculate **ISO 25178** field parameters can be found in chapter 2 of **[LEACH 2013]**.

Naming rules for 3D parameters

In the ISO 25178 standard, all areal parameters start with the upper case letter S or the upper case letter V. In contrast with naming rules used with profile parameters, prefixes of the areal parameters do not reflect the nature of the surface, distinguishing between roughness and waviness. For profiles, we have Pa, Ra and Wa; For surfaces, we only have Sa, which can therefore be a parameter of roughness, or waviness, or calculated on the primary surface, depending upon the pre-filtering that is carried out before the parameter is calculated. This decision is based upon the multiplicity of processing and filtering methods that are available to metrologists for extracting information from a surface **[ISO 16610]**. These processing methods do not necessarily separate the surface texture into two components that are roughness and waviness but in certain cases alter the surface in a more subtle manner.

Amplitude parameters

Most of the profile parameters defined in ISO 4287 have a mathematical expression that can easily be extended to surfaces. For example, ***Sq*** is simply an extension to a plane of the equation of Rq that is defined for a line:

$$Rq=\sqrt{\frac{1}{lb}\int_{lb} Z^2(x)dx} \qquad Sq=\sqrt{\frac{1}{A}\iint_{A} Z^2(x,y)dxdy}$$

Sa, Sq, Ssk, Sku, Sp, Sv, etc. can therefore be defined straightforwardly in the same way.

Parameter equations use integrals instead of sums because they represent the definition for continuous case. Obviously, practical implementations use discrete data and various approximations to the instegration. No recommended method is given, each algorithm being characterized by an uncertainty budget.

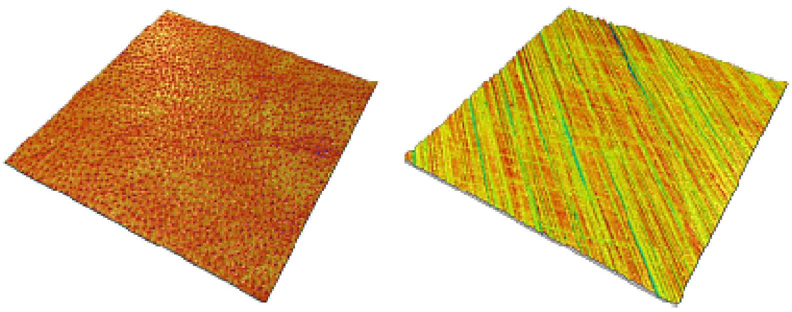
Besides the above parameters that can easily be extrapolated, certain parameters pose problems. Rz is defined in **ISO 4287** as the maximum height on a sampling length and is averaged on the number of sampling lengths contained in the evaluation length. In general, Rz is smaller than Rt. This parameter has known numerous definitions, first of all defined in ISO 4287 (1984) as the ten points height, then modified in 1997, and it has remained confusing notably because of its similarities with the Ry and Rmax parameters.

It is worth noting that ***Sz***, as defined in ISO 25178, is simply the maximum height from the highest point to the deepest valley, as St was once defined. Therefore ***St*** disappears from the standard! The absence of this well-known parameter may create confusion for some users!

ISO 25178			
Height Parameters			
Sq	22.263	µm	*Root mean square height*
Ssk	0.0098607		*Skewness*
Sku	1.6195		*Kurtosis*
Sp	37.759	µm	*Maximum peak height*
Sv	40.338	µm	*Maximum pit height*
Sz	78.097	µm	*Maximum height*
Sa	19.863	µm	*Arithmetic mean height*

Spatial Parameters

A surface is said to be **isotropic** when it presents identical characteristics regardless of the direction of measurement. This is the case, for example, for surfaces with a random surface texture that do not have any texture that stands out. This type of surface is unhappily fairly rare and most of the surfaces encountered in industry have an oriented surface (turned, ground or brushed surfaces) or a periodic structure (EBT impacts, grained plastics). In this case the surface is said to be **anisotropic**.



