Michigan Metrology, LLC®

Surface Texture Parameters Glossary

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- Spatial Parameters
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- Functional Parameters
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- Legacy Parameters

Michigan Metrology Surface Texture Parameters Glossary

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• Parameters By Family • Parameters By Name • Parameters By Symbol

Texture Parameters Indexed by Symbol

Peak Extreme Height	Sxp (p,q)	Functional
Peak Material Portion	SMr1	Functional
Peak Material Volume	Vmp(p)	Functional
Peak Valley Portion	SMr2	Functional
Reduced Peak Height	Spk	Functional
Reduced Peak Height Along X,Y	Stylus (X,Y) Rpk	2D Stylus
Reduced Peak Height to Core Ratio	Spk/Sk	Functional
Reduced Peak Height to Reduced Valley Depth Ratio	Spk/Svk	Functional
Reduced Valley Depth	Svk	Functional
Reduced Valley Depth Along X, Y	Stylus (X,Y) Rvk	2D Stylus
Reduced Valley Depth to Core Ratio	Svk/Sk	Functional
Root Mean Square Profile Wavelength Along (X, Y)	Stylus (X,Y) λq	2D Stylus
Root Mean Square Roughness	Sq	Height
Root Mean Square Slope Along X,Y	Stylus (X,Y) Δq	2D Stylus
Root Mean Square Slope in X,Y	Slope Rq (X,Y)	Legacy
Root Mean Square Surface Slope	Sdq	Hybrid
Skewness	Ssk	Height
Stylus Δq Ratio	Stylus X Δq/Stylus Y Δq	2D Stylus
Stylus λq Ratio	Stylus X λq/Stylus Yλq	2D Stylus
Stylus Pc Ratio	Stylus X Pc/ Stylus Y Pc	2D Stylus
Stylus Ra Ratio	Stylus X Ra/Stylus Y Ra	2D Stylus
Stylus Rz Ratio	Stylus X Rz/Stylus Y Rz	2D Stylus
Summit Density	Sds	Hybrid
Surface Area Index	SAI	Legacy
Texture Aspect Ratio	Str	Spatial
Texture Direction	Std	Spatial
Void Volume	Vv(mr)	Functional

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• Parameters By Family • Parameters By Name • Parameters By Symbol

Texture Parameters Indexed by Symbol

Symbol	Parameter Name	Category
ACF	Autocorrelation Function	Spatial
APSDF	Angular Power Spectral Density Function	Spatial
mr	Material Ratio	Functional
NormVolume	Normalized Surface Volume	Legacy
Rpm	Average Maximum Peak Height	Legacy
Rvm	Average Maximum Valley Depth	Legacy
Rz	Average Maximum Height of the Surface	Legacy
Sa	Average Roughness	Height
SAI	Surface Area Index	Legacy
Sal	Autocorrelation Length	Spatial
Sdc(mr)	Inverse Areal Material Ratio	Functional
Sdq	Root Mean Square (RMS) Surface Slope	Hybrid
Sdr	Developed Interfacial Area Ratio	Hybrid
Sds	Summit Density	Hybrid
Sk	Core Roughness Depth	Functional
Sku	Kurtosis	Height
Slope Rq (X,Y)	Root Mean Squared Slope in X,Y	Legacy
SMr1	Peak Material Portion	Functional
SMr2	Peak Valley Portion	Functional
Smr(c)	Areal Material Ratio	Functional
Sp	Maximum Peak Height	Height
Spk	Reduced Peak Height	Functional
Spk/Sk	Reduced Peak Height to Core Ratio	Functional
Spk/Svk	Reduced Peak Height to Reduced Valley Depth Ratio	Functional
Sq	Root Mean Square Roughness	Height
Ssc	Mean Summit Curvature	Hybrid
Ssk	Skewness	Height
Std	Texture Direction	Spatial

Str	Texture Aspect Ratio	Spatial
Stylus (X,Y) Δq	Root Mean Square Slope Along X,Y	2D Stylus
Stylus X Δq/Stylus Y Δq	Stylus Δq Ratio	2D Stylus
Stylus (X,Y) λq	Root Mean Square (rms) Profile Wavelength Along (X, Y)	2D Stylus
Stylus X λq/Stylus Yλq	Stylus Yλq Ratio	2D Stylus
Stylus (X,Y) Pc	Peak Density Along X,Y	2D Stylus
Stylus X Pc/ Stylus Y Pc	Stylus Pc Ratio	2D Stylus
Stylus (X,Y) Rpk	Reduced Peak Height Along X,Y	2D Stylus
Stylus (X,Y) Ra	Average Roughness Along X, Y	2D Stylus
Stylus X Ra/Stylus Y Ra	Stylus Ra Ratio	2D Stylus
Stylus (X,Y) Rk	Core Roughness Along X, Y	2D Stylus
Stylus (X,Y) Rsm	Mean Profile Spacing Along X,Y	2D Stylus
Stylus (X,Y) Rt	Maximum Profile Height Along X, Y	2D Stylus
Stylus (X,Y) Rvk	Reduced Valley Depth Along X, Y	2D Stylus
Stylus (X,Y) Rz	Average Maximum Profile Height Along X, Y	2D Stylus
Stylus X Rz/Stylus Y Rz	Stylus Rz Ratio	2D Stylus
Sv	Maximum Valley Depth	Height
Svk	Reduced Valley Depth	Functional
Svk/Sk	Reduced Valley Depth to Core Ratio	Functional
Sxp (p,q)	Peak Extreme Height	Functional
Sz	Maximum Height of Surface	Height
Vmc(p,q)	Core Material Volume	Functional
Vm(mr)	Material Volume	Functional
Vmp(p)	Peak Material Volume	Functional
Vvc(p,q)	Core Void Volume	Functional
Vv(mr)	Void Volume	Functional
Vvv(p)	Dale Void Volume	Functional

3D (Areal) Filtering

- **F-Operator**
- **Long Wavelength Pass Filter**
- **Short Wavelength Pass Filter**
- **Band Pass Filter**
- **Notch Filter**

The measurement dataset consists of an array of values which represent heights at various points along the surface. Depending on the measurement technology such as stylus diameter, optical lens performance, camera resolution and electronics, a minimal spatial wavelength structure may be measured. Typically the smallest spatial wavelength that can be measured consists of 5 measured resolution elements along a given direction. The largest spatial wavelength that can be measured is limited to the full extent of the measured field. For example if a measurement is made over a 1mm lateral region then the largest spatial wavelength that can be ideally measured is 1mm long.

Many applications require only certain spatial wavelengths be included in the calculation of the various texture parameters. For example, a sealing surface may be better understood by considering a limited number of shorter spatial wavelength components since longer spatial wavelength structures may be easily conformed to by a compliant sealing material. Furthermore, to support correlation between different measurement systems it is imperative that the bandwidth of the spatial wavelength structures being measured are the same.

Once a surface is measured a mathematical operation is applied to remove any base form such as Tilt, Cylinder, Sphere, etc. if necessary. This mathematical operation is referred to as an F-operator in that the “form” is removed from the “raw” measurement prior to any additional filtering operations.

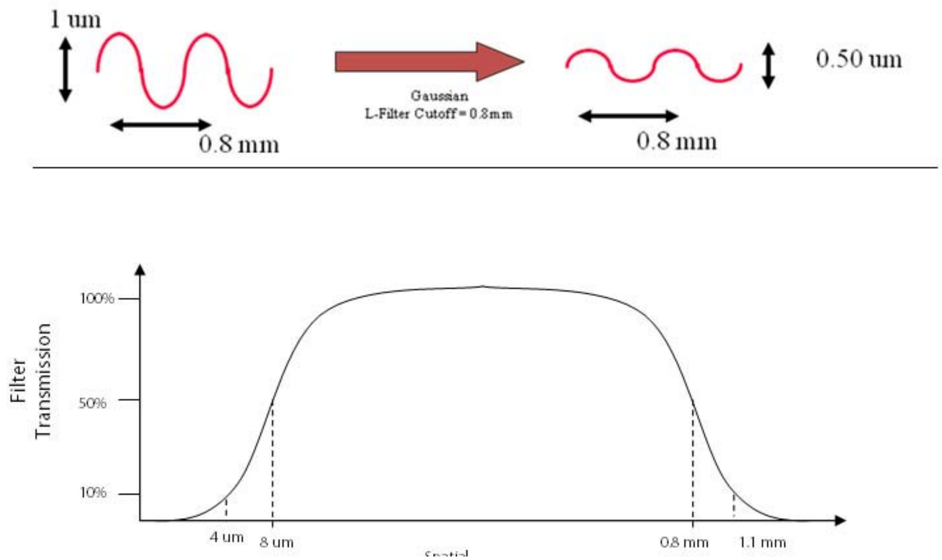
After the F-operator, a Gaussian filter is applied to the data which limits the short spatial wavelength (S-Filter) and long spatial wavelength (L-Filter) structures prior to analysis.

The S-Filter and L-Filter are characterized by cutoff lengths:

For example, a 0.8 mm cutoff-length L-Filter, implies that for structures with a spatial wavelength of 0.8 mm the amplitude presented for analysis is 50% of the amplitude of the unfiltered measured data. For spatial wavelengths greater than 0.8 mm the surface structure amplitudes are further attenuated such that spatial wavelengths components greater than 1.1 mm are attenuated by more than 90% prior to analysis. For spatial wavelengths less than 0.8 mm, surface structure amplitudes are minimally attenuated with wavelength components less than 0.5 mm being attenuated by 10% or less.

As another example, an 8 um cutoff-length S-Filter implies that for structures with a spatial wavelength of 8 um, the amplitude presented for analysis is 50% of the amplitude of the unfiltered measured data. For spatial wavelengths less than 8 um, the surface structures amplitudes are further attenuated such that spatial wavelength components less than 2 um are totally eliminated prior to analysis. For spatial wavelengths greater than 8 um, the surface features are minimally attenuated with wavelength components greater than 11 um being attenuate by about 10% or less.

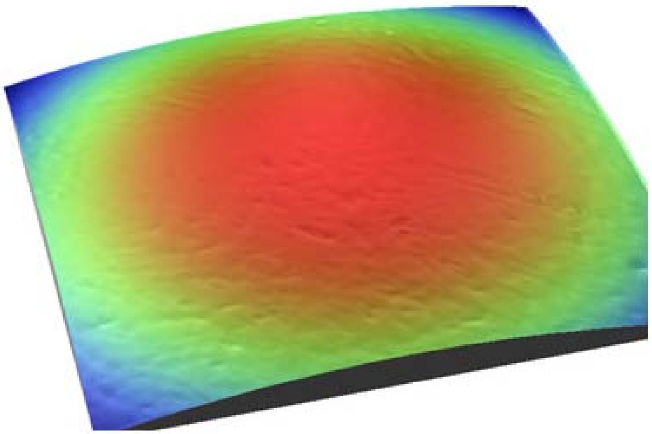
The following figure depicts the “bandwidth” and attenuation rate (rolloff) for an S-Filter of 8um and L-Filter of 0.8mm. The ASME B46.1-2002 reference includes graphs depicting the attenuation rates (rolloff) for various filter cutoff values.



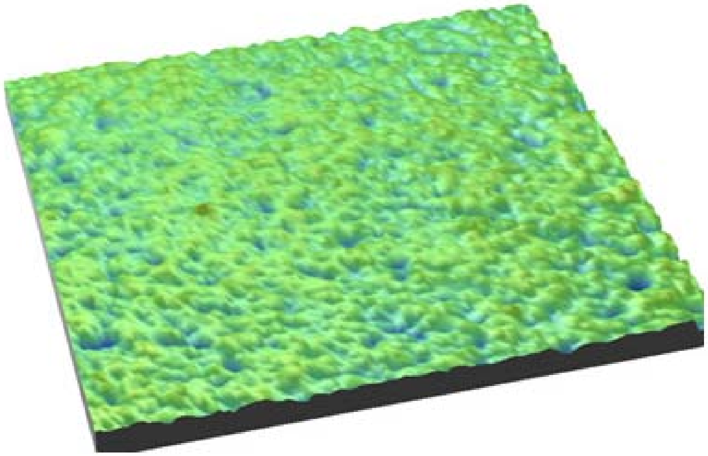
Transmission characteristics of a Gaussian filter with a S-Filter Cutoff of 8 um and a L-Filter cutoff of 0.8 mm

F-Operator

The F-Operator is used to remove the base form comprising the surface. As displayed in the figure below, a spherical surface is rendered “flat” after an F-Operator for spherical shape is applied. A number of F-Operators are available such as Tilt, Curvature (i.e. parabolic fit), Spherical (i.e. true spherical fit), Cylinder and various combinations. The F-Operator may be set to find the best fitting form based on a least squares fit or user-defined values for the radius of curvatures may be selected.



Spherical surface – as measured



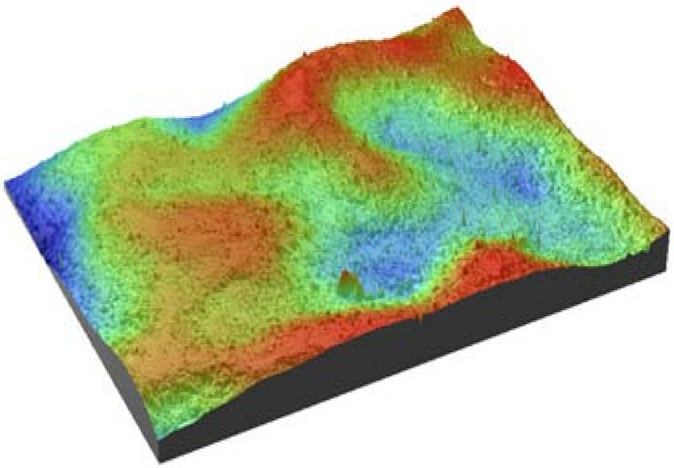
After F-Operator of spherical form applied

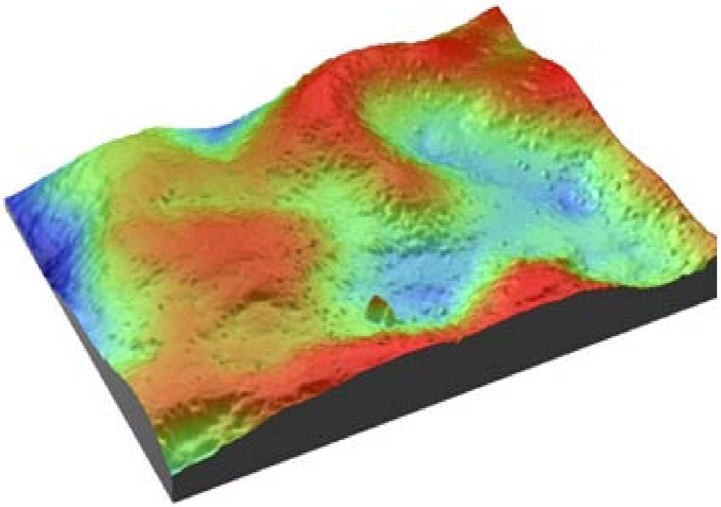
Long Wavelength Pass Filter

The S-Filter is used to attenuate the short spatial wavelength structures that may be present in the measurement from sources such as electronic noise or other measurement artifacts. Additionally, some surfaces may physically contain short spatial wavelength structures which are not relevant to the attended application and may affect subsequent analyses. The figure below demonstrates an

S-filter used to eliminate the shorter spatial wavelength components comprising the texture.

When only an S-filter is used, the type of filtering is termed **Long Wavelength Pass.**





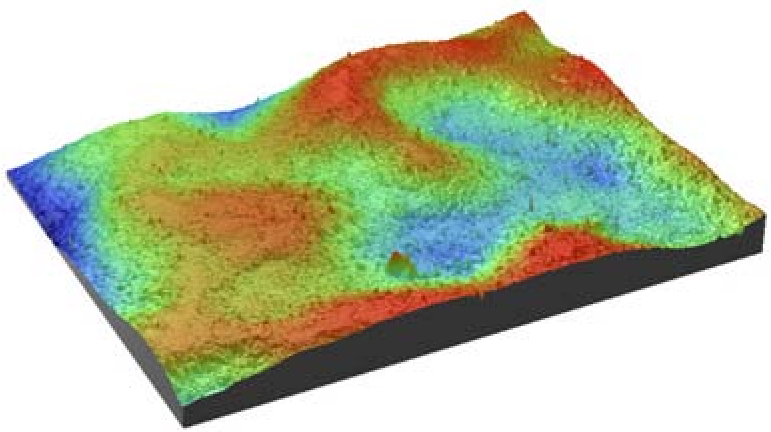
As measured surface without filtering consisting of finer spaced features superimposed on longer wavelength components.

S-Filter applied to eliminate short spatial wavelengths

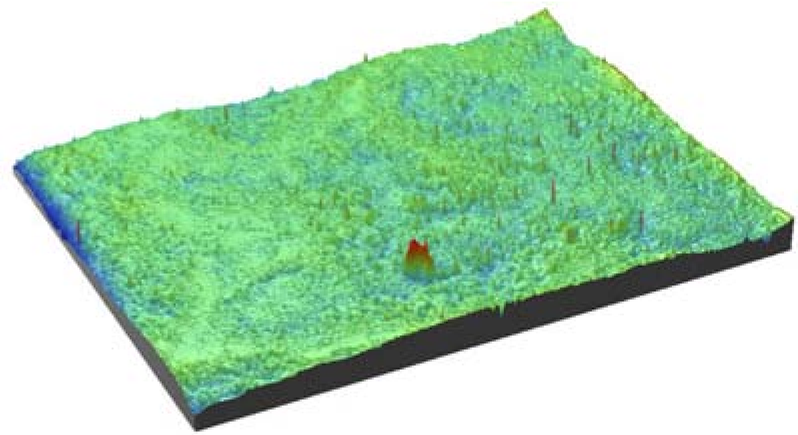
Short Wavelength Pass Filter

The L-Filter is used to attenuate the longer spatial wavelength structures that may be present in the measured surface, which are not relevant to the attended application and may affect subsequent analyses. The figure below demonstrates an L-Filter used to remove the longer spaced spatial structure revealing the finer spaced texture and peaked features..

When only an L-filter is used, the type of filtering is termed **Short Wavelength Pass.**



As measured surface without filtering consisting of finer spaced features superimposed on longer wavelength components.



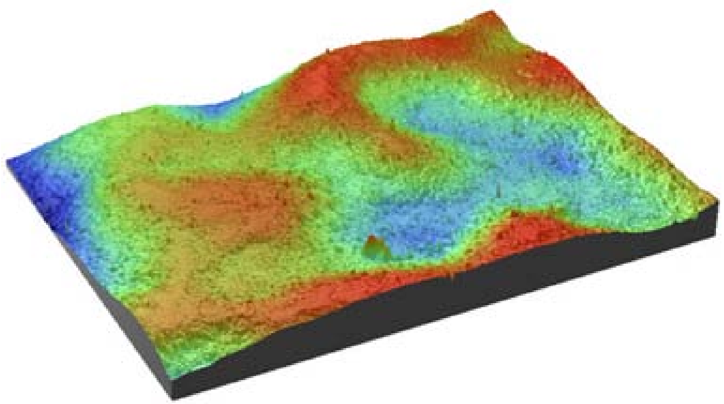
L-Filter applied to eliminate longer spatial wavelengths, revealing the finer spaced features.

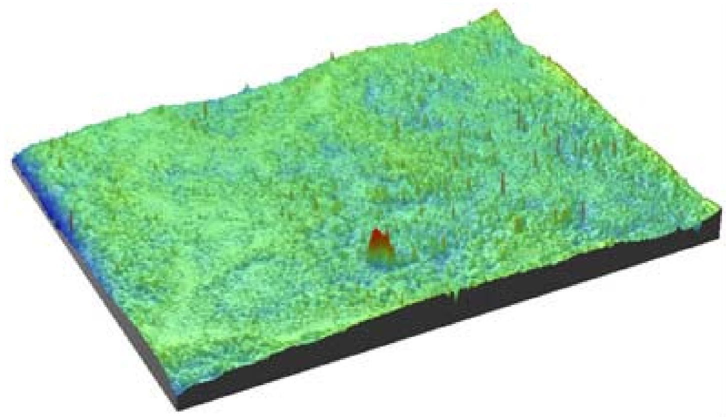
Band Pass Filter

The combination of an S-filter and an L-Filter may be used to establish a bandwidth of spatial wavelengths which are used for analysis.

When the spatial wavelength of the structure to be analyzed is contained between the S-Filter cutoff and the L-filter cutoff, the filter is termed a **Band Pass Filter.**

The figure below demonstrates the use of a Band Pass Filter which is comprised of an S-Filter to remove short spatial wavelength structures and an L-Filter used to remove the longer spatial wavelength structures. The final surface consists of a band of spatial wavelengths relevant to the application.





As measured surface without filtering consisting of finer spaced features superimposed on longer wavelength components.

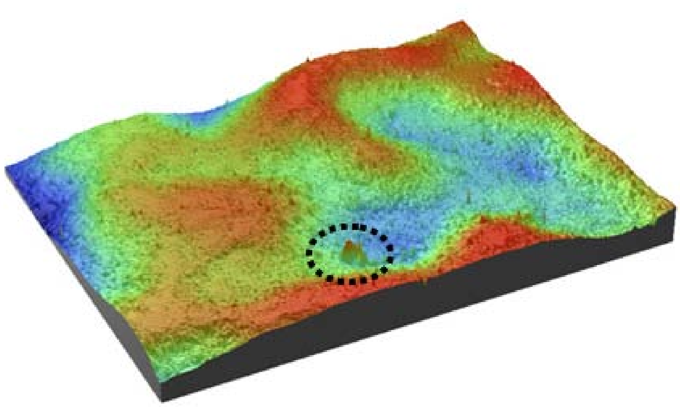
Band Pass Filter applied, eliminating long and short spatial wavelengths prior to analysis.

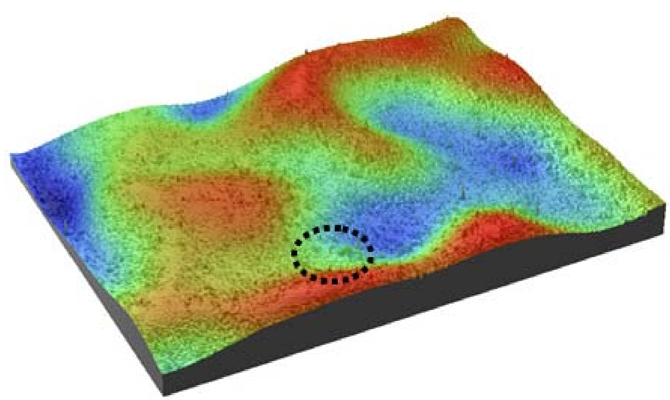
Notch Filter

The combination of an S-filter and an L-Filter may be used to eliminate a bandwidth of spatial wavelengths from analysis, maintaining the spatial structure with wavelengths less than the S-Filter Cutoff and spatial wavelengths greater than the L-filter Cutoff.

When the spatial wavelengths of the structure to be analyzed consists of spatial structure finer spaced that the S_Filter Cutoff and spatial structure with coarser spaced features than the L-Filter cutoff, the filter is referred to as a **Notch Filter.**

The figure below demonstrates that with a Notch Filter, features such as the isolated wider peaked regions (circled in the images) and moderate spatial structure lengths between the dominant mountain/valley features are eliminated.





As measured surface without filtering consisting of finer spaced features superimposed on longer wavelength components.

Notch Filter applied, resulting in the longer spatial wavelengths and shorter spatial wavelengths being preserved for subsequent analysis.