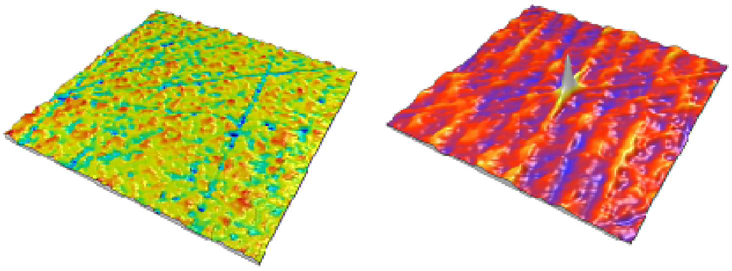
Isotropic surface (left) - anisotropic surface (right)

The isotropy of a surface can be determined and quantified by tools based upon the **Fourier transform** and autocorrelation.

Autocorrelation is a function described by the following equation:

$$ACF(\tau x,\tau y)=\frac{\iint_A Z(x,y)\,Z(x-\tau x,y-\tau y)\,dxdy}{\iint_A Z^2(x,y)\,dxdy}$$

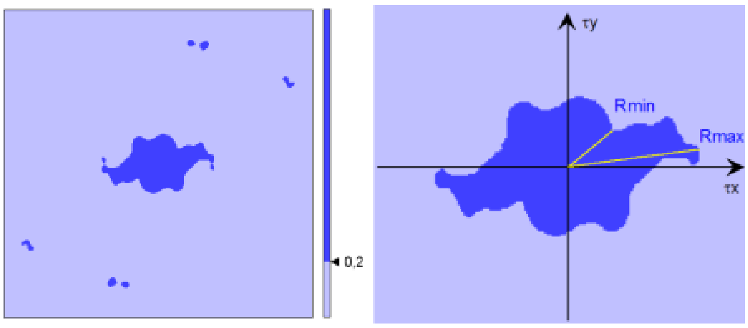
This function makes it possible to generate an image on which it is possible to measure characteristic quantities.



surface (left) - autocorrelation (right)

The autocorrelation image always includes a central peak with normalized amplitude of 1.0. In certain cases the image includes secondary peaks that indicate a certain correlation between portions of the surface with the surface itself. This is the case with surfaces including periodic or pseudo-periodic motifs. Indeed the form of the central peak is an indicator of the isotropy of the surface.

In order to characterise the form of the central peak, one carries out thresholding at 0,2 and then one quantifies the central zone of the image corresponding to the portion of the peak that remains after thresholding.



In this way it is possible to construct a parameter that will be an indicator of surface isotropy:

- ***Str*** : texture aspect ratio

$$Str=\frac{R\min}{R\max}$$

The minimum and maximum radii are sought on the image of the central lobe (generated by thresholding the central autocorrelation peak). If the surface presents the same characteristics in every direction, the central lobe will be approximately circular and the min and max radii will be approximately equal. If the surface presents a strong privileged orientation, the central lobe will be very stretched out and the max radius will be much greater than the min radius.

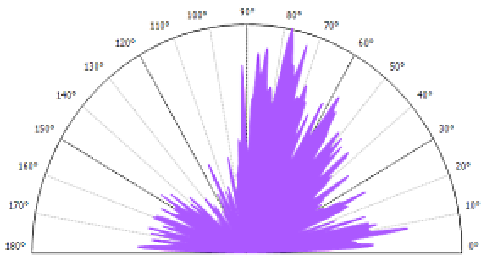
where Rmin and Rmax are the min and max radii calculated with respect to the perimeter of the central lobe. The radii are calculated from the coordinates of point (tx,ty) on the perimeter. Note that the threshold value of 0,2 is a default value but that for certain applications it can be advisable to choose a higher or lower value, notably to assure that the central lobe is well defined and does not touch the edges of the image. The Str parameter takes a value between 0 and 1, and is unitless. It can also be expressed as a percentage between 0% and 100%. An isotropic surface will have Str close to 1 (100%) while a strongly anisotropic surface will have Str close to 0.

The value Rmin equally provides a useful indication of the spectral content of the surface. A surface that is essentially made up from spectral components with long wavelengths yields a high Rmin, and inversely. Hence the parameter Sal is defined as follows:

- ***Sal***, fastest decay autocorrelation length. *Sal = Rmin*

This parameter is expressed in µm.

Another useful tool is the polar spectrum. The **Fourier spectrum**, when it is integrated in polar coordinates makes it possible to determine the privileged direction of surface structures. The polar spectrum takes into account the power spectrum of the surface in each direction. The angle with the largest power spectrum corresponds to the privileged **texture direction**.



The representation of the **polar spectrum** clearly shows the privileged directions. The angle corresponding to the polar spectrum maximum makes it possible to define the Std parameter:

- ***Std*** : texture direction.

This angle is expressed in degrees, anticlockwise.

Areal (Field) Functional Parameters

Bearing Ratio Parameters

Since bearing ratio parameters are related to the **height distribution**, they are easily extended to surfaces:

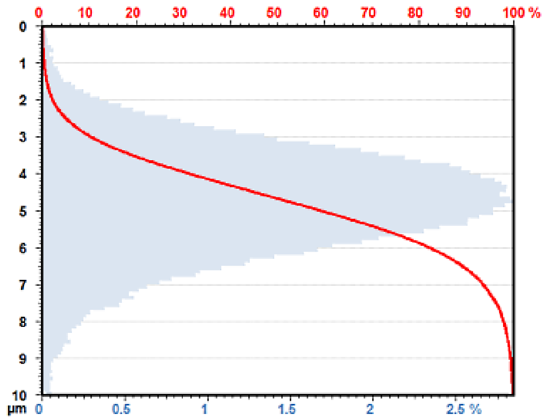
- ***Smr*** : areal material ratio
- ***Sdc*** : areal section height difference
- ***Smc*** : inverse areal material ratio

Note the appearance of a new parameter, Smc, which simply provides the inverse value of the bearing ratio, as opposed to Sdc which is the difference between two Smc.

A new parameter is defined specifically for the characterisation of emerging peaks that play a role in contacts between two surfaces:

- ***Sxp*** : peak extreme height

It is simply calculated as a Sdc with two **material ratios**, between 2,5% (highest peaks, excluding outliers) and 50% (the mean plane).



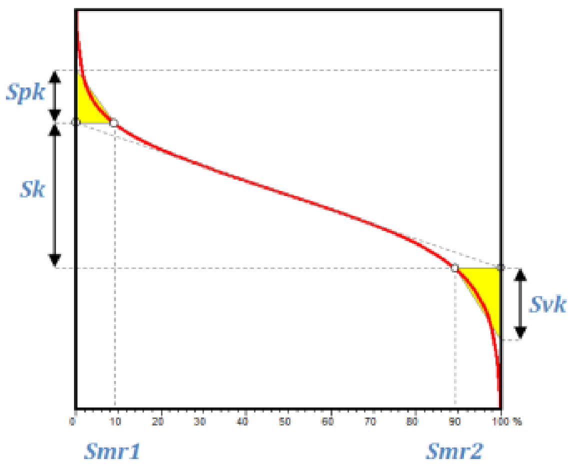
Sk Parameters

For a long time the mechanical engineering industry, and in particular the **automotive industry**, has tried to find ways of optimising parameters and filtering methods in order to make them more effective and to improve their correlation with functional phenomena.

The functional characterisation of surface texture is of fundamental importance for all mechanical parts that are in contact with another part, in other words for all parts with the exception of parts that have an aspect-related function.

The first reflex was to reproduce for a surface the graphical study of functional parameters defined in the **ISO 13565-2** standard, based upon the Rk, Rpk and Rvk parameters initially defined by the German automotive industry (DIN 4776/4777). For surfaces, their counterparts ***Sk***, ***Spk***, ***Svk***, ***Smr1*** and ***Smr2*** are calculated in the same way, with respect to the Abbott curve, itself calculated on the entire surface.

Nonetheless in due course the new volume parameters are expected to replace these functional parameters that were derived from profilometry standards.