3D S Parameters

- **3D Filtering**
- **Height Parameters**
- **Spatial Parameters**
- **Functional Parameters**
- **Hybrid Parameters**

- ANSI/ASME B46.1-2002 "Surface Texture (Surface Roughness, Waviness and Lay)," American Society of Mechanical Engineers, 2002
- ANSI/ASME Y14.36-1996 "Surface Texture Symbols", 1996
- ISO 4287:1997 "Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters"
- ISO 13565-2:1996 "Geometrical Product Specifications (GPS) - Surface texture: Profile method; Surfaces having stratified functional
- Properties - Part 2: Height characterization using the linear material ratio curve"
- ISO/TC 213 N 470-1 "Geometrical Product Specification (GPS) -Surface Texture: Areal – Terms, definitions and surface texture parameters"
- D. J. Whitehouse, Handbook of Surface Metrology, Institute of Physics Bristol, 1994
- Leigh Mummery, Surface Texture Analysis, The Handbook Hommelwerke GmbH, 1992 ((203) 827-8500)
- H. Dagnall M.A., Exploring Surface Texture, Rank Taylor Hobson Limited, Leicester, England, 1986 ((800) 872-7265)
- K. J. Stout, Development of Methods for the Characterisation of Roughness in Three Dimensions, 2000, Penton Press, London, UK ISBN 1 8571 8023 2.

• Parameters By Family • Parameters By Name • Parameters By Symbol

3D S Parameters - Spatial Parameters

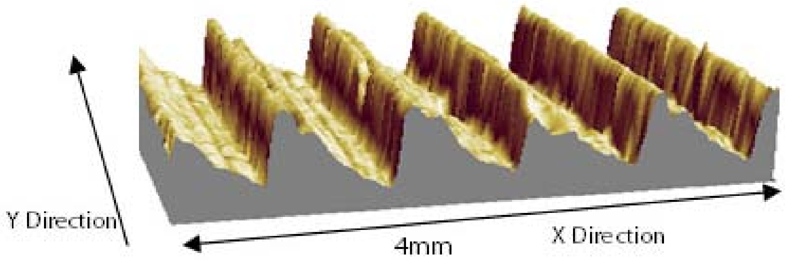
- **ACF (Autocorrelation Function)**
- **Sal (Autocorrelation Length) and Str (Texture Aspect Ratio)**
- **APSDF (Angular Power Spectral Density Function)**
- **Std (Texture Direction)**

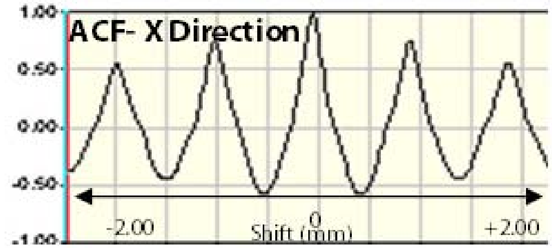
ACF (Autocorrelation Function)

The development of the spatial parameters involves the use of the mathematical technique of the autocorrelation function (ACF). This section will review the basic concepts behind the ACF necessary to understand the various spatial parameters.

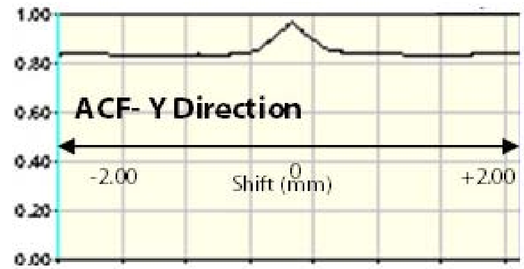
The ACF is found by taking a duplicate surface (Z(x-Dx,y-Dy)) of the measured surface ((Z (x, y)) and mathematically multiplying the two surfaces together, with a relative lateral displacement (Dx,Dy) between the two surfaces. Once multiplied together, the resulting function is integrated and normalized to Sq, to yield a measure of the degree of overlap between the two functions. If the shifted version of the surface is identical to the original surface then the ACF is 1.00. If the shifted surface is such that all peaks align with corresponding valleys then the ACF will approach –1.00.

Thus the ACF is a measure of how similar the texture is at a given distance from the original location. If the ACF stays near 1.00 for a given amount of shift, then the texture is similar along that direction. If the ACF falls rapidly to zero along a given direction, then the surface is different and thus “uncorrelated” with the original measurement location.





For the turned surface above, the ACF in the X direction falls to zero quickly as the peaks of the shifted surface align with the mean plane. The ACF along X becomes negative as the peaks of the surface align with the valleys of the shifted surface. Shifting along the Y direction, the surface is near identical to the original, resulting in the ACF in the Y direction remaining near 1.00.

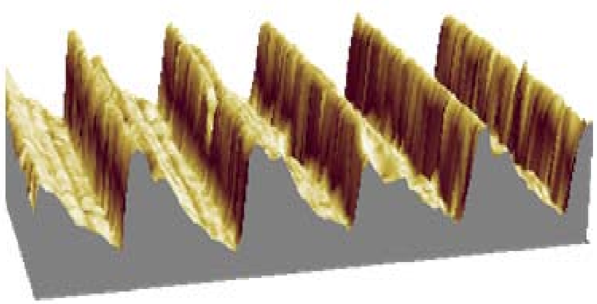


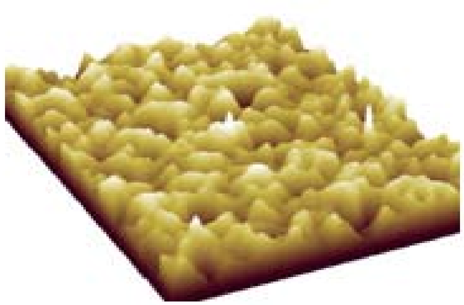
Sal (Auto-Correlation Length) and Str (Texture Aspect Ratio)

Sal, the Auto-Correlation Length, is a measure of the distance over the surface such that the new location will have minimal correlation with the original location. The direction over the surface chosen to find **Sal** is the direction which yields the lowest **Sa**l value. **Str**, the Texture Aspect Ratio, is a measure of the spatial isotropy or directionality of the surface texture. For a surface with a dominant lay, the **Str** parameter will tend towards 0.00, whereas a spatially isotropic texture will result in a **Str** of 1.00.

Sal = Length of fastest decay of ACF in any direction

$$\textbf{Str} = \frac{\textbf{Length of fastest decay of ACF in any direction}}{\textbf{Length of slowest decay ACF in any direction}}$$





Highly Directional Surface with Str of 0.11 and Sal of 37mm *Highly isotropic surface with Str of 0.88 with an Sal of 21mm*

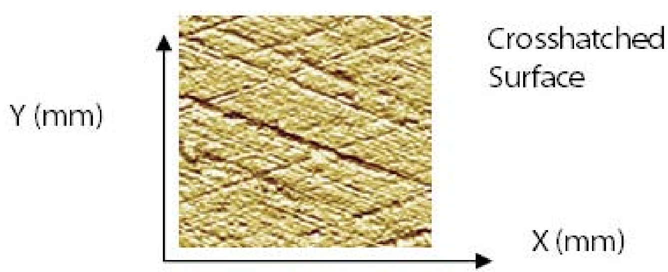
Application

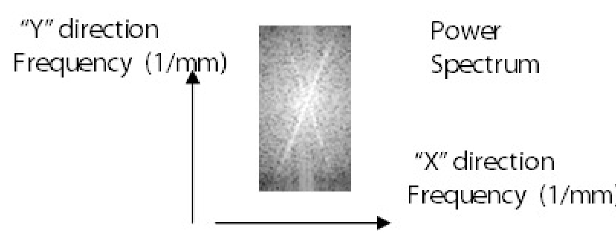
Str is useful in determining the presence of lay in any direction. For applications where a surface is produced by multiple processes,
Str may be used to detect the presence of underlying surface modifications. **Str** may find application in detecting subtle directionality on an otherwise isotropic texture. **Sal** is a quantitative measure as to the distance along the surface by which one would find a texture that is statistically different from the original location. **Sal** is useful in establishing the distance between multiple measurements made on the surface to adequately determine the general texture specification of the surface. **Sal** may find application related to the interaction of electromagnetic radiation with the surface and also tribological characteristics such as friction and wear.

APSDF (Angular Power Spectral Density Function)

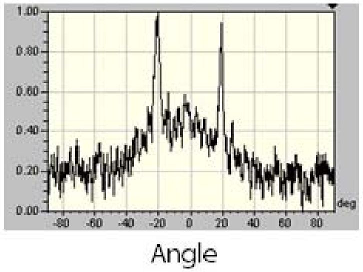
The development of the spatial parameters involves the use of the mathematical technique of the Angular Power Spectral Density Function (APSDF) This section will review the basic concepts behind the APSDF necessary to understand the Std spatial parameter.

From Fourier analysis, the surface texture is composed of a series of sine waves in all directions with different spatial frequencies (i.e. 1÷ spatial wavelength) and amplitudes. The power spectrum is a measure of the amplitude of each sine wave for a particular spatial frequency, along a given direction. Thus for a 3D surface, the power spectrum would be displayed as a “3D” function in which the X and Y axes represent the various spatial frequencies for a given direction. The amplitude of the power spectrum (displayed on the Z axis) represents the amplitude of the sine wave at a particular spatial frequency direction. The angular power spectrum is found by integrating the amplitudes of each component sine wave as a function of angle. The figures below demonstrate a crosshatched surface, the power spectral density of the surface and the angular power spectral density function.





The bright regions of the power spectrum for the crosshatched surface correspond to higher amplitude sine waves at a given combination of spatial frequencies along the X / Y directions. The two dominant bright lines are thus along a direction perpendicular to the two lay patterns of the crosshatched surface. The APSDF is found by integrating the power spectrum from the center out along a given radius and displaying the relative magnitude vs. angle. The two peaks in the APSDF correspond to the large sine wave amplitudes found along directions perpendicular to the two lay patterns of the crosshatched surface.

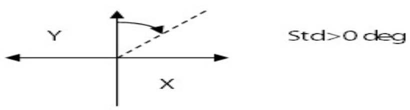


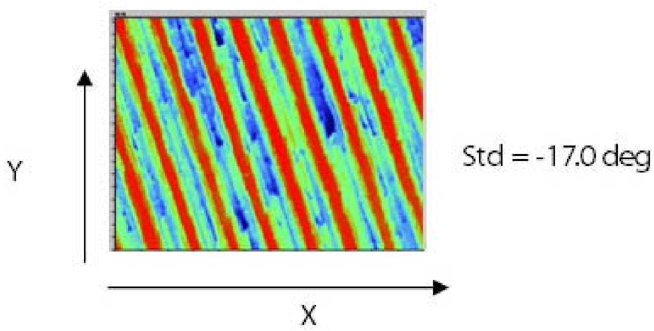
Std (Texture Direction)

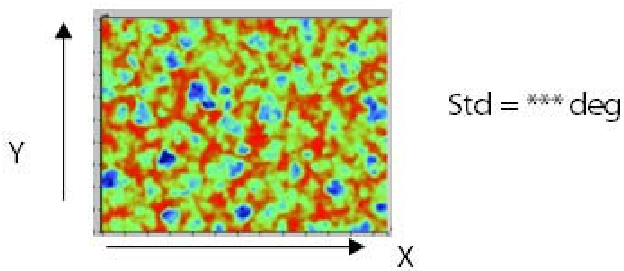
Std, the *texture direction*, is determined by the APSDF and is a measure of the angular direction of the dominant lay comprising a surface. **Std** is defined relative to the Y axis. Thus a surface with a lay along the Y axis will return a **Std** of 0 deg.

(Note that Std is not strictly defined in the ISO 25178-2 but was established earlier in the research which contributed to ISO 25178-2. Future sections of ISO 25178-2 may address parameters such as Std)

Std= Major direction of lay derived from APSDF







Since this surface is spatially isotropic there is no lay and thus Std is indeterminate

Application

Std is useful in determining the lay direction of a surface relative to a datum by positioning the part in the instrument in a known orientation. In some applications such as sealing, a subtle change in the surface texture direction may lead to adverse conditions. **Std** may also be used to detect the presence of a preliminary surface modification process (e.g. turning) which is to be removed by a subsequent operation (e.g. grinding followed by tumbling).

• Parameters By Family • Parameters By Name • Parameters By Symbol

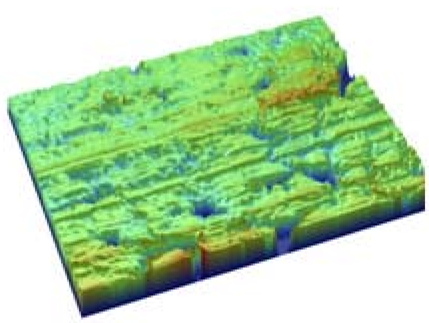
3D S Parameters - Hybrid Parameters

- **Sdq (RMS Surface Slope)**
- **Sdr (Developed Interfacial Area Ratio)**
- **Sds (Summit Density)**
- **Ssc (Mean Summit Curvature)**

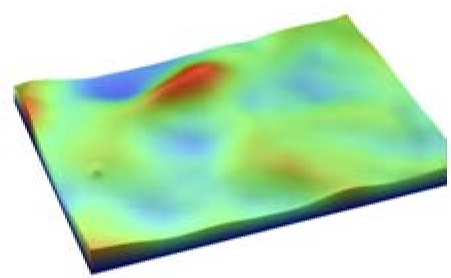
Sdq (Root Mean Square (RMS) Surface Slope)

Sdq is the Root Mean Square (RMS) Surface Slope comprising the surface, evaluated over all directions.

$$Sdq=\sqrt{\frac{1}{A}\int_0^{Lx}\int_0^{Ly}\left(\frac{\partial Z(x,y)}{\partial x}\right)^2+\left(\frac{\partial Z(x,y)}{\partial y}\right)^2 dydx}$$



Sa = 80 nm, Sdq=11.0 deg



Sa = 75 nm, Sdq=0.2 deg

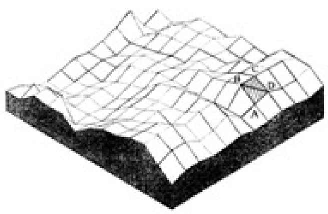
Application

Sdq is a general measurement of the slopes which comprise the surface and may be used to differentiate surfaces with similar average roughness, **Sa**. **Sdq** may find application for sealing systems, surface cosmetic appearance and may be related to the degree of surface wetting by various fluids. **Sdq** is affected both by texture amplitude and spacing. Thus for a given **Sa,** a wider spaced texture may indicate a lower **Sdq** value than a surface with the same **Sa** but finer spaced features, as demonstrated above.

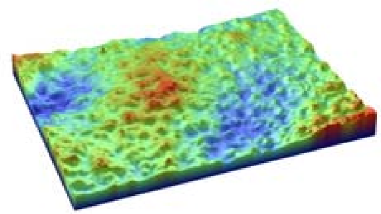
Sdr (Developed Interfacial Area Ratio)

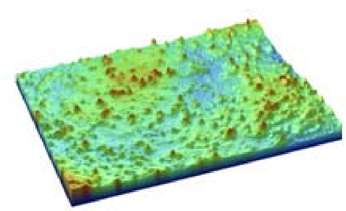
Sdr, the Developed Interfacial Area Ratio, is expressed as the percentage of additional surface area contributed by the texture as compared to an ideal plane the size of the measurement region.

$$Sdr = \frac{(Texture\_Surface\_Area) - (Cross\_Sectional\_Area)}{Cross - Sectional - Area}$$



Surface Area is the total area of all triangles formed over the texture at the resolution of measurement





Christopher A. Brown, William A. Johnsen, Kevin M. Hult, Scale-sensitivity, Fractal Analysis and Simulations, Int. J. Mach. Tools Manufact. Vol 38, Nos 5-6, pp. 633-637, 1998

Sa= 0.52 um , Sdr=0.0023%

Sa= 0.33 um , Sdr=0.0623%

Application

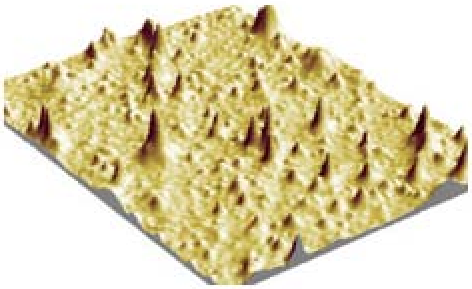
Sdr may further differentiate surfaces of similar amplitudes and average roughness. Typically **Sdr** will increase with the spatial intricacy of the texture whether or not **Sa** changes. **Sdr** is useful in applications involving surface coatings and adhesion. **Sdr** and may find relevance when considering surfaces used with lubricants and other fluids. **Sdr** is affected both by texture amplitude and spacing. Thus higher **Sa,** wider spaced texture may have actually a lower **Sdr** value than a lower **Sa** but finer spaced texture, as displayed above.

Sds (Summit Density)

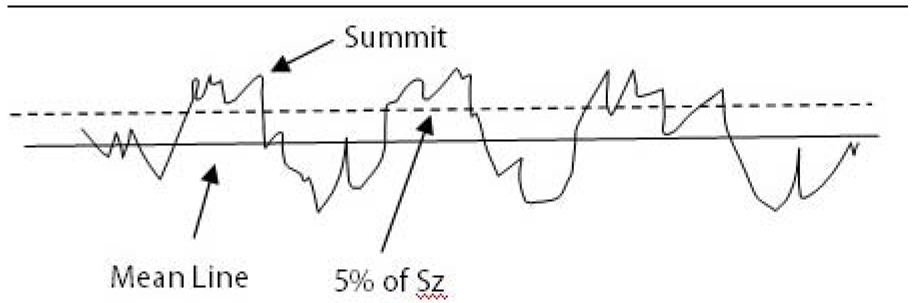
Sds, the Summit Density, is the number of summits per unit area making up the surface. Summits are derived from peaks. A peak is defined as any point, above all 8 nearest neighbors. Summits are constrained to be separated by at least 1% of the minimum “X” or “Y” dimension comprising the 3D measurement area. Additionally, summits are only found above a threshold that is 5% of Sz above the mean plane.

(Note that Sds is not strictly defined in the ISO 25178-2 but was established earlier in the research which contributed to ISO 25178-2. Future sections of ISO 25178-2 may address parameters such as Sds as “Feature Parameters”.)

$$S_{ds} = \frac{Number - of - Peaks}{Area}$$



Surface with Sds ~ 2600 summits/mm



Although a 2D profile is shown here, it is understood that this criteria is applied to the 3D features of the surface.

Application

Sds is a key parameter when considering surfaces used in applications such as bearings, seals and electronic contacts. The manner in which the summits elastically and plastically deform under load is related to the **Sds** parameter. Depending on the application, a low **Sds** may result in higher localized contact stresses resulting in possible pitting and debris generation. In applications involving sliding components, a number of summits are needed to prevent optical contacting while maintaining a reasonable load distribution. Summit density may also be related to the cosmetic appearance of a surface once painted.

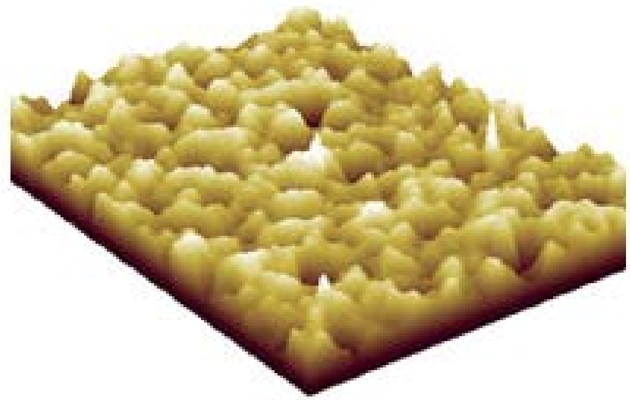
Ssc (Mean Summit Curvature)

Ssc is the Mean Summit Curvature for the various peak structures. Peaks are found as described above for the summit density. **Ssc** is given by the following:

(Note that Ssc is not strictly defined in the ISO 25178-2 but was established earlier in the research which contributed to ISO 25178-2. Future sections of ISO 25178-2 may address parameters such as Sds as “Feature Parameters”.)

$$Ssc = \frac{1}{N} \iint_{Summit-Area} \left(\frac{\partial^2 z(x,y)}{\partial x^2} \right) + \left(\frac{\partial^2 z(x,y)}{\partial y^2} \right) dxdy$$

Evaluated only over the summit features.



Shot Peened Surface for which Ssc = 37 mm-1 (i.e. mean radius of curvature is 27mm)

Application

Ssc is useful in predicting the degree of elastic and plastic deformation of a surface under different loading conditions and thus may be used in predicting friction, wear and real area of contact for thermal/electrical applications.

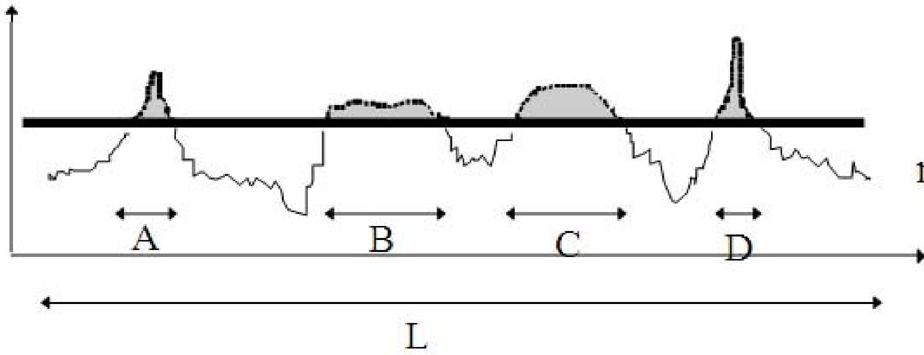
3D S Parameters - Functional Parameters

- **mr (Material Ratio)**
- **Smr(c) Areal Material Ratio**
- **Sdc(mr) Inverse Areal Material Ratio**
- **Spk, Sk, Svk, SMr1, SMr2**
- **Spk/Sk, Svk/Sk, Spk/Svk**
- **Sxp (p,q) (Peak Extreme Height)**
- **Vv(mr), Vvv(p), Vvc(p,q)**
- **Vm(mr), Vmp(p), Vmc(p,q)**

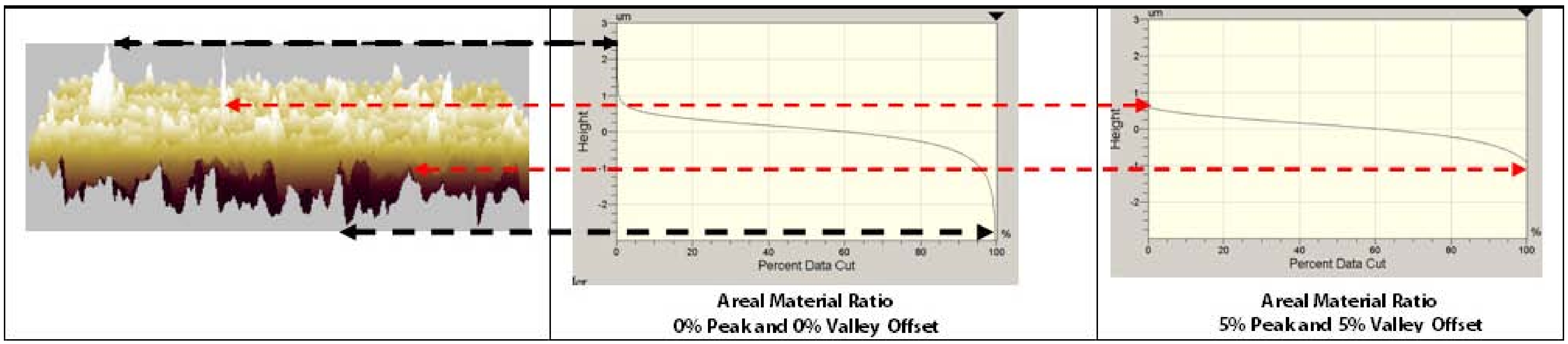
mr (Material Ratio)

The Material Ratio, **mr**, is the ratio of the intersecting area of a plane (i.e. parallel to the mean plane) passing through the surface at a given height to the cross sectional area of the evaluation region. The **Areal Material Ratio Curve** (*aka* **Bearing Area Curve** or **Abbot Firestone Curve**) is established by evaluating **mr** at various levels from the highest peak to the lowest valley.