Similarily, parameters defined in **ISO 13565-3** have been extrapolated to surfaces with ***Spq***, ***Svq*** and ***Smq***.

Functional Indices

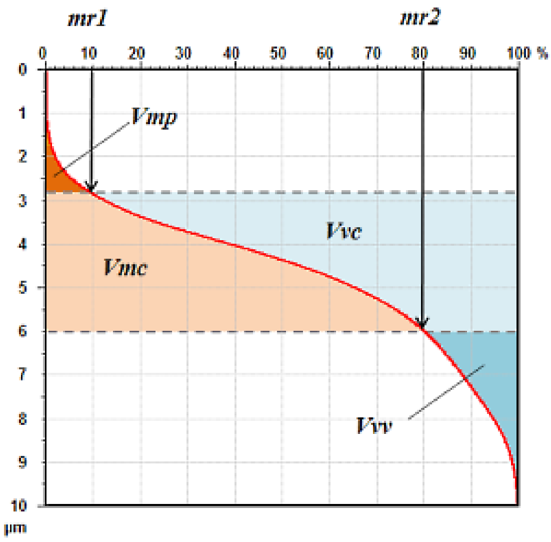
The European **SurfStand project** defined a set of functional indices making it possible to characterize surface zones involved in lubrication, wear and contact phenomena.

- ***Sbi***, surface bearing index characterizes, as Spk does, the upper zone of the surface involved in wear phenomena.
- ***Sci***, surface core fluid retention index characterizes the main void volume acting as a lubricant reserve.
- ***Svi***, surface valley fluid retention index characterizes, as Svk does, the void volume of the deepest valleys.

These parameters, despite their utility, only represent an intermediate step towards the definition of Volume parameters that further improve correlation with functional phenomena and are more relevant, while continuing to provide the support that has been provided by the functional indices. As a result, in the ISO 25178 standard, the functional indices have been superseded by Volume parameters.

Volume Parameters

These parameters represent an evolution of the functional indices and are defined, like the functional indices and the family of Sk parameters, with respect to the **Abbott curve**:



The parameters are defined with respect to two bearing ratio thresholds, set by default to 10% and 80%. Two material volume and two void volume parameters are defined:

- ***Vmp***: peak material volume
- ***Vmc***: core material volume
- ***Vvc***: core void volume
- ***Vvv***: valley void volume

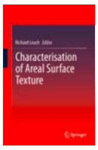
These parameters are expressed in units of volume per unit of surface (ml/m2 or µm3/mm2).

ISO 25178			
Functional Parameters (Volume)			
Vm	0.0072433	mm³/mm²	p = 25%
Vv	0.052237	mm³/mm²	p = 25%
Vmp	0.002144	mm³/mm²	p = 10%
Vmc	0.058961	mm³/mm²	p = 10%, q = 80%
Vvc	0.071198	mm³/mm²	p = 10%, q = 80%
Vvv	0.0062604	mm³/mm²	p = 80%

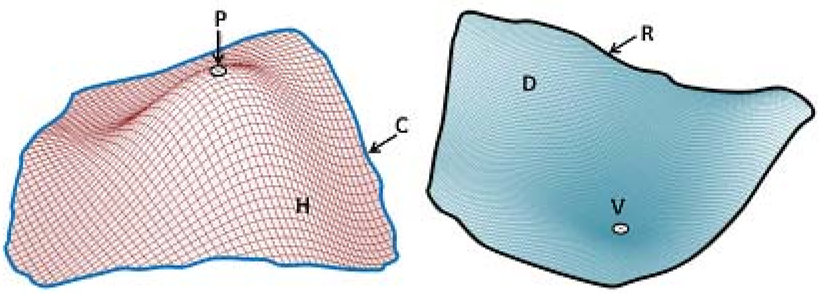
Topological characterization of surface motifs

In the 1970s, in France, engineers from the school of "Arts et Métiers" together with Peugeot and Renault conceived a graphical method for analysing **motifs**, adapted to the characterization of **functional and structured surface** texture. The great interest of this method is that it takes the functional requirements of the surface into account and attempts to find relationships between peak and valley locations and these requirements. This method, known as CNOMO E00.14.015.N had a great success in French industry and ended up being incorporated into an international standard in 1996 [ISO 12085]. During the past ten years, many players have tried to extrapolate this method to 3D, with little success. It was only when methods derived from image analysis were applied to areal surface texture that the benefits of the motifs method were rediscovered [SCOTT 1997, BARRÉ 2000]. This method is now officially integrated into the ISO 25178 standard, as a method of discriminating between significant peaks and holes, and equally as a method of characterizing 3D motifs.

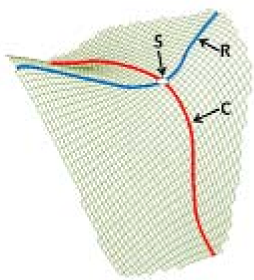
The method, currently called **segmentation**, is based upon the application of a **watersheds** algorithm, associated with an algorithm for simplifying graphs that describe the relationships between individual points (**Wolf pruning**) [WOLF 1993].



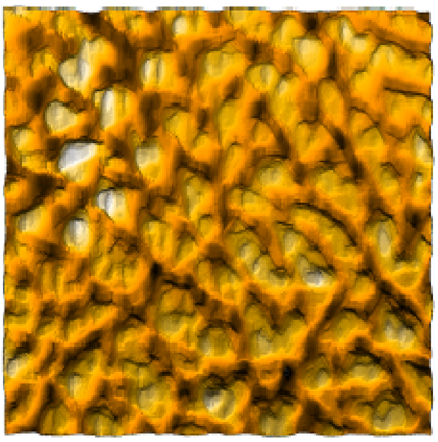
Details on how to calculate **ISO 25178** field parameters can be found in chapter 3 of [LEACH 2013].

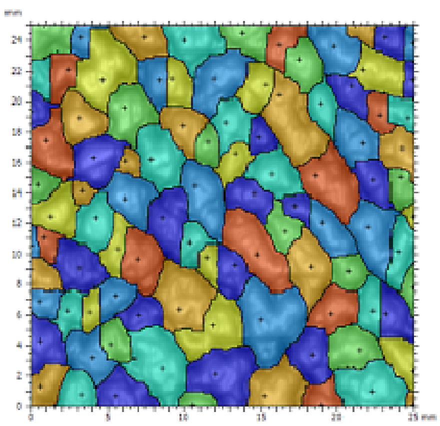


The name **Motifs** is used for either **hills** (H) or **dales** (D). A dale is surrounded by a **ridge line** (R) and its minimum point is the **pit** (V). A hill is delimited by a **course line** (C) and its maximum point is a **peak** (P).



Saddle (S) points are located at the intersection between course lines and ridge lines.





Above: Segmentation of a grained surface. The black crosses show the location of the peaks on each motif. Each motif represents a constituent element of the surface texture, capable of affecting the functionality of the part (lubrication, wear, contact, etc.) On the right image, each motif is represented by a different colour. MountainsMap® makes it possible to count and quantify the motifs, to sort them into ***open and closed motifs****, and to measure their area, mean depth, volume, etc.*

Segmentation is also a powerful tool for identifying **significant peaks** and **significant pits**, and is recommended when calculating peak density and peak curvature. ISO 25178 defines two new parameters that replace Sds and Ssc that were defined in the SurfStand report.

- ***Spd*** : density of peaks
- ***Spc*** : mean peak curvature

From the significant peaks and pits, it is then possible to define robust heights:

- ***S5p*** : five-point peak height
- ***S5v*** : five-point pit height
- ***S10z*** : ten-point height

With segmentation, these parameters become much more relevant than they were previously (when they were applied in accordance with the definitions in preceding European reports).

In addition, specific parameters have been created to quantify the area and mean volume of motifs identified by segmentation, distinguishing between open and closed motifs, depending upon whether or not they touch the edge of the image.

- ***Sha*** : mean hills area
- ***Sda*** : mean dales area
- ***Shv*** : mean hills volume
- ***Sdv*** : mean dales volume