Prior to establishing the Areal Material Ratio Curve, a certain percentage of the peak points (i.e., the **Peak Offset**) and valley points (i.e., the **Valley Offset**) are eliminated to minimize the effects of outliers. Typically the Peak Offset and Valley Offset are set to 1%, unless otherwise specified. **mr** is also referred to as “**Percent Data Cut**.”



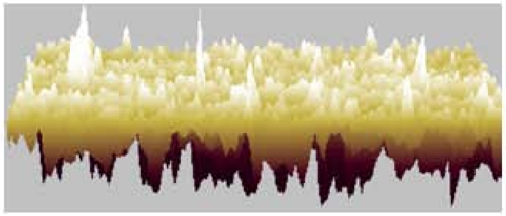
$$mr = 100\% \times (A + B + C + D)/L$$

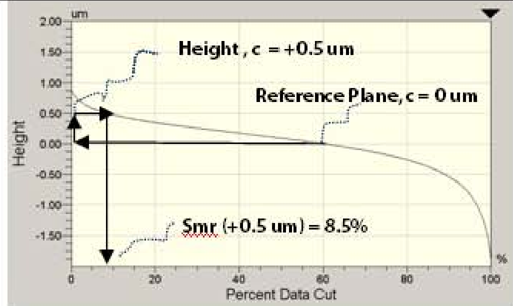


Areal Material Ratio Curve and evaluation of mr. Note that the profiles is shown above for simplicity. When evaluating the 3D (Areal) parameters the analysis applies to the complete 3D dataset.

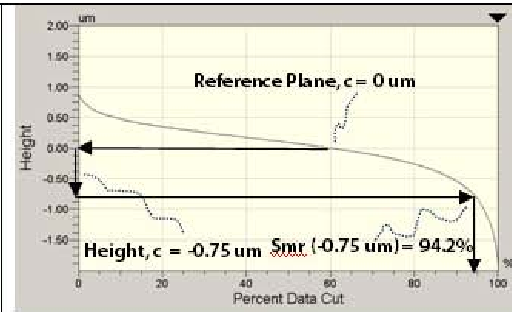
Smr(c) (Areal Material Ratio)

The Areal Material Ratio, **Smr(c)** is the ratio (expressed as a percentage) of the cross sectional area of the surface at a height (c) relative to the evaluation cross sectional area. The height (c) may be measured from the best fitting least squares mean plane or as a depth down from the maximum point of the Areal Material Ratio Curve.

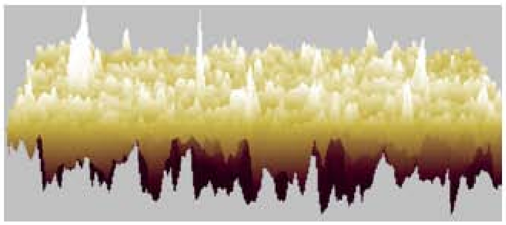


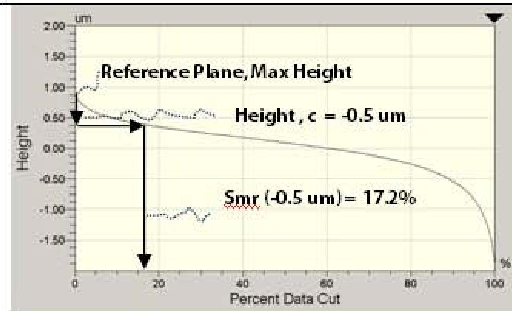


Smr(+0.5 um) = 8.5%
Reference Plane = Best Fit Mean Plane

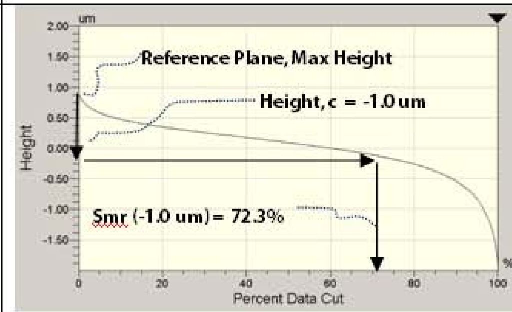


Smr(-0.75 um) = 94.2%
Reference Plane = Best Fit Mean Plane





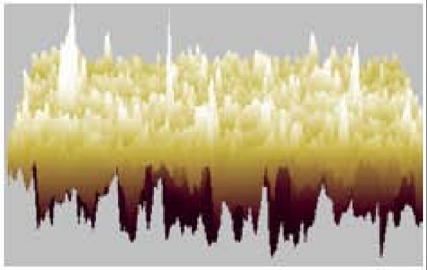
Smr(-0.5um) = 17.2%
Reference Plane = Max of Areal Material Ratio Curve

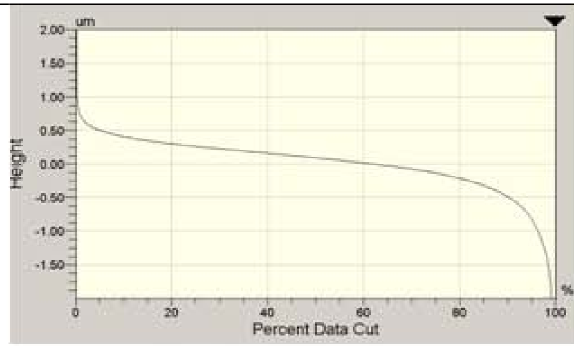


Smr(-1.0 um) = 72.3%
Reference Plane = Max of Areal Material Ratio Curve

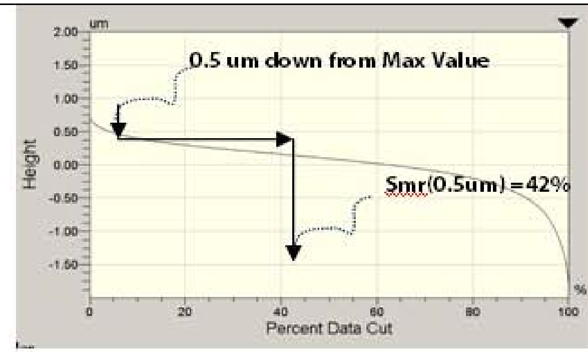
Application

Smr(c) may used to determine the amount of bearing area remaining after a certain depth of material is removed from the surface. A typical application may be in the specification of engine cylinder bore surfaces prior to running-in. Typically a cylinder bore may be honed to produce a pattern consisting of a plateau-like surface upon which are superimposed fine peaked structures. The fine peaked structure is provided to augment final running-in/seating of the sliding piston rings. Thus a specification for a surface may be **Smr(0.5µm) > 40%,** measured from the Max Value Areal Material Ratio curve with 1% peak and 1% valley offsets. This specification would be developed based on experiments that determine, for example, that running-in typically removes the top 0.5µm of the surface heights before surface stabilization.





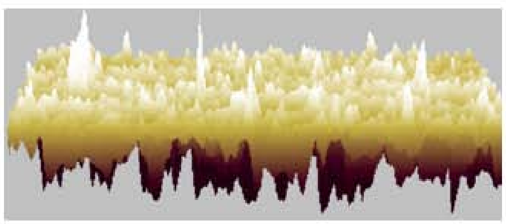
Areal Material Ratio Curve
0% Peak and 0% Valley Offset

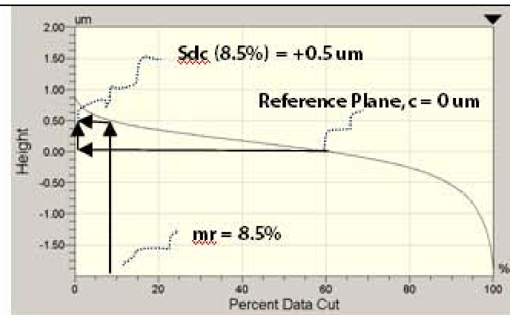


Bearing Ratio Curve 1% Peak and 1% Valley Offset
Smr(0.5um) >40%

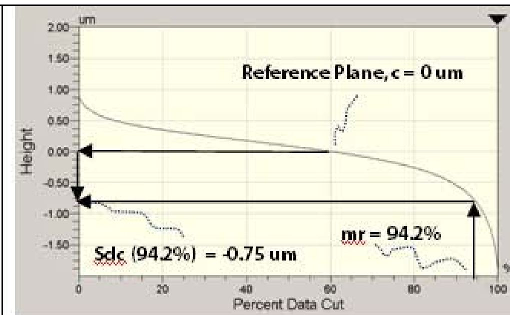
Sdc(mr) (Inverse Areal Material Ratio)

The Inverse Areal Material ratio, **Sdc(mr)** is the height , **c**, which gives the specified material ratio, **mr.** The height **c** may be measured from the best fitting least squares mean plane or as a depth down from the maximum point of the Areal Material Ratio Curve.

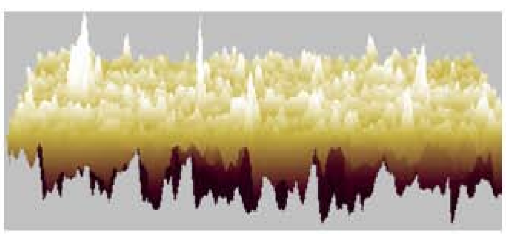


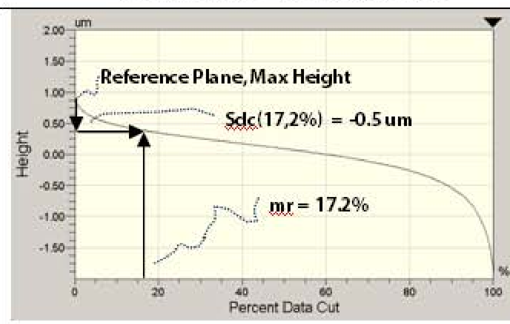


Sdc(8.5%) = +0.5um
Reference Plane = Best Fit Mean Plane

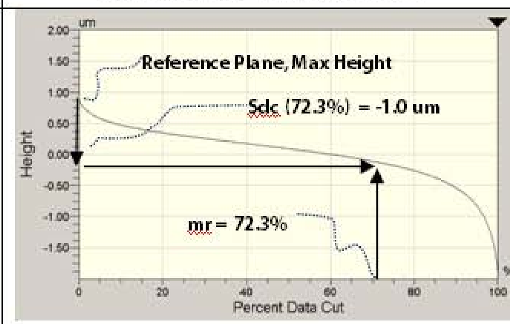


Sdc(94.2%) = -0.75um
Reference Plane = Best Fit Mean Plane





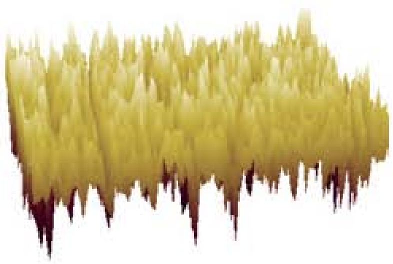
Sdc(17.2%) = -0.5 um
Reference Plane = Max of Areal Material Ratio Curve

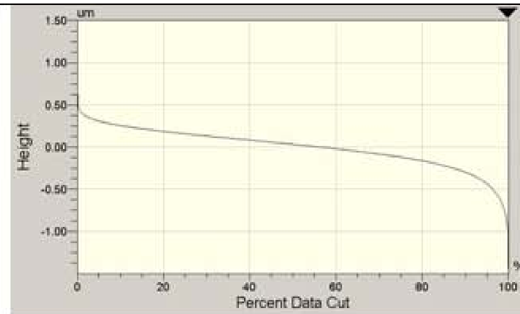


Sdc (72.3%) = -1.0 um
Reference Plane = Max of Areal Material Ratio Curve

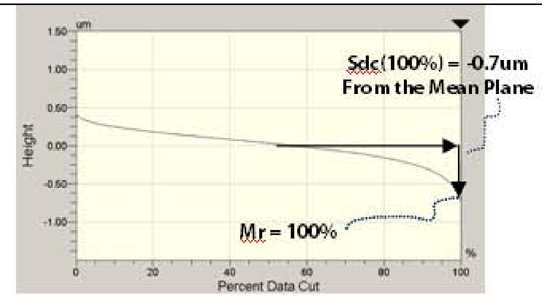
Application

Sdc(mr) might be used to assure that an optimum crevice volume is produced for a sealing surface to allow for some lubricant entrapment (to prevent running dry) but not be too deep to prevent leakage. For example, a specification such as -0.4 um <Sdc(100%)<-0.8 µm with a 1% peak and 1% valley offset, measured from the mean plane, would assure that the bottom 50% or the surface would extend at least 0.4 um below the mean plane but no greater than 0.8µm.





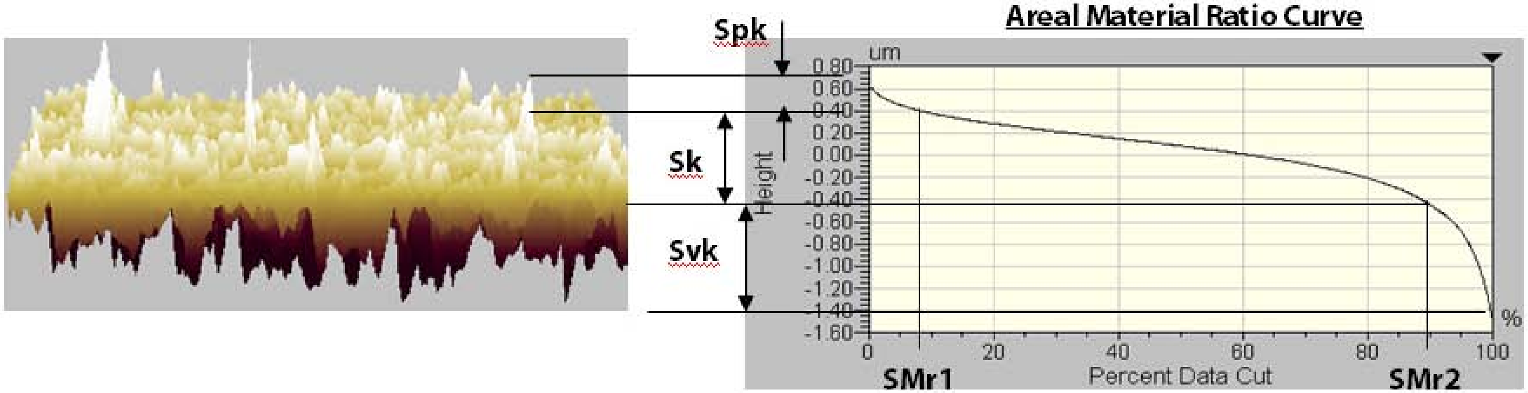
Areal Material Ratio Curve
0% Peak and 0% Valley Offset



Bearing Ratio Curve 1% Peak and 1% Valley Offset
-0.4 um < Sdc(100%) < -0.8 um
Reference Plane = Best Fit Mean Plane

Spk (Reduced Peak Height), Sk (Core Roughness Depth), Svk (Reduced Valley Depth), SMr1 (Peak Material Portion), SMr2 (Peak Valley Portion)

The parameters **Spk**, **Sk**, **Svk**, **SMr1**, and **SMr2** are all derived from the Areal Material Ratio curve based on the ISO 13565-2:1996 standard. The Reduced Peak Height, **Spk**, is a measure of the peak height above the core roughness. The Core Roughness Depth, **Sk**, is a measure of the "core" roughness (peak-to-valley) of the surface with the predominant peaks and valleys removed. The Reduced Valley Depth, **Svk**, is a measure of the valley depth below the core roughness. **SMr1**, the Peak Material Portion, indicates the percentage of material that comprises the peak structures associated with **Spk**. The Valley Material Portion, **SMr2**, relates to the percentage (i.e., 100%-**SMr2**) of the measurement area that comprises the deeper valley structures associated with **Svk**.

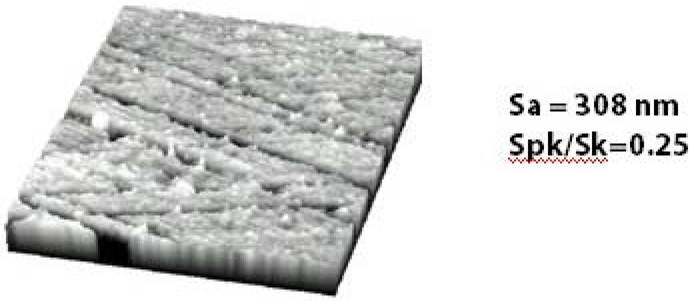


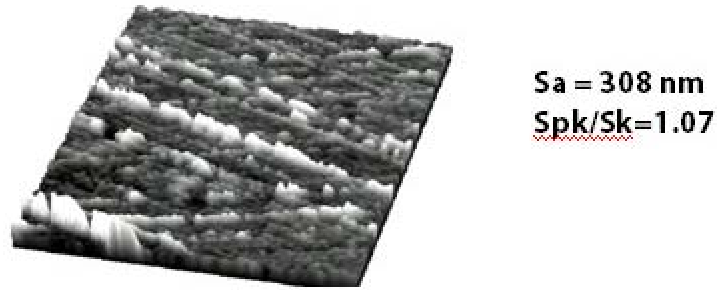
Application

A large **Spk** implies a surface composed of high peaks providing small initial contact area and thus high areas of contact stress (force/area) when the surface is contacted. Thus **Spk** may represent the nominal height of the material that may be removed during a running-in operation. Consistent with **Spk**, **SMr1** represents the percentage of the surface that may be removed during running-in. **Sk** represents the core roughness of the surface over which a load may be distributed after the surface has been run-in. **Svk** is a measure of the valley depths below the core roughness and may be related to lubricant retention and debris entrapment. **Sk** is a measure of the nominal roughness (peak to valley) and may be used to replace parameters such as **Sz** when anomalous peaks or valleys may adversely affect the measurement.

Spk/Sk (Reduced Peak Height to Core Ratio), Svk/Sk (Reduced Valley Depth to Core Ratio), Spk/Svk (Reduced Peak Height to Reduced Valley Depth Ratio)

The ratios of the various areal material ratio parameters **Spk/Sk** , the Reduced Peak Height to Core Ratio, **Svk/Sk**, the Reduced Valley Depth to Core Ratio, and **Spk/Svk**, the Reduced Peak Height to Reduced Valley Depth Ratio may be helpful in further understanding the nature of a particular surface texture. In some instances, two surfaces with indistinguishable roughness average (**Sa**) may be easily distinguished by a ratio such as **Spk/Sk**. For example a surface with high peaks as opposed to a surface with deep valleys may have the same **Sa** but with vastly different **Spk/Sk** values.





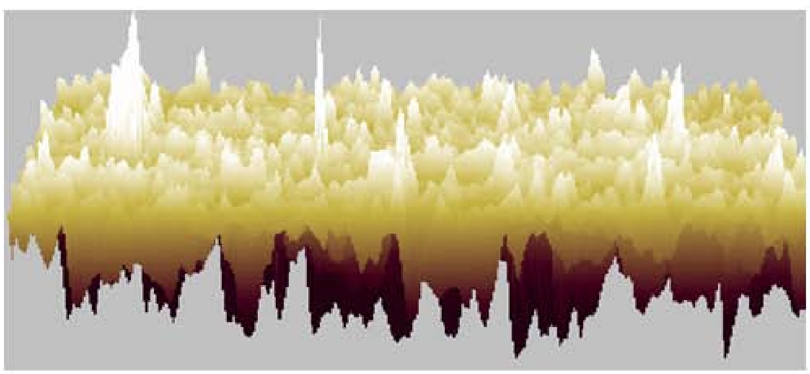
Two surfaces with the same Sa but different Spk/Sk values.

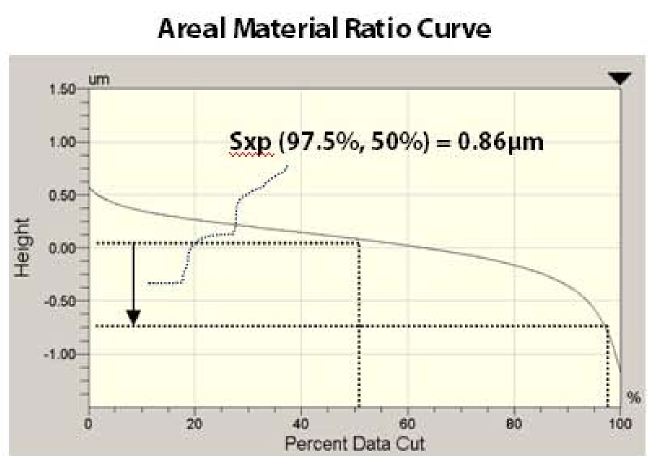
Application

By considering the ratios such as **Spk/Sk**, **Svk/Sk** and **Spk/Svk** one may determine quantitatively the dominance of peak structures relative to valley structures. In typical tribological applications such as seals and bearings these ratios may be useful in differentiating surfaces that have similar surface roughness as measured by **Sa**. The ratios may be further thought of as a measure of the texture amplitude distribution normalized by the overall roughness magnitude and thus may be used to characterize the texture amplitude symmetry.

Sxp (p,q) Peak Extreme Height

The Peak Extreme Height, **Sxp (p,q)**, is a measure of the difference in heights on the surface from the areal material ratio value of "p" and the areal material ratio of "q". The default value for "p" is 97.5% and the default value for "q" is 50%.





Application

Assuming a surface was worn or modified such that the resulting material area was 50%, **Sxp** (97.5%, 50%) indicates the depth of the remaining material to the lowest regions of the texture. Thus **Sxp** (97.5%,50%) may be used to determine the depth of material available after 50% or the surface has either been removed or deformed to a plateau-like structure. By changing the values of "p" and "q", **Sxp** (p,q) may be used to control other aspects of the texture.

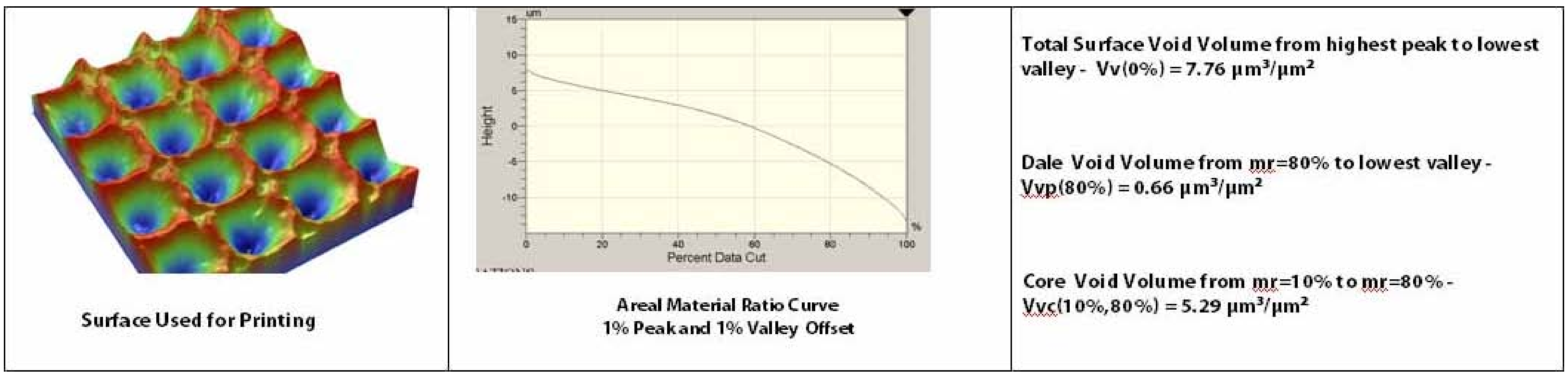
As another example, **Sxp** (90%, 10%) may be used to control the overall "peak-to valley" height of the surface by not accounting for the top 10% of the surface which may likely be easily deformed/worn and the bottom 10% which may be easily filled in during initial surface interactions.

Vv(mr) (Void Volume), Vvv(p) (Dale Void Volume), Vvc(p,q) (Core Void Volume)

Vv(mr), the Void Volume, is the volume of space bounded by the surface texture from a plane at a height corresponding to a chosen "**mr**" value to the lowest valley. "**mr**" may be set to any value from 0% to 100%.

Vvv(p), the Dale Void Volume, is the volume of space bounded by the surface texture from a plane at a height corresponding to a material ratio (mr) level, "**p**" to the lowest valley. The default value for "**p**" is 80% but may be changed as needed.

Vvc(p,q), The Core Void Volume, is the volume of space bounded by the texture at heights corresponding to the material ratio values of "**p**" and "**q**". The default value for "**p**" is 10% and the default value for "**q**" is 80%.



Example of Void, Dale Void and Core Void volumes. Note: The units for the Vv(mr), Vv(p) and Vvc(p,q) are ***um3/um2*** *- the void volume normalized by the cross sectional area of the measurement area. The peak offsets and valley offsets are applied prior to analysis.*

Application

Vv(mr), **Vvv(p)** and **Vvc(p,q)** all indicate a measure of the void volume provided by the surface between various heights as established by the chosen material ratio(s) values. Thus these three void volume parameters indicate how much fluid would fill the surface (normalized to the measurement area) between the chosen material ratio values. For example, a **Vv(25%)** = 0.5 µm3/µm2 in (note how the units µm3/µm2 reduce to µm) that a 0.5 µm thick film over the measurement area would provide the same volume of fluid as needed to fill the measured surface from a height corresponding to mr=25% to the lowest valley.

The void volume parameters are useful when considering fluid flow, coating applications and debris entrapment. A new surface may be specified by **Vv(0%)** which would indicate the total initial void volume provided by the texture. The Core Void Volume ,

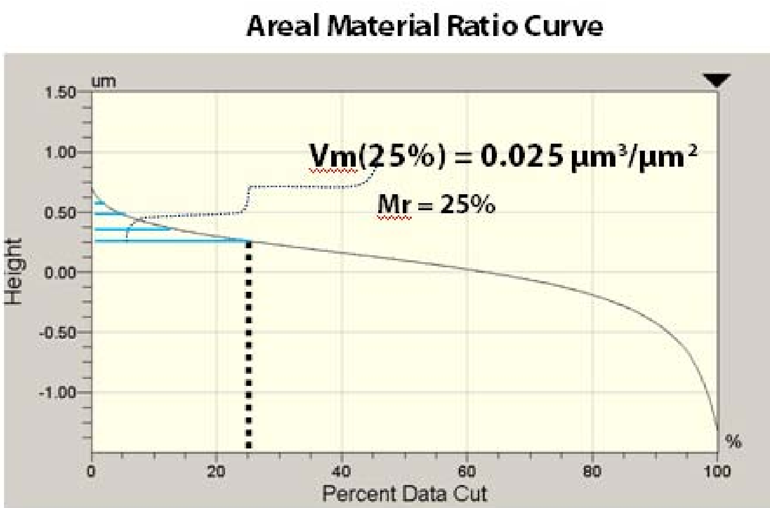
Vvc, may be useful to establish how much core space is available once a surface has been run-in resulting in decreased peak heights . The Dale Void Volume, **Vvv(p)** may be useful in indicating the potential remaining volume after significant wear of a surface has resulted.

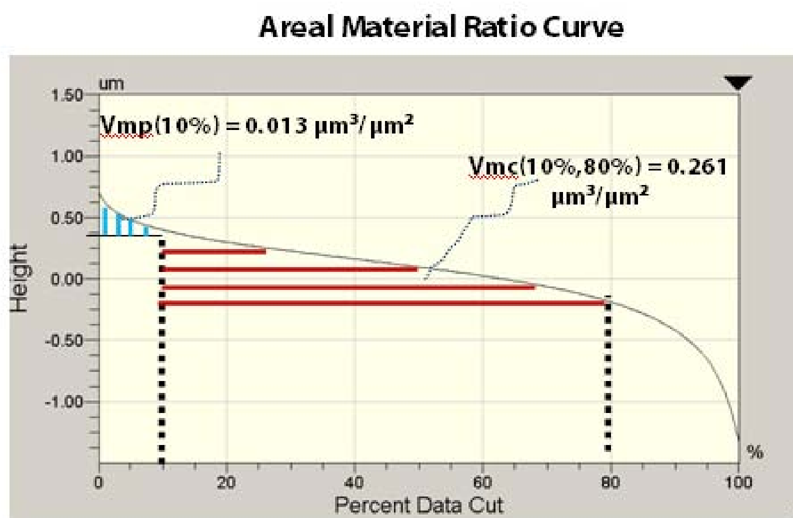
Vm(mr) (Material Volume) , Vmp(p) (Peak Material Volume), Vmc(p,q) (Core Material Volume)

Vm(mr), the Material Volume**,** is the volume of material comprising the surface from the height corresponding to **mr** to the highest peak of the surface. "**mr**" may be set to any value from 0% to 100%.

Vmp(p), the Peak Material Volume, is the volume of material comprising the surface from the height corresponding to a material ratio level, "**p**", to the highest peak. The default value for "**p**" is 10% but may be changed as needed.

Vmc(p,q), the Core Material Volume, is the volume of material comprising the texture between heights corresponding to the material ratio values of "**p**" and "**q**". The default value for "**p**" is 10% and the default value for "**q**" is 80% but may be changed as needed.





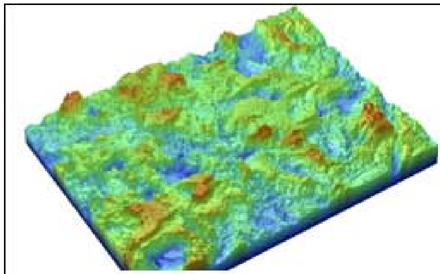
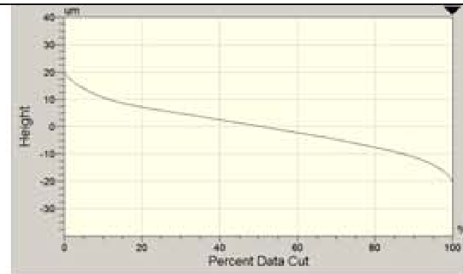
*Note: The units for the Vv(mr), Vv(p) and Vvc(p,q) are **µm3/µm2** - the void volume normalized by the cross sectional area of the measurement area. The peak offsets and valley offsets are applied prior to analysis.*

Application

Vm(mr), **Vmp(p)** and **Vmc(p,q)** all indicate a measure of the material forming the surface at the various heights down from the highest peak of surface or between various heights as defined for Vmc(p,q).

For example, a **Vm(10%)** =0.35µm3/µm2 would indicate (note how the units µm3/µm2 reduce to µm) that a layer 0.35µm thick of material over the measured cross section would account for all the material from the highest peak to the 10% point on the bearing area curve.

The various Material Volume parameters are useful to understand how much material may be worn away for a given depth of the bearing curve (i.e. **Vmp(p)**) and how much material is available for load support once the top levels of a surfaces are worn away (i.e. **Vmc(p,q)**). For sealing applications, **Vmp(p)** may provide insight into the amount of material available for seal engagement whereas **Vvc(p.q)** (see above) may then provide information about the resulting void volume for fluid entrapment or leakage.

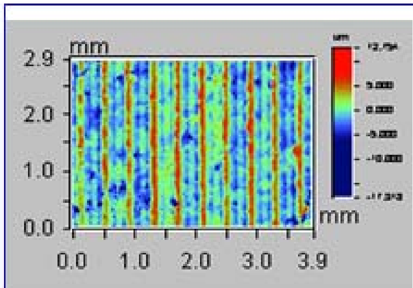
 **Blasted Biomedical Implant**	 **Areal Material Ratio Curve** **1% Peak and 1% Valley Offset**	**Total Surface Material Volume from highest peak to lowest valley - Vm(100%) = 19.3 µm³/µm²** **Peak Material Volume from mr=10% to highest peak - Vmp(10%) = 0.84 µm³/ µm²** **Core Material Volume from mr=10% to mr=80% - Vmc(10%,80%) = 3.64 µm³/µm²**

2D (Profile) Stylus Parameters

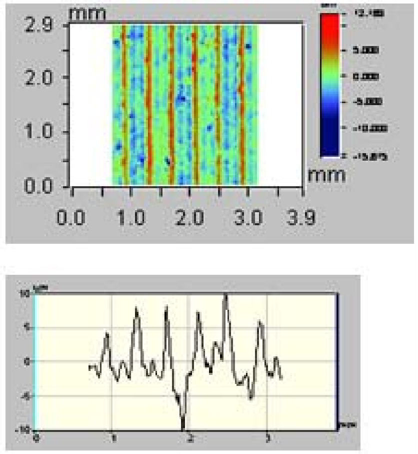
- **Stylus (X,Y) (Ra, Rt, Rz)**
- **Stylus (X,Y) Rk, Rpk, Rvk**
- **Stylus (X,Y) Δq**
- **Stylus (X,Y) λq**
- **Stylus (X,Y) Pc**
- **Stylus (X,Y) Rsm**
- **Stylus X to Stylus Y Ratios**

Once 3D data is acquired, a number of surface calculations are performed simulating the measurement of the surface with a 2D stylus profiling device. The 3D data is considered as a series of profiles in parallel along the X and Y axes. Each profile is filtered according to the ANSI/ASME B46.1 Standard, with short wavelength and long wavelength cutoffs. A filtered profile may consist of multiple sampling lengths (typically equal to the long wavelength cutoff). The total length of a filtered profile is termed the Evaluation Length. For the WYKO data, there is typically only 1 cutoff length and thus the cutoff length equals the Evaluation Length. However, some application may result in multiple cutoff lengths (i.e. sampling lengths) per evaluation length. After filtering, the various surface texture parameters are evaluated for each profile. Finally, the average value for a given surface texture parameter is then found over all the profiles considered.

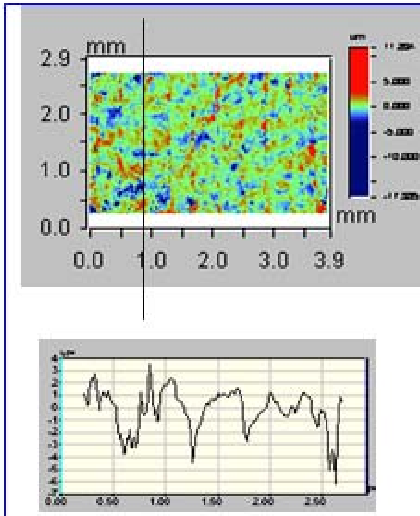
Typically, over 400 profiles are analyzed per 3D image in both the X and Y directions. The figure below demonstrates how a turned surface would appear after the various Stylus X and Stylus Y filters are applied prior to the evaluation of the individual profile.



3 Data as measured before any filtering



Typical 2D Profile in the "X" direction after filtering



Typical 2D Profile in the "Y" direction after filtering

Stylus X Ra, Stylus X Rt, Stylus X Rz, Stylus Y Ra, Stylus Y Rt, Stylus Y Rz

Stylus X Ra and **Stylus Y Ra ,** the Average Roughness Along X and the Average Roughness Along Y, are found from the integral of the profiles along the respective directions:

$$Stylus \quad X \; Ra = \frac{1}{Lx} \int_{0}^{Lx} \left| Z(X) \right| dx$$

$$Stylus \;\; Y \; Ra = \frac{1}{Ly} \int_{0}^{Ly} \left| Z(y) \right| dx$$

Stylus (X, Y) Rt, the Maximum Profiler Height Along (X,Y), is determined from the difference between the highest peak and lowest valley found along the evaluation length.

Stylus (X,Y) Rz, the Average Maximum Profiler Height Along (X,Y), is derived from the average, over all cutoff lengths (i.e. sampling lengths), of the difference between the highest peak and lowest valley. Note, if the evaluation length equals the sampling length then the Stylus (X.Y) Rt and Stylus (X,Y) Rz values are equal.

Note that the value reported in the database is the average of all **Stylus (X,Y) Ra**, **Rt**, **Rz** values found over the 400+ profiles that comprise the 3D surface in the relevant direction.

Application

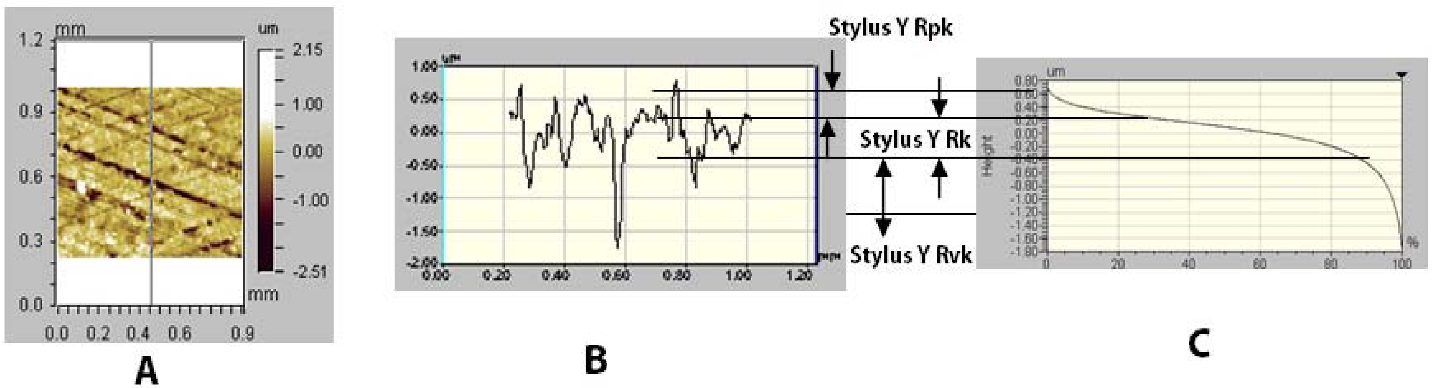
Stylus (X,Y) (**Ra**, **Rt**, **Rz)** may be useful in understanding any directionally dependent surface texture function. For example, a surface used for sealing may require a larger roughness average along the leak path direction (e.g. the X direction) and lower roughness average perpendicular (e.g. the Y direction) to the leak path for proper seal engagement.

Stylus (X, Y) Rk, Rpk, Rvk

The **Stylus (X, Y) Rk** parameters, are derived from the bearing ratio curve based on the ISO 13565-2:1996 standard. For each profile, a bearing area curve is generated by simulating a horizontal line moving through the profile from the top down, evaluating the percentage of contact the line would make with the surface at each level.

From the bearing area curve, **Stylus (X,Y) Rpk,** the Reduced Peak Height Along (X,Y), is found from a measure of the peak height above the core roughness. **Stylus (X,Y) Rvk,** the Reduced Valley Depths Along (X, Y), is found from a measure of the valley depths below the core roughness. **Stylus (X, Y) Rk**, the Core Roughness Along (X, Y), is a measure of the core (peak to valley) roughness of the surface with the major peaks and valleys (established by **Stylus (X, Y) Rpk** and **Stylus (X, Y) Rvk** removed.

Note that each profile in the X and Y directions are evaluated individually and the resulting average of a given parameter is reported.



Depiction of the bearing area calculation for the Stylus X and Stylus Y parameters (Rpk, Rk, Rvk).The contour plot (A) shows a line through the center over which the profile (B) is selected. The resulting bearing area curve (C) is constructed as described above for the 3D parameters.

Application

A high **Stylus (X, Y) Rpk** implies a surface composed of high peaks providing small initial contact area and thus high areas of contact stress when the surface is contacted. **Stylus (X, Y) Rpk** may represent the nominal height of the material that may be removed during a running-in operation. **Stylus (X, Y) Rvk** is a measure of the valley depths below the core roughness and may be related to lubricant retention and debris entrapment. By comparing the various parameters along the different directions (X vs. Y) one may also assess the uniformity of the surface peak and valley distributions relative to a particular direction of interest. **Stylus (X, Y) Rk** is a measure of the nominal roughness (peak to valley) and may be used to replace parameters such as **Stylus (X, Y) Ra**, **Stylus (X, Y) Rt**, or **Stylus (X, Y) Rz** when anomalous peaks or valleys may adversely affect the repeatability of these parameters.

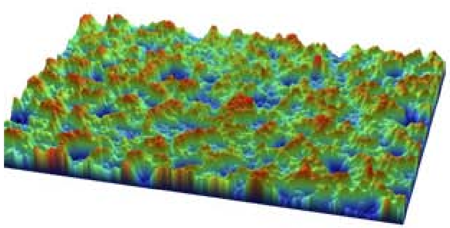
Stylus XΔq, Stylus YΔq

Stylus (X, Y) Δq is the Root Mean Square Slope Along (X,Y). The **Stylus X Δq** and **Stylus Y Δq** calculations find the rms (standard deviation) of the profile slope given by:

$$Stylus\ X\,\Delta q = \left(\frac{1}{Lx}\int_0^{Lx}\left(\frac{dZ(x)}{dx} - \left\langle\frac{dZ(x)}{dx}\right\rangle\right)^2 dx\right)^{1/2} \quad Stylus\ Y\,\Delta q = \left(\frac{1}{Lx}\int_0^{Lx}\left(\frac{dZ(y)}{dy} - \left\langle\frac{dZ(y)}{dy}\right\rangle\right)^2 dy\right)^{1/2}$$

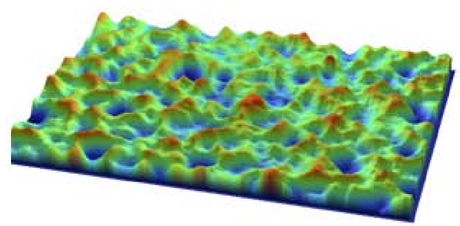
From Fourier analysis, the surface texture is composed of a series of sine waves in all directions with different spatial frequencies (i.e. 1 /spatial wavelength) and amplitudes. The power spectrum is a measure of the amplitude of each sine wave for a particular spatial frequency, along a given direction. Thus for a 3D surface, the power spectrum would be displayed as a "3D" function in which the X and Y axes represent the various spatial frequencies for a given direction. The amplitude of the power spectrum (displayed on the Z axis) represents the amplitude of the sine wave at a particular spatial frequency direction. The angular power spectrum is found by integrating the amplitudes of each component sine wave as a function of angle.

The figures below demonstrate a crosshatched surface, the power spectral density of the surface and the angular power spectral density function.



Stylus X Δq = 9.21 deg

Stylus Y Δq = 9.17 deg



Stylus X Δq = 5.01 deg

Stylus Y Δq = 4.76 deg

Depiction of two surfaces with similar overall roughness but different surface texture slopes along the X and Y directions as a result of the presence or absence of finer spaced features.

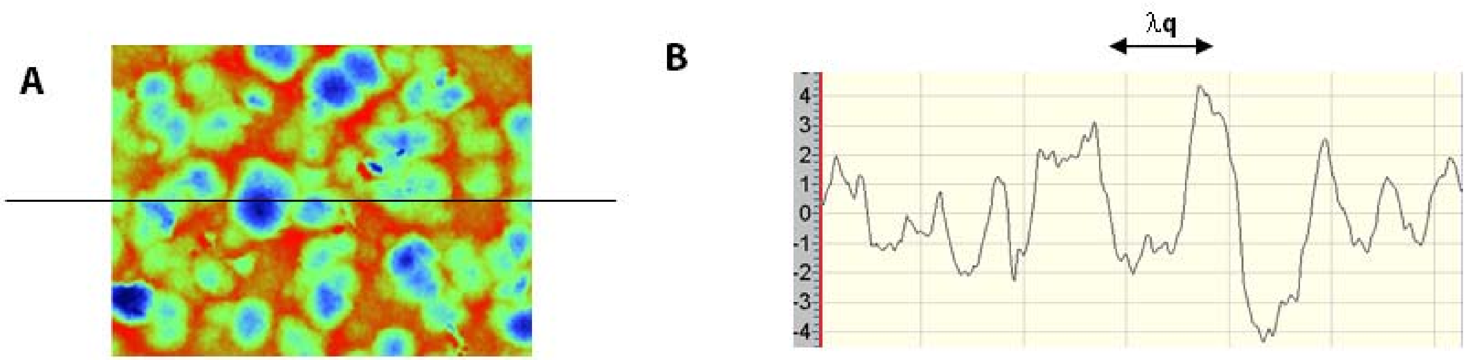
Application

The **Δq** measurements along the X and Y directions provides a quantitative assessment of the rate of change of the surface heights over the profile length. Since the slope values are squared prior to integration, the polarity (i.e. positive or negative) of the slope is lost in the calculation. The **Δq** measurements may be useful in applications where a machining process is producing parts with nominally correct amplitude parameters (e.g. **Ra**) but has other functional or process problems. For machining operations, parameters associated with the materials or machine setup may be manifested in significant changes in the surface slopes, easily measured by **Δq**. The wetting characteristics of a surface and the surface area of a texture may be related to **Δq.**

Stylus Xλq, Stylus Yλq

Stylus (X ,Y) λq , the Root Mean Square (rms) Profile Wavelength Along (X, Y), is a measure of the dominant spatial wavelength that comprises the surface weighted by the amplitude of the various spatial components. The evaluation of these parameters stems from Fourier analysis of the surface texture resulting in the following:

$$Stylus\ X\ \lambda q = 2\pi \frac{Stylus\ X\ Rq}{Stylus\ X\ \Delta q} \qquad Stylus\ Y\ \lambda q = 2\pi \frac{Stylus\ Y\ Rq}{Stylus\ Y\ \Delta q}$$



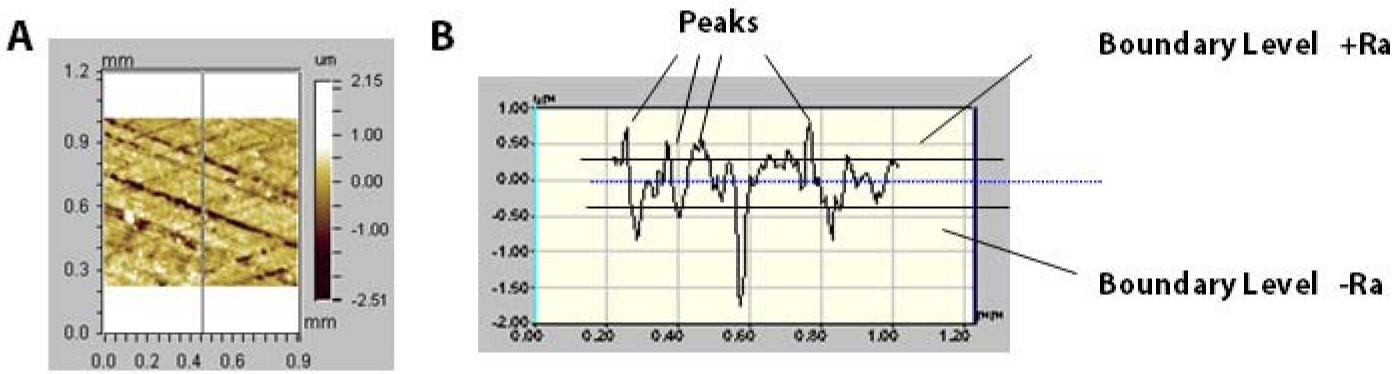
Depiction of the evaluation of the lq parameter. The contour plot (A) shows a line through the center over which the profile (B) is selected. After evaluation, a representation of λq is depicted in (B).

Application

The **λq** measurements along the X and Y directions provide a quantitative measure of the key spatial wavelengths that comprise the texture in the respective directions. A surface that has a high amplitude long wavelength wavy structure on which are superimposed small amplitude short wavelength texture features will have a **λq** representative of the long wavelength structure. However, as the amplitude of the shorter wavelength structure begins to approach that of the long wavelength structure, the measured **λq** will seek a value somewhere between the long wavelength and short wavelength values. **λq** is used when tool feed rates are under investigation and as a further means to differentiate surfaces/processes that yield similar amplitude parameters (e.g. **Ra**) but function differently. **λq** may be related to the appearance of a surface and also the real area of contact between loaded components.

Stylus X Pc, Stylus Y Pc

Stylus (X,Y) Pc the Peak Density Along (X,Y), measures the number of peaks per unit length in the X and Y directions respectively. A peak is defined as when the profile intersects consecutively a lower and upper boundary level set at a height above and depth below the mean line, equal to **Ra,** for the profile being analyzed.



The contour plot (A) shows a line through the center over which the profile (B) is selected to determine Pc..

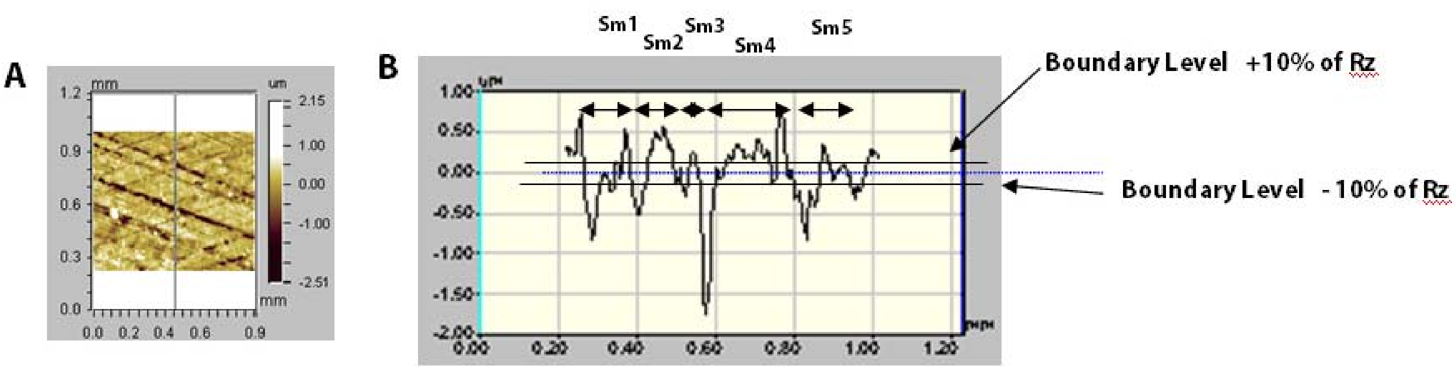
Application

Stylus X Pc and **Stylus Y Pc** are useful parameters for assessing the peak density (e.g. peaks/mm) along a given direction. Applications involved in coating a surface, or when fluid leakage/retention are of issue may make use of the **Pc** parameters to optimize the surface texture design. Sometimes the combination of parameters such as **Rz** with **Pc** will yield additional information about the spacing and depth of dominant surface features that may affect the function of a component.

Stylus X Rsm, Stylus Y Rsm

Stylus (X,Y) Rsm, the Mean Profile Spacing Along (X,Y), is a measure of the average length between points along the profile which cross the mean line with the same slope direction. For a profile element to be considered, the feature must extend above and below the mean line by more than 10% of Rz and be spaced apart from a previous feature by at least 1% of the sampling length.

$$Rsm = \left(\frac{1}{n}\right)\sum_{i}^{n} Sm_i$$



The contour plot (A) shows a line through the center over which the profile (B) is selected to determine Rsm.

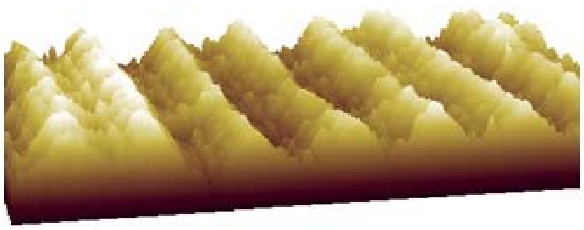
Application

Stylus X Rsm and **Stylus Y Rsm** are used to understand the dominant width of features and thus may be useful in understanding chanels for fluid flow and void space for coating coverage applications. Depending on the material properties, closer spaced texture (i.e. small Rsm) may be more prone to plastic deformation upon contact than wider spaced (i.e. large **Rsm**) features.

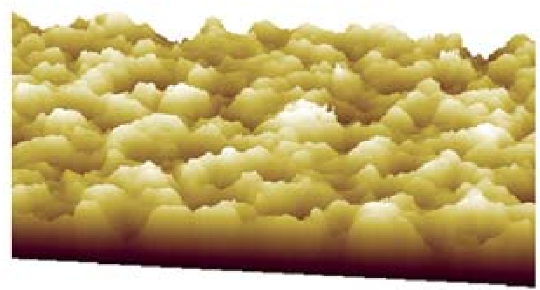
Stylus X Ra/Stylus Y Ra, Stylus X Rz/Stylus Y Rz, Stylus X Δq/Stylus Y Δq, Stylus X λq/Stylus Yλq, Stylus X Pc/ Stylus Y Pc

The various **Stylus X/Stylus Y** ratios are found by dividing the corresponding Stylus X parameter(e.g. **Stylus X Ra**) by the corresponding Stylus Y Parameter (e.g. **Stylus Y Ra**). Thus the various ratios are unitless quantities.

A



B



A lathe- turned surface (A) for which Stylus X Ra/Stylus Y Ra is about 2.5 and a peened surface (B) where Stylus X λq/Stylus Y λq is about 1.0.

Application

The ratio of the various Stylus X and Stylus Y parameters demonstrates the spatial isotropy of the surface texture. For example, the lathe-turned surface (Figure A) has a high degree of anisotropy and thus the ratio of **Stylus X Ra/Stylus Y Ra** is greater than 1.00. A shot peened isotropic surface will tend to have Stylus X & Y ratios of about 1.00. The ratios may be used to assess the ability for a given surface finishing operation to remove remnants of a previous operation. The ratios may also be used to uncover any dominant surface directional paths that may contribute to fluid leakage.

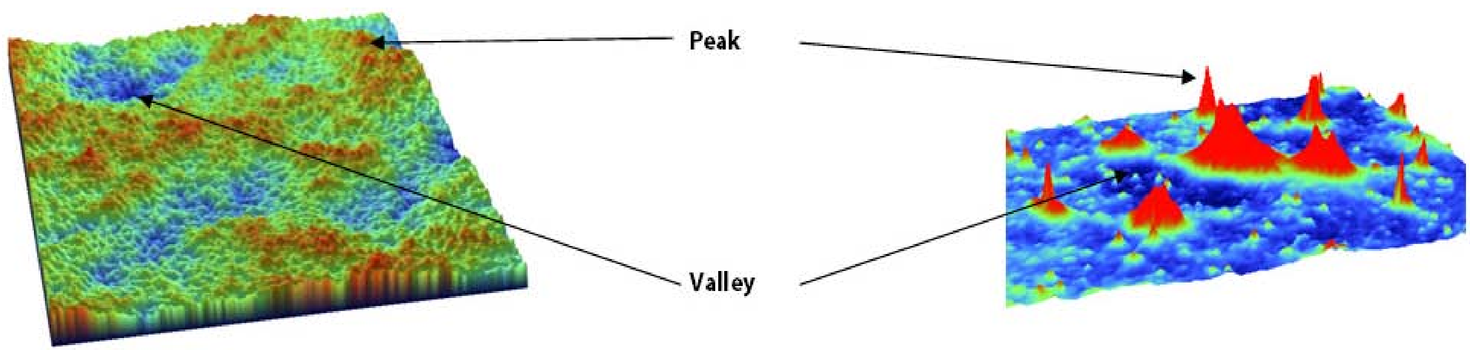
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D Legacy Parameters (WYKO 3D Parameters)

- **Rpm, Rvm, Rz**
- **(X,Y) Slope Rq**
- **NormVolume**
- **SAI**

Rpm, Rvm and Rz (Average Max Peak Height, Valley Depth and Height of Surface)

The **Rpm**, **Rvm**, and **Rz** parameters are evaluated from an average of the heights and depths of a number of extreme peaks and valleys. **Rpm** the Average Maximum Peak Height, is found by averaging the heights of the ten (10) highest peaks found over the complete 3D image. **Rvm,** the Average Maximum Valley Depth, is found by averaging the depths of the ten (10) lowest valleys found over the complete 3D image. **Rz,** the Average Maximum Height of the Surface, is found from **Rpm**-**Rvm**. Note that in determining the peaks and valleys, the analysis software eliminates a grid of 11 x 11 pixels around a given peak/valley before searching for the next peak/valley, thus assuring that significantly separated peaks/valleys are found.



Application

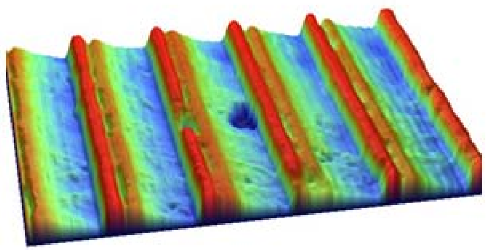
Rpm may be useful in establishing the height of the dominant peaked structures which may easily be plastically deformed under contact or penetrate a coating. **Rvm** provides an estimate of the average valley depths and may be useful in understanding fluid flow through an interface and space for debris entrapment. **Rz** provides an estimate of the overall peak to valley magnitude of a surface and may serve to predict the thickness of coating needed to completely cover and level a surface.

X Slope Rq and Y Slope Rq (X and Y Root Mean Squared Slope)

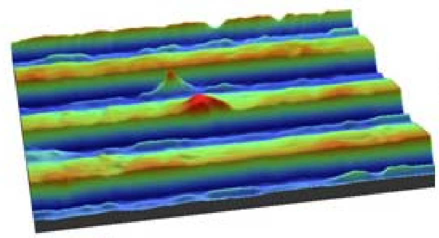
X Slope Rq and **Y Slope Rq**, the Root Mean Squared X Slope and Root Mean Squared Y Slope are found by calculating the standard deviation (i.e. rms) of the slopes of the surface along the X and Y directions respectively. The slope is found by taking the derivative of the surface profiles along each direction, using the lateral resolution of the measurement area as the point spacing. Analytically, **X Slope Rq** and **Y Slope Rq** are given by:

$$X\ Slope\ Rq = \left(\iint_a \left(\frac{\partial Z(x,y)}{\partial x} - \left\langle \frac{\partial Z(x,y)}{\partial x} \right\rangle \right)^2 dxdy \right)^{1/2} \qquad Y\ Slope\ Rq = \left(\iint_a \left(\frac{\partial Z(x,y)}{\partial y} - \left\langle \frac{\partial Z(x,y)}{\partial y} \right\rangle \right)^2 dxdy \right)^{1/2}$$

Where the brackets, <   >, represent the average value of all slopes in the relevant direction.



X Slope Rq = 9.28 deg
Y Slope Rq = 1.85 deg



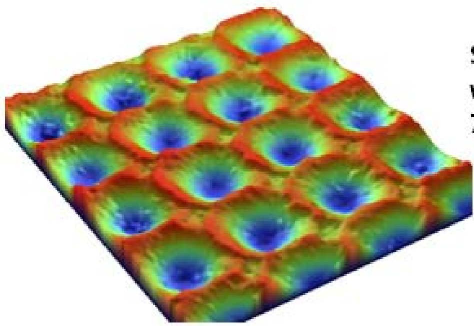
X Slope Rq = 1.66 deg
Y Slope Rq = 9.10 deg

Application

Slopes may be used to investigate the behavior of various surface texture forming techniques in that material and process conditions may change the slopes considerably, whereas the height parameters such as **Ra** are relatively unaffected. The surface slope may also be useful in relating the nature of the surface when used in coating and visual appearance applications.

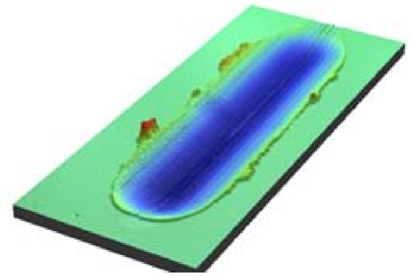
NormVolume (Normalized Surface Volume)

NormVolume, the Normalized Surface Volume, is found by calculating the volume contained by the surface and a “plane” that is placed near the top of the surface. The placement of the reference plane is done on a statistical basis to ensure that the very high peak locations are not used as the reference point for the plane. Once the volume is calculated (e.g. in units of cm3), the volume result is “normalized” to the cross sectional area of the plane (e.g. units of m^2). Other units of **NormVolume** are BCM which is an acronym for “Billions of Cubic Microns per Inch Squared”. The BCM units are typically used in the printing industry.



Surface used for printing with a NormVolume of 7.53 BCM

NormVolume is useful for measuring the volume of a wear scar (0.66 BCM)

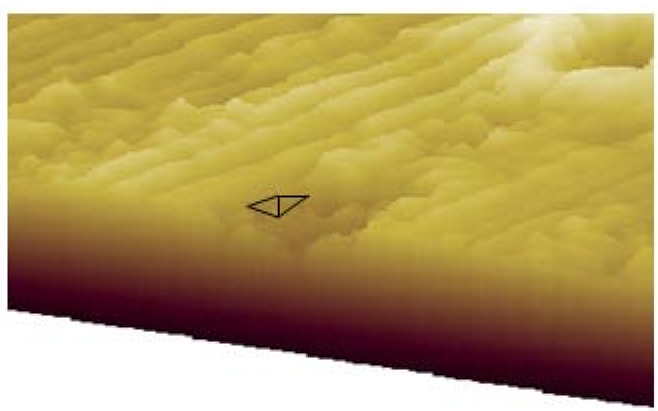


Application

NormVolume finds application in the printing industry, by providing a measure of the fluid holding properties of printing device surfaces (e.g. anilox rolls, Lithoplates, etc.) and the printed media (e.g. paper). Other applications, such as in the tribology field use the NormVolume to establish the volume of space a surface provides for lubricant containment. The measurement of various wear patters may result in a structure in which NormVolume may quantify the amount of material removed from a surface or displaced along a surface.

SAI (Surface Area Index)

SAI, the Surface Area Index, is the surface area at the lateral resolution of the measured/filtered surface as compared to that of a perfectly flat/smooth surface. The calculation involves fitting triangular patches between the measured points and adding up the total area of all patches. A ratio is then formed of the total surface area measured and the nominal flat area of measurement. This analysis is a precursor to a complete fractal analysis of the surface.[i] Since **SAI** is a ratio, it is a unitless quantity.



Depiction of the calculation of the Surface Area Index (SAI). Demonstrating only a few triangular patches whereas the complete analysis involves fitting patches over the complete image.

Application

The combination of different surface texture amplitudes and spacings are further manifested in the overall surface provided by the texture. The SAI parameter finds application for issues relating to surface wetting, fluid flow, coating adhesion, printing etc.

[i] C.A. Brown, P.D. Charles, W.A. Johnsen, S. Chester, fractal analysis of topographic data by the patchwork method, Wear 161 (1993) 61-67.

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• Parameters By Family • Parameters By Name • Parameters By Symbol

Texture Parameters Indexed by Family

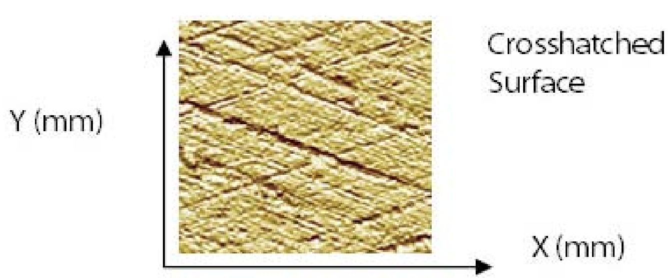
• Parameters By Family • Parameters By Name • Parameters By Symbol

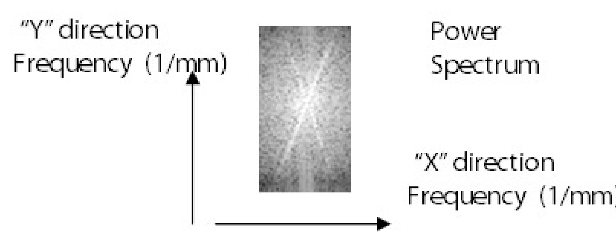
3D S Parameters - Spatial Parameters

APSDF (Angular Power Spectral Density Function)

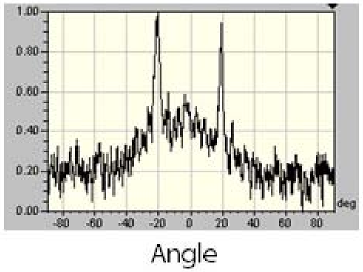
The development of the spatial parameters involves the use of the mathematical technique of the Angular Power Spectral Density Function (APSDF) This section will review the basic concepts behind the APSDF necessary to understand the Std spatial parameter.

From Fourier analysis, the surface texture is composed of a series of sine waves in all directions with different spatial frequencies (i.e. 1÷ spatial wavelength) and amplitudes. The power spectrum is a measure of the amplitude of each sine wave for a particular spatial frequency, along a given direction. Thus for a 3D surface, the power spectrum would be displayed as a "3D" function in which the X and Y axes represent the various spatial frequencies for a given direction. The amplitude of the power spectrum (displayed on the Z axis) represents the amplitude of the sine wave at a particular spatial frequency direction. The angular power spectrum is found by integrating the amplitudes of each component sine wave as a function of angle. The figures below demonstrate a crosshatched surface, the power spectral density of the surface and the angular power spectral density function.





The bright regions of the power spectrum for the crosshatched surface correspond to higher amplitude sine waves at a given combination of spatial frequencies along the X / Y directions. The two dominant bright lines are thus along a direction perpendicular to the two lay patterns of the crosshatched surface. The APSDF is found by integrating the power spectrum from the center out along a given radius and displaying the relative magnitude vs. angle. The two peaks in the APSDF correspond to the large sine wave amplitudes found along directions perpendicular to the two lay patterns of the crosshatched surface.



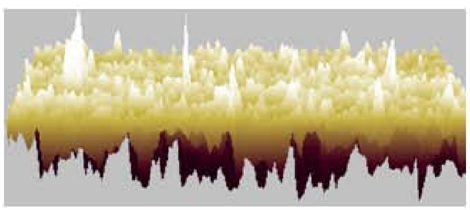
Angular Power Spectrum Density Function (APSDF)

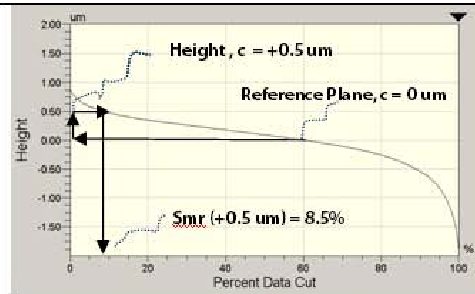
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D Functional Parameters

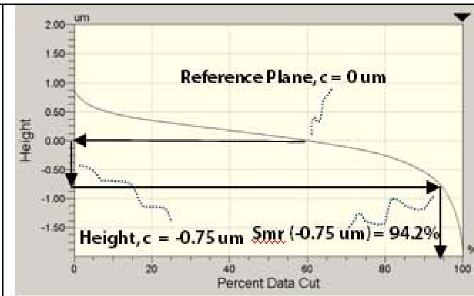
Smr(c) (Areal Material Ratio)

The Areal Material Ratio, **Smr(c)** is the ratio (expressed as a percentage) of the cross sectional area of the surface at a height (c) relative to the evaluation cross sectional area. The height (c) may be measured from the best fitting least squares mean plane or as a depth down from the maximum point of the Areal Material Ratio Curve.

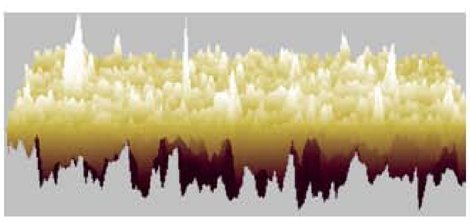


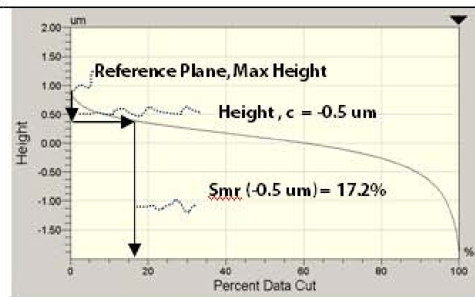


Smr(+0.5 um) = 8.5%
Reference Plane = Best Fit Mean Plane

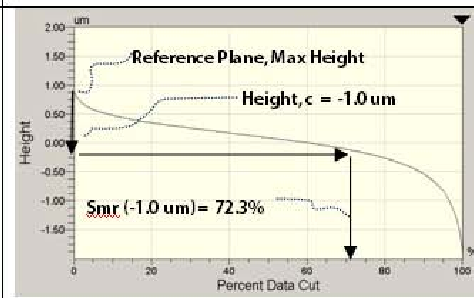


Smr(-0.75 um) = 94.2%
Reference Plane = Best Fit Mean Plane





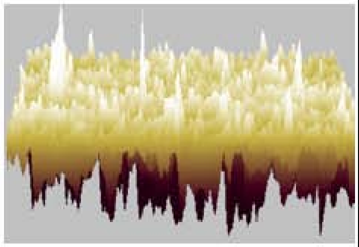
Smr(-0.5um) = 17.2%
Reference Plane = Max of Areal Material Ratio Curve

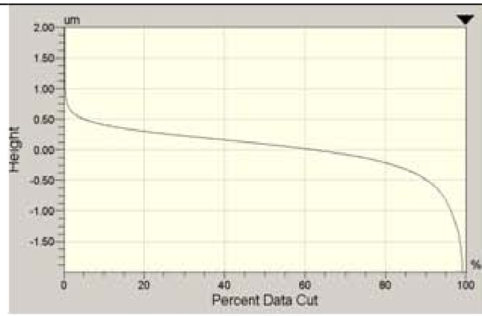


Smr(-1.0 um) = 72.3%
Reference Plane = Max of Areal Material Ratio Curve

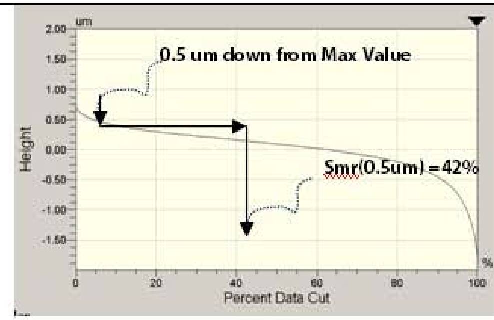
Application

Smr(c) may used to determine the amount of bearing area remaining after a certain depth of material is removed from the surface. A typical application may be in the specification of engine cylinder bore surfaces prior to running-in. Typically a cylinder bore may be honed to produce a pattern consisting of a plateau-like surface upon which are superimposed fine peaked structures. The fine peaked structure is provided to augment final running-in/seating of the sliding piston rings. Thus a specification for a surface may be **Smr(0.5µm) > 40%,** measured from the Max Value Areal Material Ratio curve with 1% peak and 1% valley offsets. This specification would be developed based on experiments that determine, for example, that running-in typically removes the top 0.5µm of the surface heights before surface stabilization.





Areal Material Ratio Curve
0% Peak and 0% Valley Offset



Bearing Ratio Curve 1% Peak and 1% Valley Offset
Smr(0.5um) > 40%

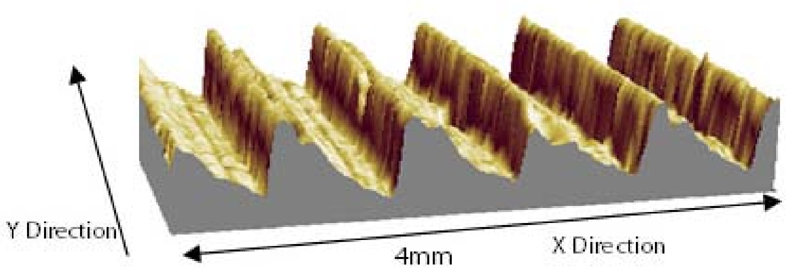
3D S Parameters - Spatial Parameters

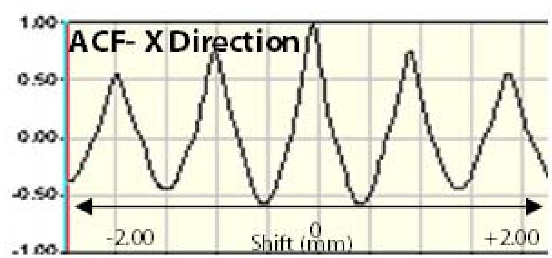
ACF (Autocorrelation Function)

The development of the spatial parameters involves the use of the mathematical technique of the autocorrelation function (ACF). This section will review the basic concepts behind the ACF necessary to understand the various spatial parameters.

The ACF is found by taking a duplicate surface (Z(x-Dx,y-Dy)) of the measured surface ((Z (x, y)) and mathematically multiplying the two surfaces together, with a relative lateral displacement (Dx,Dy) between the two surfaces. Once multiplied together, the resulting function is integrated and normalized to Sq, to yield a measure of the degree of overlap between the two functions. If the shifted version of the surface is identical to the original surface then the ACF is 1.00. If the shifted surface is such that all peaks align with corresponding valleys then the ACF will approach –1.00.

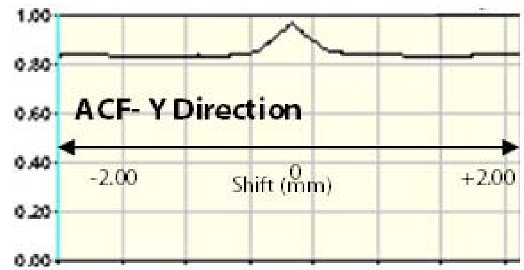
Thus the ACF is a measure of how similar the texture is at a given distance from the original location. If the ACF stays near 1.00 for a given amount of shift, then the texture is similar along that direction. If the ACF falls rapidly to zero along a given direction, then the surface is different and thus "uncorrelated" with the original measurement location.





For the turned surface above, the ACF in the X direction falls to zero quickly as the peaks of the shifted surface align with the mean plane.

The ACF along X becomes negative as the peaks of the surface align with the valleys of the shifted surface. Shifting along the Y direction, the surface is near identical to the original, resulting in the ACF in the Y direction remaining near 1.00.



• Parameters By Family • Parameters By Name • Parameters By Symbol

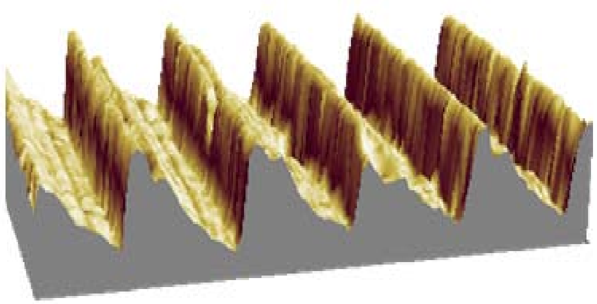
3D S Parameters - Spatial Parameters

Sal (Auto-Correlation Length) and Str (Texture Aspect Ratio)

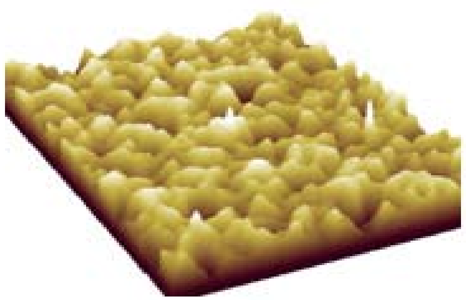
Sal, the Auto-Correlation Length, is a measure of the distance over the surface such that the new location will have minimal correlation with the original location. The direction over the surface chosen to find **Sal** is the direction which yields the lowest **Sa**l value. **Str**, the Texture Aspect Ratio, is a measure of the spatial isotropy or directionality of the surface texture. For a surface with a dominant lay, the **Str** parameter will tend towards 0.00, whereas a spatially isotropic texture will result in a **Str** of 1.00.

Sal = Length of fastest decay of ACF in any direction

$$Str = \frac{\text{Length of fastest decay of ACF in any direction}}{\text{Length of slowest decay ACF in any direction}}$$



Highly Directional Surface with Str of 0.11 and Sal of 37mm



Highly isotropic surface with Str of 0.88 with an Sal of 21mm

Application

Str is useful in determining the presence of lay in any direction. For applications where a surface is produced by multiple processes,

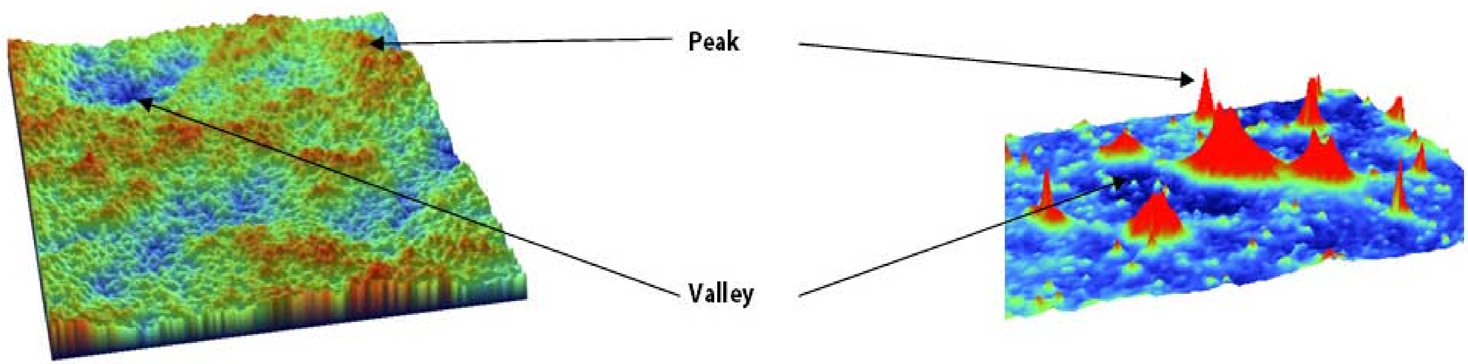
Str may be used to detect the presence of underlying surface modifications. **Str** may find application in detecting subtle directionality on an otherwise isotropic texture. **Sal** is a quantitative measure as to the distance along the surface by which one would find a texture that is statistically different from the original location. **Sal** is useful in establishing the distance between multiple measurements made on the surface to adequately determine the general texture specification of the surface. **Sal** may find application related to the interaction of electromagnetic radiation with the surface and also tribological characteristics such as friction and wear.

• Parameters By Family • Parameters By Name • Parameters By Symbol

3D Legacy Parameters (WYKO 3D Parameters)

Rpm, Rvm and Rz (Average Max Peak Height, Valley Depth and Height of Surface)

The **Rpm**, **Rvm**, and **Rz** parameters are evaluated from an average of the heights and depths of a number of extreme peaks and valleys. **Rpm** the Average Maximum Peak Height, is found by averaging the heights of the ten (10) highest peaks found over the complete 3D image. **Rvm,** the Average Maximum Valley Depth, is found by averaging the depths of the ten (10) lowest valleys found over the complete 3D image. **Rz,** the Average Maximum Height of the Surface, is found from **Rpm**-**Rvm**. Note that in determining the peaks and valleys, the analysis software eliminates a grid of 11 x 11 pixels around a given peak/valley before searching for the next peak/valley, thus assuring that significantly separated peaks/valleys are found.



Application

Rpm may be useful in establishing the height of the dominant peaked structures which may easily be plastically deformed under contact or penetrate a coating. **Rvm** provides an estimate of the average valley depths and may be useful in understanding fluid flow through an interface and space for debris entrapment. **Rz** provides an estimate of the overall peak to valley magnitude of a surface and may serve to predict the thickness of coating needed to completely cover and level a surface.

• Parameters By Family • Parameters By Name • Parameters By Symbol

2D (Profile) Stylus Parameters

Stylus (X, Y) Ra, Rt, Rz

Stylus X Ra and **Stylus Y Ra ,** the Average Roughness Along X and the Average Roughness Along Y, are found from the integral of the profiles along the respective directions:

$$Stylus\ \ X\ \ Ra = \frac{1}{Lx}\int_{0}^{Lx}\left|Z(X)\right|dx$$

$$Stylus\ \ Y\ \ Ra = \frac{1}{Ly}\int_{0}^{Ly}\left|Z(y)\right|dx$$

Stylus (X, Y) Rt, the Maximum Profiler Height Along (X,Y), is determined from the difference between the highest peak and lowest valley found along the evaluation length.

Stylus (X,Y) Rz, the Average Maximum Profiler Height Along (X,Y), is derived from the average, over all cutoff lengths (i.e. sampling lengths), of the difference between the highest peak and lowest valley. Note, if the evaluation length equals the sampling length then the Stylus (X.Y) Rt and Stylus (X,Y) Rz values are equal.

Note that the value reported in the database is the average of all **Stylus (X,Y) Ra**, **Rt**, **Rz** values found over the 400+ profiles that comprise the 3D surface in the relevant direction.

Application

Stylus (X,Y) (**Ra**, **Rt**, **Rz)** may be useful in understanding any directionally dependent surface texture function. For example, a surface used for sealing may require a larger roughness average along the leak path direction (e.g. the X direction) and lower roughness average perpendicular (e.g. the Y direction) to the leak path for proper seal engagement.

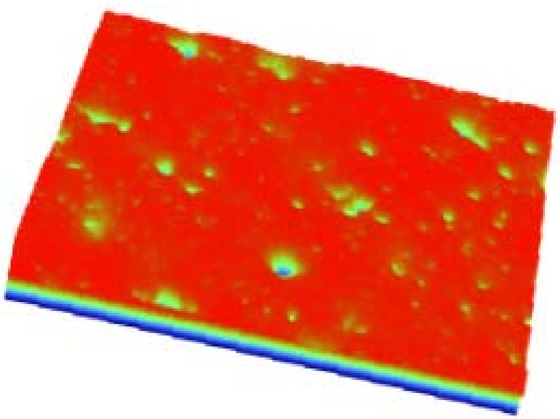
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D S Parameters - Height (Amplitude) Parameters

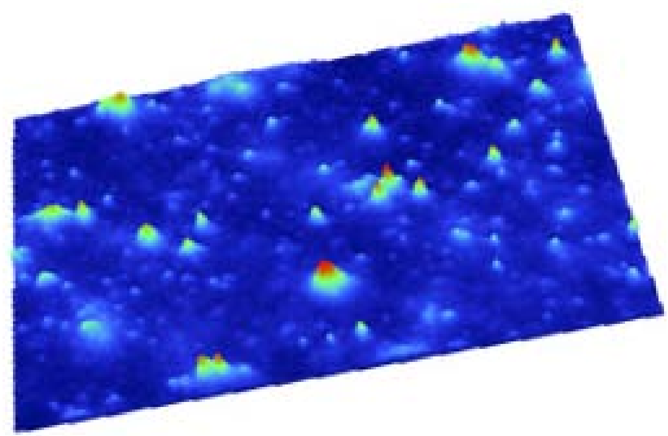
Sa and Sq

Sa and **Sq** are the Average Roughness and Root Mean Square Roughness are evaluated over the complete 3D surface respectively. Mathematically, **Sa** and **Sq** are evaluated as follows:

$$S_a = \iint_a |Z(x,y)| dxdy \qquad Sq = \sqrt{\iint_a (Z(x,y))^2 dxdy}$$



Plateau-like surface Sa = 16.03 nm   Sq= 25.4 nm



Surface with Peaks Sa = 16.03 nm   Sq= 25.4 nm

Application

The **Sa** and **Sq** parameters represent an overall measure of the texture comprising the surface. **Sa** and **Sq** are insensitive in differentiating peaks, valleys and the spacing of the various texture features. Thus **Sa** or **Sq** may be misleading in that many surfaces with grossly different spatial and height symmetry features (e.g., milled vs. honed) may have the same **Sa or Sq**, but function quite differently. The figure above demonstrates two very different surfaces with identical **Sa** and **Sq** values, indicating the insensitivity of the **Sa** and **Sq** parameters. Nonetheless, once a surface type has been established, the **Sa** and **Sq** parameters may be used to indicate significant deviations in the texture characteristics. **Sq** is typically used to specify optical surfaces and **Sa** is used for machined surfaces.

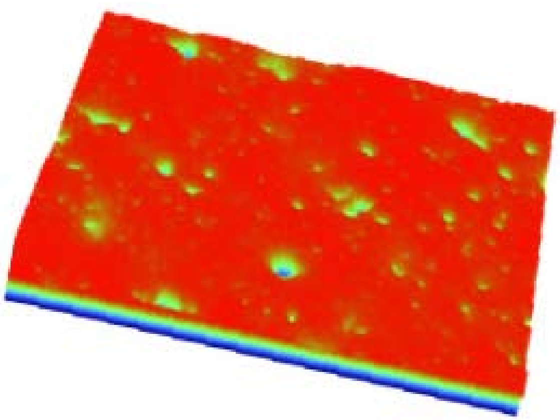
3D S Parameters - Height (Amplitude) Parameters

- Sa and Sq
- Ssk and Sku
- Sp, Sv, Sz

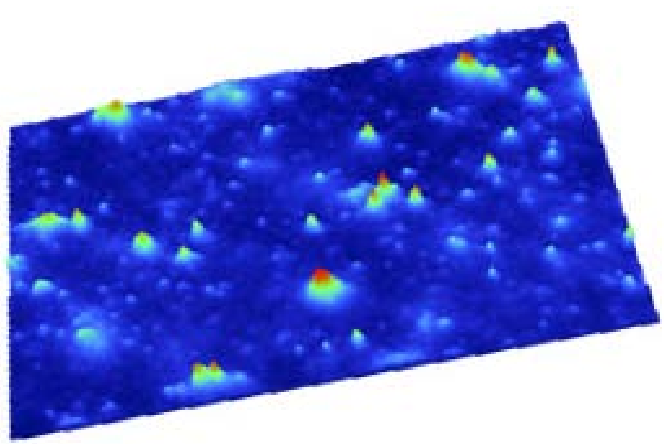
Sa and Sq

Sa and **Sq** are the Average Roughness and Root Mean Square Roughness are evaluated over the complete 3D surface respectively. Mathematically, **Sa** and **Sq** are evaluated as follows:

$$S_a = \iint_a |Z(x,y)| dxdy \qquad Sq = \sqrt{\iint_a (Z(x,y))^2 dxdy}$$



Plateau-like surface Sa = 16.03 nm   Sq= 25.4 nm



Surface with Peaks Sa = 16.03 nm   Sq= 25.4 nm

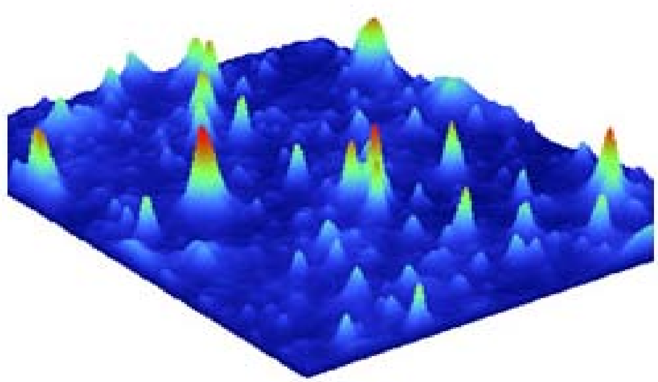
Application

The **Sa** and **Sq** parameters represent an overall measure of the texture comprising the surface. **Sa** and **Sq** are insensitive in differentiating peaks, valleys and the spacing of the various texture features. Thus **Sa** or **Sq** may be misleading in that many surfaces with grossly different spatial and height symmetry features (e.g., milled vs. honed) may have the same **Sa or Sq**, but function quite differently. The figure above demonstrates two very different surfaces with identical **Sa** and **Sq** values, indicating the insensitivity of the **Sa** and **Sq** parameters. Nonetheless, once a surface type has been established, the **Sa** and **Sq** parameters may be used to indicate significant deviations in the texture characteristics. **Sq** is typically used to specify optical surfaces and **Sa** is used for machined surfaces.

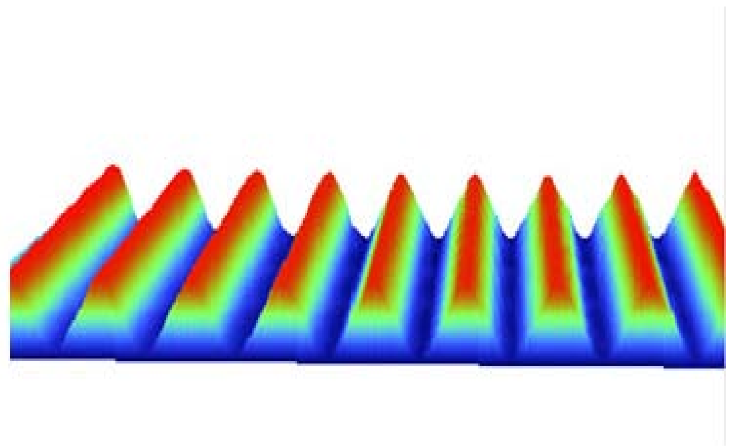
Ssk (Skewness) and Sku (Kurtosis)

Ssk and **Sku** are the Skewness and *Kurtosis of the 3D surface texture respectively. Figuratively, a histogram of the heights of all measured points is established and the symmetry and deviation from an ideal Normal (i.e. bell curve) distribution is represented by* ***Ssk*** *and* ***Sku****. Mathematically, the* ***Ssk*** *and* ***Sku*** *are evaluated as follows:*

$$Ssk = \frac{1}{S_q^3}\iint_a (Z(x,y))^3 dxdy \qquad S_{ku} = \frac{1}{S_q^4}\iint_a (Z(x,y))^4 dxdy$$



Surface with multiple peaks Ssk = 3.20 Sku = 18.71



Periodic Texture Ssk = 0.16 Sku= 1.63

Application

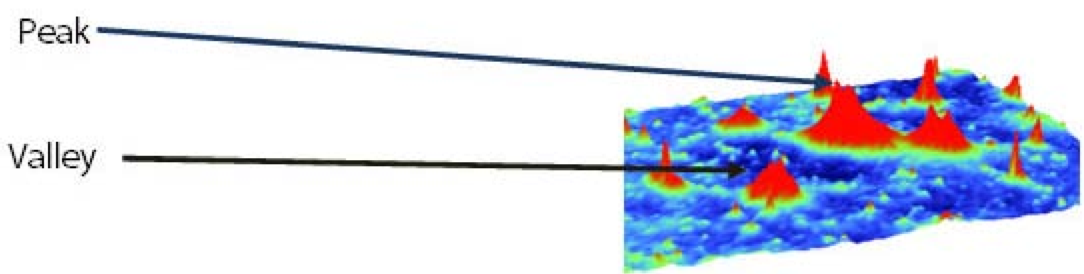
Ssk *represents the degree of symmetry of the surface heights about the mean plane. The sign of* ***Ssk*** *indicates the predominance of peaks (i.e.* ***Ssk****>0) or valley structures (****Ssk****<0) comprising the surface.* ***Sku*** *indicates the presence of inordinately high peaks/ deep valleys (****Sku****>3.00) or lack thereof (****Sku****<3.00) making up the texture. If the surface heights are*

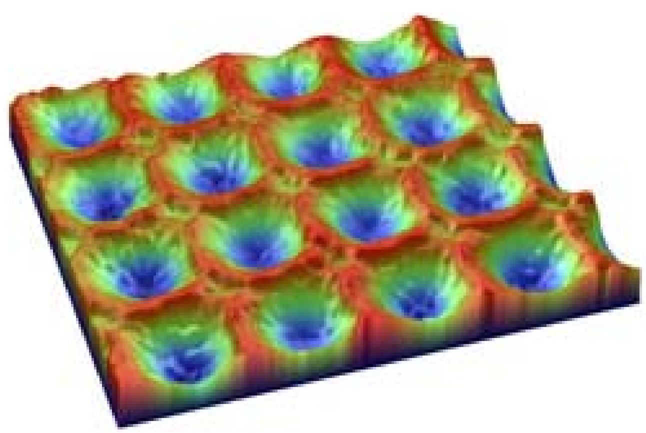
*Normally distributed (i.e. bell curve) then **Ssk** is 0.00 and **Sku** is 3.00. Surfaces described as gradually varying, free of extreme peaks or valley features, will tend to have **Sku** <3.00. **Ssk** is useful in specifying honed surfaces and monitoring for different types of wear conditions. **Sku** is useful for indicating the presence of either peak or valley defects which may occur on a surface. Since **Ssk** and **Sku** involve the higher order powers of the surface heights, one must make enough measurements to provide statistically significant values and/or properly select filtering bandwidths to eliminate erroneous peaks or valleys.*

Sp (Max Peak Height), Sv Max Valley Depth) and Sz (Max Height of Surface)

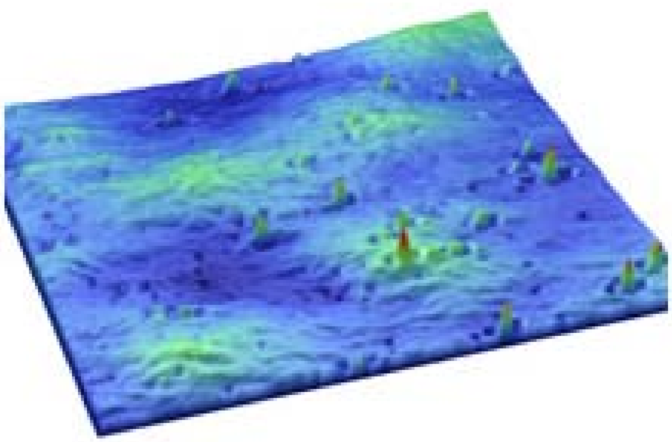
***Sp**, **Sv**, and **Sz** are parameters evaluated from the absolute highest and lowest points found on the surface. **Sp,** the Maximum Peak Height**,** is the height of the highest point, **Sv**, the Maximum Valley Depth, is the depth of the lowest point (expressed as a negative number) and **Sz** the Maximum Height of the Surface), is found from **Sz = Sp – Sv**.*

*Note: **earlier standards** referred to **Rz** as a average of the 10 highest to 10 Lowest Points and other variations. The ISO community agreed for the newer standard, ISO 25178-2 to establish Sz as strictly the peak to valley height over a areal measurement.*





A surface used in the printing industry characterized by deep valley structures with Sv being ~ -15µm



A polymer surface prepared with asperities as measured by Sp being ~0.90 µm

Application

*Since **Sp**, **Sv**, and **Sz** are found from single points, they tend to result in unrepeatable measurements. Thus when using these three parameters, one must properly set spatial filtering bandwidths to eliminate erroneous peaks/valleys and average multiple measurements at random locations along the sample, to obtain a statistically significant result. Typical applications for **Sz** may include sealing surfaces and coating applications. **Sp** may find application when considering surfaces that will be used in a sliding contact application. **Sv** may find application when valley depths relating to fluid retention may be of concern such as for lubrication and coating systems.*

• Parameters By Family • Parameters By Name • Parameters By Symbol

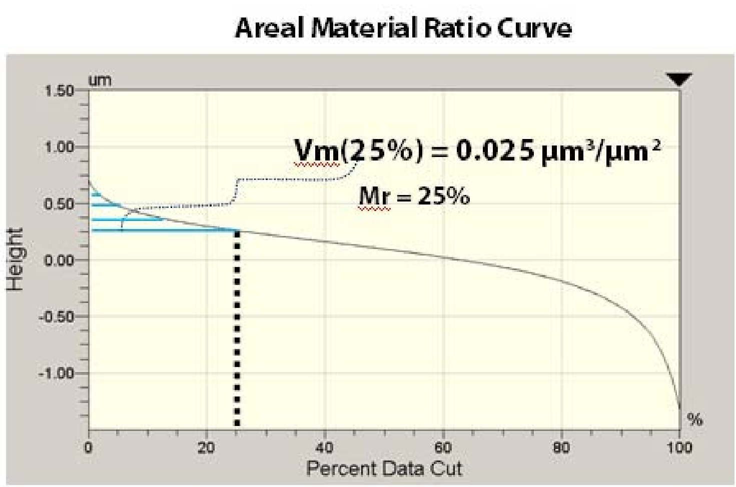
3D Functional Parameters

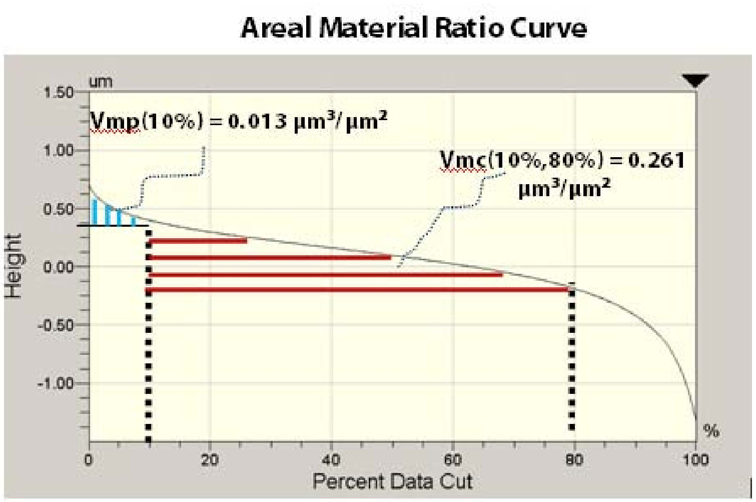
Vm(mr) (Material Volume) , Vmp(p) (Peak Material Volume), Vmc(p,q) (Core Material Volume)

Vm(mr), the Material Volume, is the volume of material comprising the surface from the height corresponding to **mr** to the highest peak of the surface. "**mr**" may be set to any value from 0% to 100%.

Vmp(p), the Peak Material Volume, is the volume of material comprising the surface from the height corresponding to a material ratio level, "**p**", to the highest peak. The default value for "**p**" is 10% but may be changed as needed.

Vmc(p,q), the Core Material Volume, is the volume of material comprising the texture between heights corresponding to the material ratio values of "**p**" and "**q**". The default value for "**p**" is 10% and the default value for "**q**" is 80% but may be changed as needed.





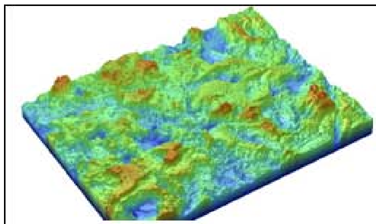
*Note: The units for the Vv(mr), Vv(p) and Vvc(p,q) are **µm3/µm2** - the void volume normalized by the cross sectional area of the measurement area. The peak offsets and valley offsets are applied prior to analysis.*

Application

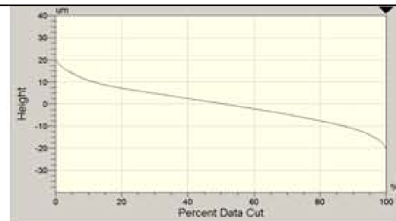
Vm(mr), **Vmp(p)** and **Vmc(p,q)** all indicate a measure of the material forming the surface at the various heights down from the highest peak of surface or between various heights as defined for Vmc(p,q).

For example, a **Vm(10%)** =0.35µm3/µm2 would indicate (note how the units µm3/µm2 reduce to µm) that a layer 0.35µm thick of material over the measured cross section would account for all the material from the highest peak to the 10% point on the bearing area curve.

The various Material Volume parameters are useful to understand how much material may be worn away for a given depth of the bearing curve (i.e. **Vmp(p)**) and how much material is available for load support once the top levels of a surfaces are worn away (i.e. **Vmc(p,q)**). For sealing applications, **Vmp(p)** may provide insight into the amount of material available for seal engagement whereas **Vvc(p.q)** (see above) may then provide information about the resulting void volume for fluid entrapment or leakage.



Blasted Biomedical Implant



Areal Material Ratio Curve
1% Peak and 1% Valley Offset

Total Surface Material Volume from highest peak to lowest valley - Vm(100%) = 19.3 $\mu m^3/\mu m^2$

Peak Material Volume from mr=10% to highest peak - Vmp(10%) = 0.84 $\mu m^3/\mu m^2$

Core Material Volume from mr=10% to mr=80% - Vmc(10%,80%) = 3.64 $\mu m^3/\mu m^2$

• Parameters By Family • Parameters By Name • Parameters By Symbol

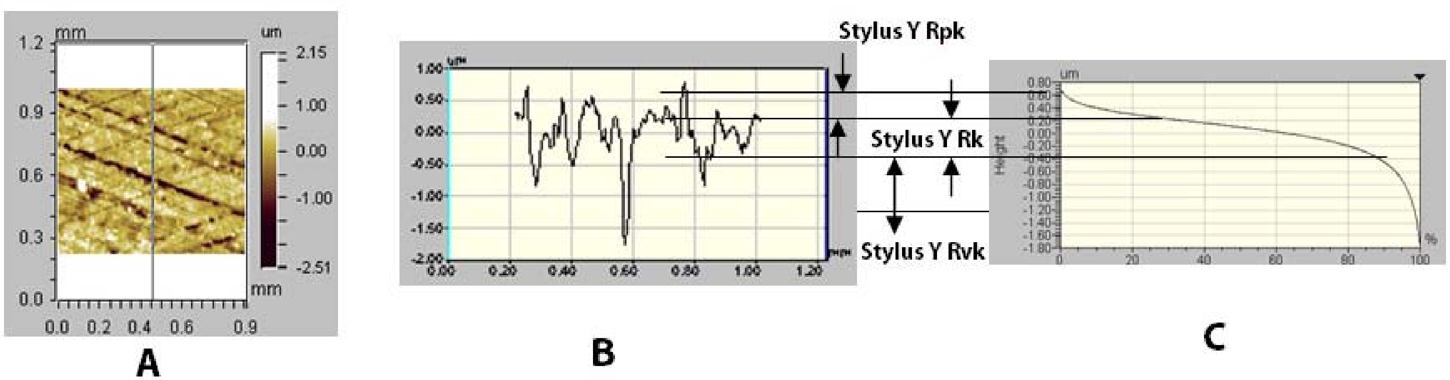
2D (Profile) Stylus Parameters

Stylus (X, Y) Rk, Rpk, Rvk

The **Stylus (X, Y) Rk** parameters, are derived from the bearing ratio curve based on the ISO 13565-2:1996 standard. For each profile, a bearing area curve is generated by simulating a horizontal line moving through the profile from the top down, evaluating the percentage of contact the line would make with the surface at each level.

From the bearing area curve, **Stylus (X,Y) Rpk,** the Reduced Peak Height Along (X,Y), is found from a measure of the peak height above the core roughness. **Stylus (X,Y) Rvk,** the Reduced Valley Depths Along (X, Y), is found from a measure of the valley depths below the core roughness. **Stylus (X, Y) Rk**, the Core Roughness Along (X, Y), is a measure of the core (peak to valley) roughness of the surface with the major peaks and valleys (established by **Stylus (X, Y) Rpk** and **Stylus (X, Y) Rvk** removed.

Note that each profile in the X and Y directions are evaluated individually and the resulting average of a given parameter is reported.



Depiction of the bearing area calculation for the Stylus X and Stylus Y parameters (Rpk, Rk, Rvk).The contour plot (A) shows a line through the center over which the profile (B) is selected. The resulting bearing area curve (C) is constructed as described above for the 3D parameters.

Application

A high **Stylus (X, Y) Rpk** implies a surface composed of high peaks providing small initial contact area and thus high areas of contact stress when the surface is contacted. **Stylus (X, Y) Rpk** may represent the nominal height of the material that may be removed during a running-in operation. **Stylus (X, Y) Rvk** is a measure of the valley depths below the core roughness and may be related to lubricant retention and debris entrapment. By comparing the various parameters along the different directions (X vs. Y) one may also assess the uniformity of the surface peak and valley distributions relative to a particular direction of interest. **Stylus (X, Y) Rk** is a measure of the nominal roughness (peak to valley) and may be used to replace parameters such as **Stylus (X, Y) Ra**, **Stylus (X, Y) Rt**, or **Stylus (X, Y) Rz** when anomalous peaks or valleys may adversely affect the repeatability of these parameters.

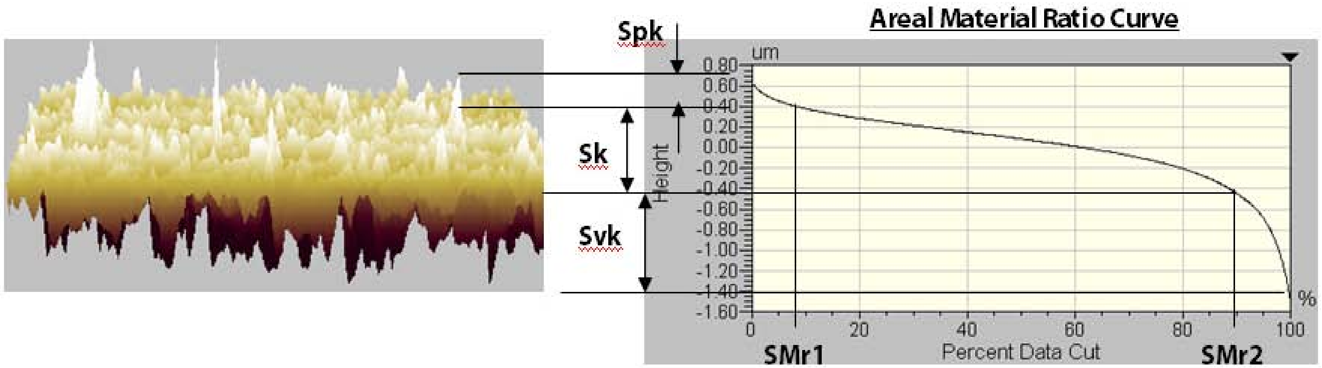
Call toll free
866-953-5030
or email us at
info@michmet.com

• Parameters By Family • Parameters By Name • Parameters By Symbol

3D Functional Parameters

Spk (Reduced Peak Height), Sk (Core Roughness Depth), Svk (Reduced Valley Depth), SMr1 (Peak Material Portion), SMr2 (Peak Valley Portion)

The parameters **Spk**, **Sk**, **Svk**, **SMr1**, and **SMr2** are all derived from the Areal Material Ratio curve based on the ISO 13565-2:1996 standard. The Reduced Peak Height, **Spk**, is a measure of the peak height above the core roughness. The Core Roughness Depth, **Sk**, is a measure of the "core" roughness (peak-to-valley) of the surface with the predominant peaks and valleys removed. The Reduced Valley Depth, **Svk**, is a measure of the valley depth below the core roughness. **SMr1**, the Peak Material Portion, indicates the percentage of material that comprises the peak structures associated with **Spk**. The Valley Material Portion, **SMr2**, relates to the percentage (i.e., 100%-**SMr2**) of the measurement area that comprises the deeper valley structures associated with **Svk**.



Application

A large **Spk** implies a surface composed of high peaks providing small initial contact area and thus high areas of contact stress (force/area) when the surface is contacted. Thus **Spk** may represent the nominal height of the material that may be removed during a running-in operation. Consistent with **Spk**, **SMr1** represents the percentage of the surface that may be removed during running-in. **Sk** represents the core roughness of the surface over which a load may be distributed after the surface has been run-in. **Svk** is a measure of the valley depths below the core roughness and may be related to lubricant retention and debris entrapment. **Sk** is a measure of the nominal roughness (peak to valley) and may be used to replace parameters such as **Sz** when anomalous peaks or valleys may adversely affect the measurement.

• Parameters By Family • Parameters By Name • Parameters By Symbol

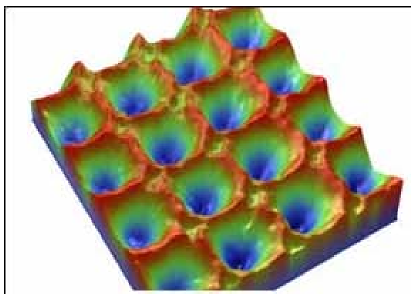
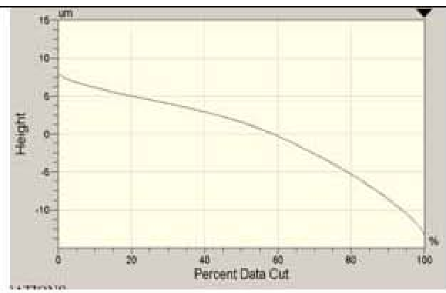
3D Functional Parameters

Vv(mr) (Void Volume), Vvv(p) (Dale Void Volume), Vvc(p,q) (Core Void Volume)

Vv(mr), the Void Volume, is the volume of space bounded by the surface texture from a plane at a height corresponding to a chosen "**mr**" value to the lowest valley. "**mr**" may be set to any value from 0% to 100%.

Vvv(p), the Dale Void Volume, is the volume of space bounded by the surface texture from a plane at a height corresponding to a material ratio (mr) level, "**p**" to the lowest valley. The default value for "**p**" is 80% but may be changed as needed.

Vvc(p,q), The Core Void Volume, is the volume of space bounded by the texture at heights corresponding to the material ratio values of "**p**" and "**q**". The default value for "**p**" is 10% and the default value for "**q**" is 80%.

 Surface Used for Printing	 Areal Material Ratio Curve 1% Peak and 1% Valley Offset	Total Surface Void Volume from highest peak to lowest valley - Vv(0%) = 7.76 µm³/µm² Dale Void Volume from mr=80% to lowest valley - Vvp(80%) = 0.66 µm³/µm² Core Void Volume from mr=10% to mr=80% - Vvc(10%,80%) = 5.29 µm³/µm²

Example of Void, Dale Void and Core Void volumes. Note: The units for the Vv(mr), Vv(p) and Vvc(p,q) are ***um3/um2*** *- the void volume normalized by the cross sectional area of the measurement area. The peak offsets and valley offsets are applied prior to analysis.*

Application

Vv(mr), **Vvv(p)** and **Vvc(p,q)** all indicate a measure of the void volume provided by the surface between various heights as established by the chosen material ratio(s) values. Thus these three void volume parameters indicate how much fluid would fill the surface (normalized to the measurement area) between the chosen material ratio values. For example, a **Vv(25%)** = 0.5

μm3/μm2 in (note how the units μm3/μm2 reduce to μm) that a 0.5 μm thick film over the measurement area would provide the same volume of fluid as needed to fill the measured surface from a height corresponding to mr=25% to the lowest valley.

The void volume parameters are useful when considering fluid flow, coating applications and debris entrapment. A new surface may be specified by **Vv(0%)** which would indicate the total initial void volume provided by the texture. The Core Void Volume , **Vvc,** may be useful to establish how much core space is available once a surface has been run-in resulting in decreased peak heights . The Dale Void Volume, **Vvv(p)** may be useful in indicating the potential remaining volume after significant wear of a surface has resulted.

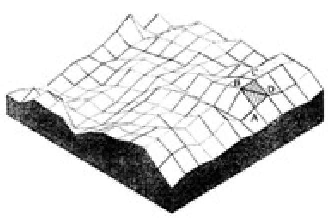
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D S Parameters - Hybrid Parameters

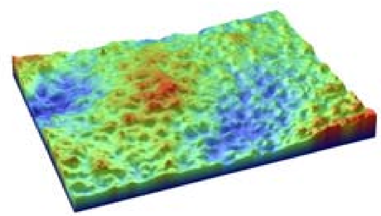
Sdr (Developed Interfacial Area Ratio)

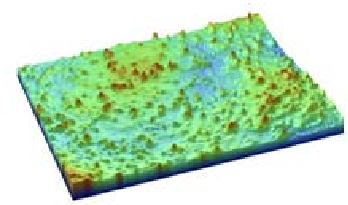
Sdr, the Developed Interfacial Area Ratio, is expressed as the percentage of additional surface area contributed by the texture as compared to an ideal plane the size of the measurement region.

$$Sdr = \frac{(Texture\_Surface\_Area) - (Cross\_Sectional\_Area)}{Cross - Sectional - Area}$$



Surface Area is the total area of all triangles formed over the texture at the resolution of measurement





Christopher A. Brown, William A. Johnsen, Kevin M. Hult, Scale-sensitivity, Fractal Analysis and Simulations, Int. J. Mach. Tools Manufact. Vol 38, Nos 5-6, pp. 633-637, 1998

Sa= 0.52 um , Sdr=0.0023%

Sa= 0.33 um , Sdr=0.0623%

Application

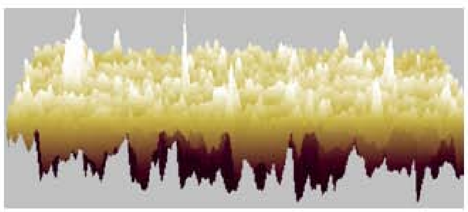
Sdr may further differentiate surfaces of similar amplitudes and average roughness. Typically **Sdr** will increase with the spatial intricacy of the texture whether or not **Sa** changes. **Sdr** is useful in applications involving surface coatings and adhesion. **Sdr** and may find relevance when considering surfaces used with lubricants and other fluids. **Sdr** is affected both by texture amplitude and spacing. Thus higher **Sa,** wider spaced texture may have actually a lower **Sdr** value than a lower **Sa** but finer spaced texture, as displayed above.

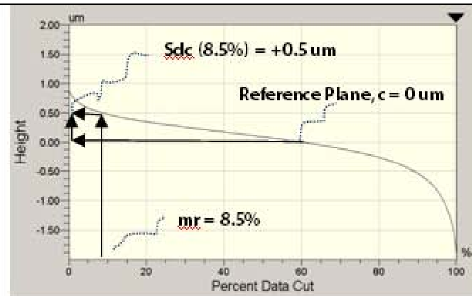
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D Functional Parameters

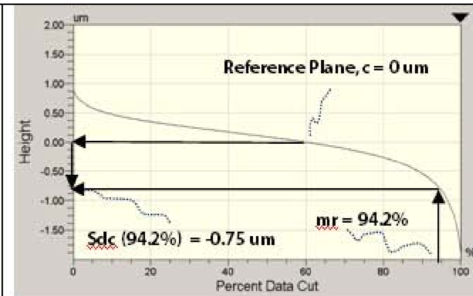
Sdc(mr) (Inverse Areal Material Ratio)

The Inverse Areal Material ratio, **Sdc(mr)** is the height , **c**, which gives the specified material ratio, **mr**. The height **c** may be measured from the best fitting least squares mean plane or as a depth down from the maximum point of the Areal Material Ratio Curve.

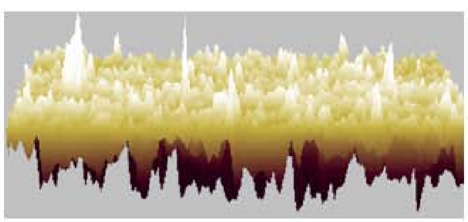


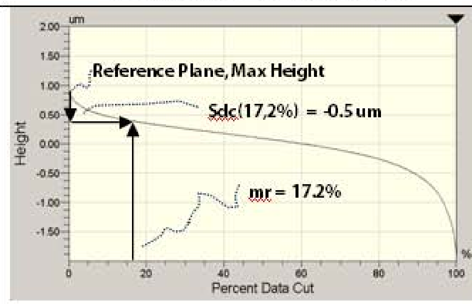


Sdc(8.5%) = +0.5um
Reference Plane = Best Fit Mean Plane

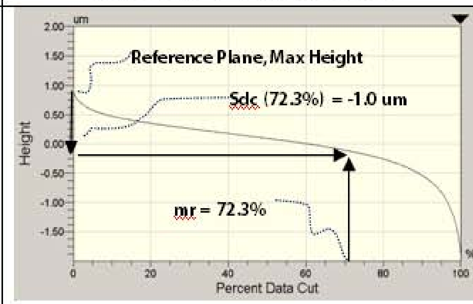


Sdc(94.2%) = -0.75um
Reference Plane = Best Fit Mean Plane





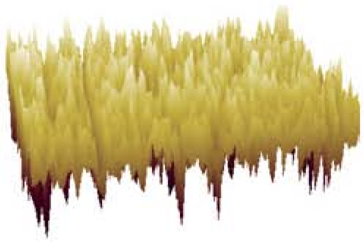
Sdc(17.2%) = -0.5 um
Reference Plane = Max of Areal Material Ratio Curve

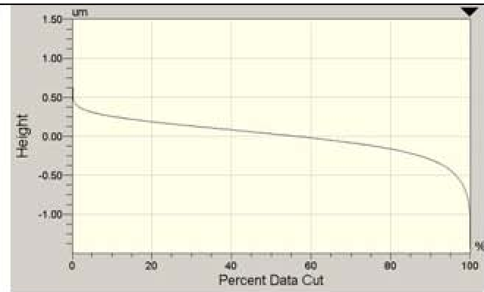


Sdc (72.3%) = -1.0 um
Reference Plane = Max of Areal Material Ratio Curve

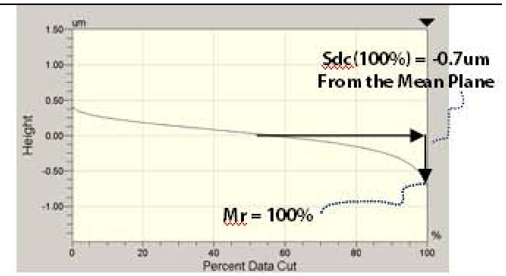
Application

Sdc(mr) might be used to assure that an optimum crevice volume is produced for a sealing surface to allow for some lubricant entrapment (to prevent running dry) but not be too deep to prevent leakage. For example, a specification such as -0.4 um <Sdc(100%)<-0.8 µm with a 1% peak and 1% valley offset, measured from the mean plane, would assure that the bottom 50% or the surface would extend at least 0.4 um below the mean plane but no greater than 0.8µm.





Areal Material Ratio Curve
0% Peak and 0% Valley Offset



Bearing Ratio Curve 1% Peak and 1% Valley Offset
-0.4 um < Sdc(100%) < -0.8 um
Reference Plane = Best Fit Mean Plane

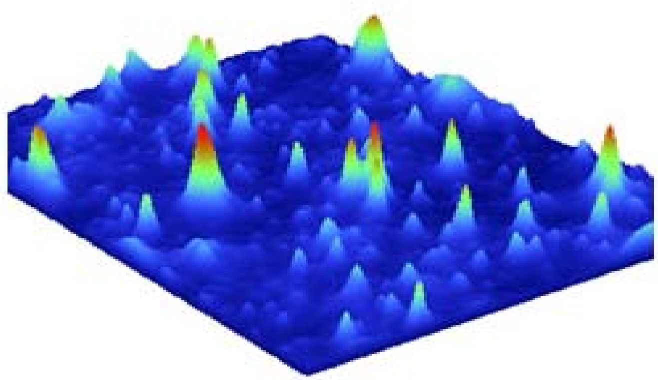
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D S Parameters - Height (Amplitude) Parameters

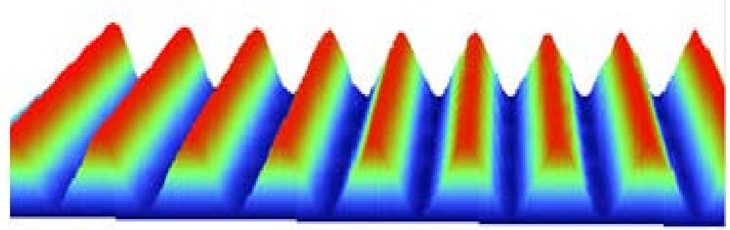
Ssk (Skewness) and Sku (Kurtosis)

Ssk and **Sku** are the Skewness and *Kurtosis of the 3D surface texture respectively. Figuratively, a histogram of the heights of all measured points is established and the symmetry and deviation from an ideal Normal (i.e. bell curve) distribution is represented by* ***Ssk*** *and* ***Sku****. Mathematically, the* ***Ssk*** *and* ***Sku*** *are evaluated as follows:*

$$Ssk = \frac{1}{S_q^3} \iint_a \left(Z(x,y)\right)^3 dxdy \qquad S_{ku} = \frac{1}{S_q^4} \iint_a \left(Z(x,y)\right)^4 dxdy$$



Surface with multiple peaks Ssk = 3.20 Sku = 18.71



Periodic Texture Ssk = 0.16 Sku= 1.63

Application

***Ssk** represents the degree of symmetry of the surface heights about the mean plane. The sign of **Ssk** indicates the predominance of peaks (i.e. **Ssk**>0) or valley structures (**Ssk**<0) comprising the surface. **Sku** indicates the presence of inordinately high peaks/ deep valleys (**Sku**>3.00) or lack thereof (**Sku**<3.00) making up the texture. If the surface heights are Normally distributed (i.e. bell curve) then **Ssk** is 0.00 and **Sku** is 3.00. Surfaces described as gradually varying, free of extreme peaks or valley features, will tend to have **Sku** <3.00. **Ssk** is useful in specifying honed surfaces and monitoring for different types of wear conditions. **Sku** is useful for indicating the presence of either peak or valley defects which may occur on a surface. Since **Ssk** and **Sku** involve the higher order powers of the surface heights, one must make enough measurements to provide statistically significant values and/or properly select filtering bandwidths to eliminate erroneous peaks or valleys.*

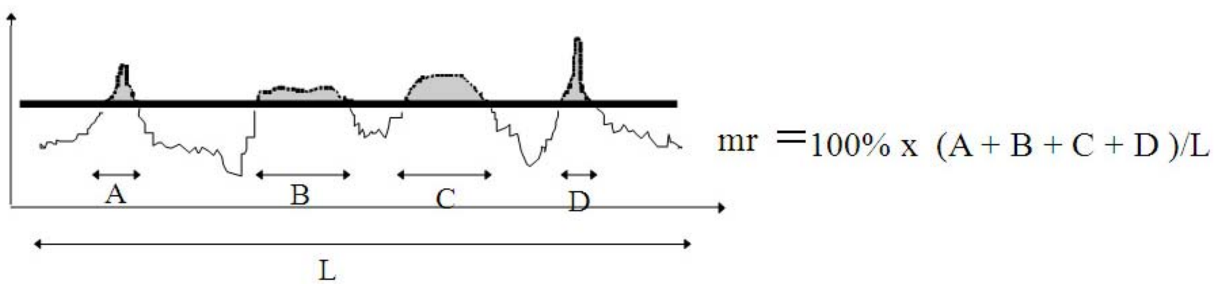
• Parameters By Family • Parameters By Name • Parameters By Symbol

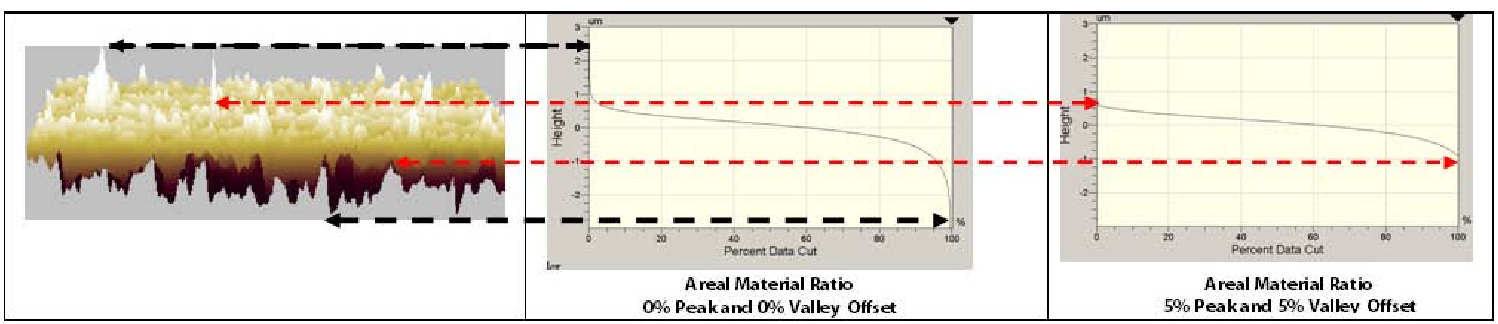
3D Functional Parameters

mr (Material Ratio)

The Material Ratio, **mr**, is the ratio of the intersecting area of a plane (i.e. parallel to the mean plane) passing through the surface at a given height to the cross sectional area of the evaluation region. The **Areal Material Ratio Curve** (*aka* **Bearing Area Curve** or **Abbot Firestone Curve**) is established by evaluating **mr** at various levels from the highest peak to the lowest valley.

Prior to establishing the Areal Material Ratio Curve, a certain percentage of the peak points (i.e., the **Peak Offset**) and valley points (i.e., the **Valley Offset**) are eliminated to minimize the effects of outliers. Typically the Peak Offset and Valley Offset are set to 1%, unless otherwise specified. **mr** is also referred to as "**Percent Data Cut**."





Areal Material Ratio Curve and evaluation of mr. Note that the profiles is shown above for simplicity. When evaluating the 3D (Areal) parameters the *analysis applies to the complete 3D dataset.*

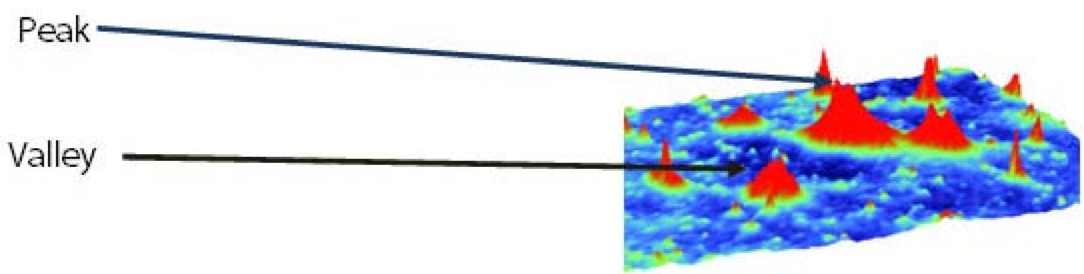
• Parameters By Family • Parameters By Name • Parameters By Symbol

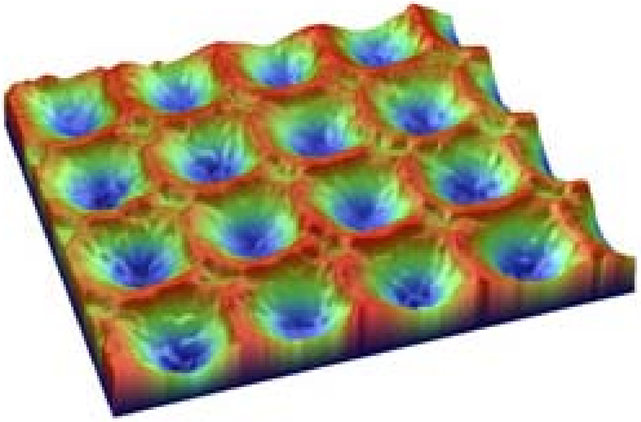
3D S Parameters - Height (Amplitude) Parameters

Sp (Max Peak Height), Sv Max Valley Depth), Sz (Max Height of Surface)

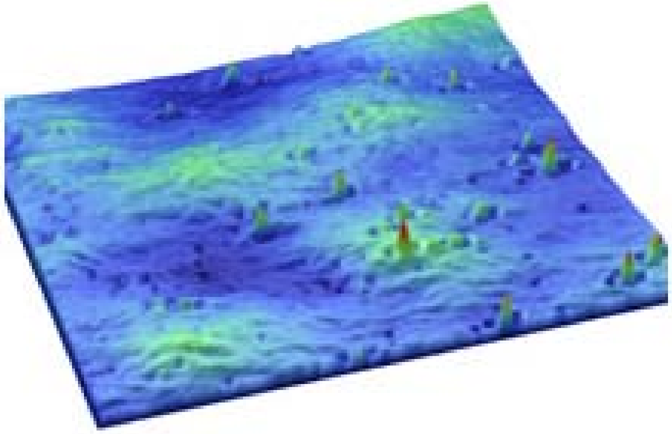
Sp, **Sv**, and **Sz** are parameters evaluated from the absolute highest and lowest points found on the surface. **Sp,** the Maximum Peak Height**,** is the height of the highest point, **Sv**, the Maximum Valley Depth, is the depth of the lowest point (expressed as a negative number) and **Sz** the Maximum Height of the Surface), is found from **Sz = Sp – Sv**.

Note: **earlier standards** referred to **Rz** as a average of the 10 highest to 10 Lowest Points and other variations. The ISO community agreed for the newer standard, ISO 25178-2 to establish Sz as strictly the peak to valley height over a areal measurement.





A surface used in the printing industry characterized by deep valley structures with Sv being ~ -15µm



A polymer surface prepared with asperities as measured by Sp being ~0.90 µm

Application

Since **Sp**, **Sv**, and **Sz** are found from single points, they tend to result in unrepeatable measurements. Thus when using these three parameters, one must properly set spatial filtering bandwidths to eliminate erroneous peaks/valleys and average multiple measurements at random locations along the sample, to obtain a statistically significant result. Typical applications for **Sz** may include sealing surfaces and coating applications. **Sp** may find application when considering surfaces that will be used in a sliding contact application. **Sv** may find application when valley depths relating to fluid retention may be of concern such as for lubrication and coating systems.

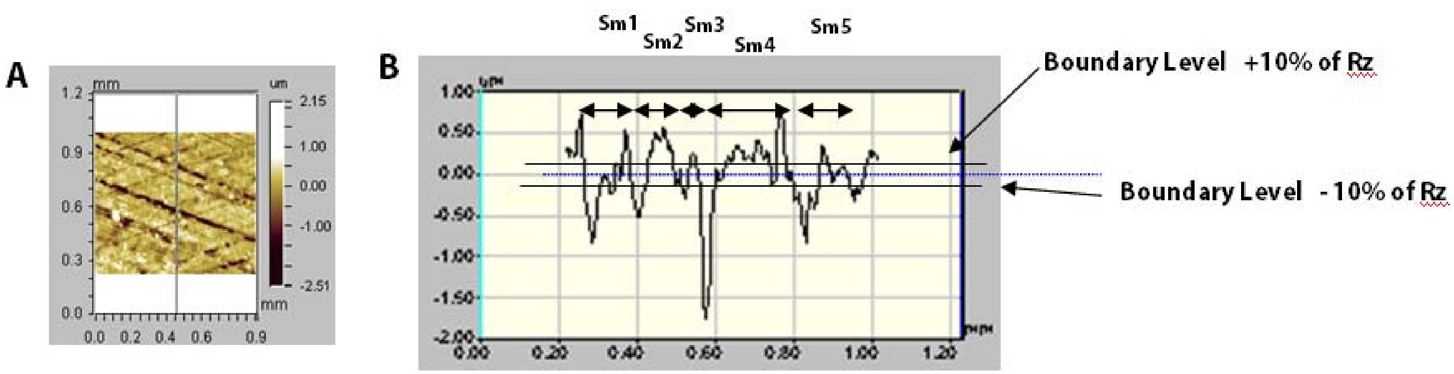
• Parameters By Family • Parameters By Name • Parameters By Symbol

2D (Profile) Stylus Parameters

Stylus (X,Y) Rsm

Stylus (X,Y) Rsm, the Mean Profile Spacing Along (X,Y), is a measure of the average length between points along the profile which cross the mean line with the same slope direction. For a profile element to be considered, the feature must extend above and below the mean line by more than 10% of Rz and be spaced apart from a previous feature by at least 1% of the sampling length.

$$Rsm = \left(\frac{1}{n}\right)\sum_{i}^{n} Sm_i$$



The contour plot (A) shows a line through the center over which the profile (B) is selected to determine Rsm.

Application

Stylus X Rsm and **Stylus Y Rsm** are used to understand the dominant width of features and thus may be useful in understanding chanels for fluid flow and void space for coating coverage applications. Depending on the material properties, closer spaced texture (i.e. small Rsm) may be more prone to plastic deformation upon contact than wider spaced (i.e. large **Rsm**) features.

3D S Parameters - Hybrid Parameters

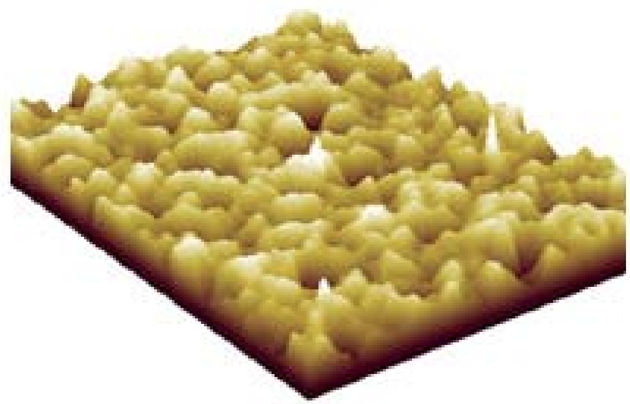
Ssc (Mean Summit Curvature)

Ssc is the Mean Summit Curvature for the various peak structures. Peaks are found as described above for the summit density. **Ssc** is given by the following:

(Note that Ssc is not strictly defined in the ISO 25178-2 but was established earlier in the research which contributed to ISO 25178-2. Future sections of ISO 25178-2 may address parameters such as Sds as “Feature Parameters”.)

$$Ssc = \frac{1}{N} \iint_{Summit-Area} \left(\frac{\partial^2 z(x,y)}{\partial x^2} \right) + \left(\frac{\partial^2 z(x,y)}{\partial y^2} \right) dxdy$$

Evaluated only over the summit features.



Shot Peened Surface for which Ssc = 37 mm-1 (i.e. mean radius of curvature is 27 µm)

Application

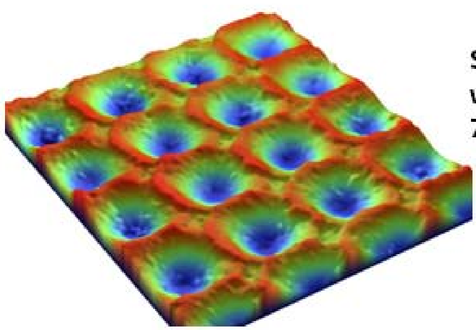
Ssc is useful in predicting the degree of elastic and plastic deformation of a surface under different loading conditions and thus may be used in predicting friction, wear and real area of contact for thermal/electrical applications.

• Parameters By Family • Parameters By Name • Parameters By Symbol

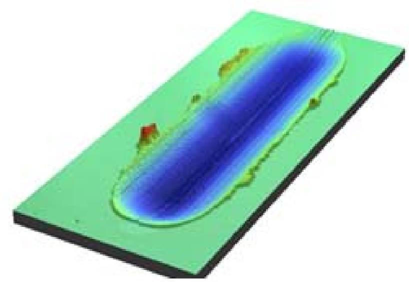
3D Legacy Parameters (WYKO 3D Parameters)

NormVolume (Normalized Surface Volume)

NormVolume, the Normalized Surface Volume, is found by calculating the volume contained by the surface and a “plane” that is placed near the top of the surface. The placement of the reference plane is done on a statistical basis to ensure that the very high peak locations are not used as the reference point for the plane. Once the volume is calculated (e.g. in units of cm3), the volume result is “normalized” to the cross sectional area of the plane (e.g. units of m^2). Other units of **NormVolume** are BCM which is an acronym for “Billions of Cubic Microns per Inch Squared”. The BCM units are typically used in the printing industry.



Surface used for printing with a NormVolume of 7.53 BCM



NormVolume is useful for measuring the volume of a wear scar (0.66 BCM)

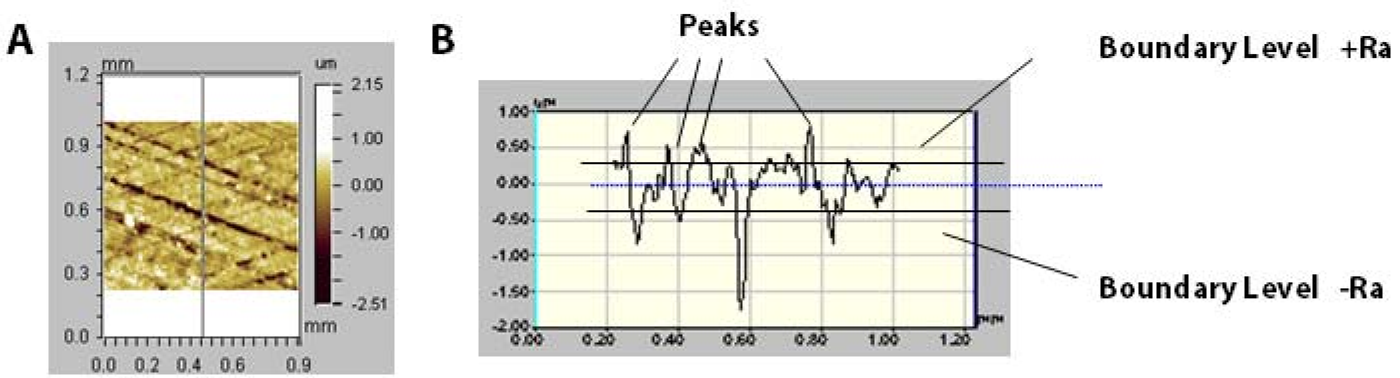
Application

NormVolume finds application in the printing industry, by providing a measure of the fluid holding properties of printing device surfaces (e.g. anilox rolls, Lithoplates, etc.) and the printed media (e.g. paper). Other applications, such as in the tribology field use the NormVolume to establish the volume of space a surface provides for lubricant containment. The measurement of various wear patters may result in a structure in which NormVolume may quantify the amount of material removed from a surface or displaced along a surface.

2D (Profile) Stylus Parameters

Stylus (X,Y) Pc

Stylus (X,Y) Pc the Peak Density Along (X,Y), measures the number of peaks per unit length in the X and Y directions respectively. A peak is defined as when the profile intersects consecutively a lower and upper boundary level set at a height above and depth below the mean line, equal to **Ra,** for the profile being analyzed.



The contour plot (A) shows a line through the center over which the profile (B) is selected to determine Pc..

Application

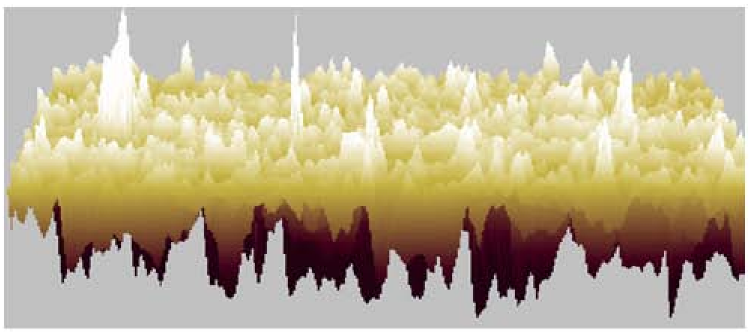
Stylus X Pc and **Stylus Y Pc** are useful parameters for assessing the peak density (e.g. peaks/mm) along a given direction. Applications involved in coating a surface, or when fluid leakage/retention are of issue may make use of the **Pc** parameters to optimize the surface texture design. Sometimes the combination of parameters such as **Rz** with **Pc** will yield additional information about the spacing and depth of dominant surface features that may affect
the function of a component.

• Parameters By Family • Parameters By Name • Parameters By Symbol

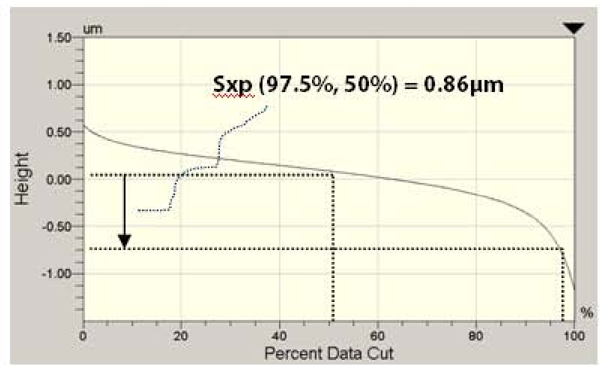
3D Functional Parameters

Sxp (p,q) Peak Extreme Height

The Peak Extreme Height, **Sxp (p,q)**, is a measure of the difference in heights on the surface from the areal material ratio value of “p” and the areal material ratio of “q”. The default value for “p” is 97.5% and the default value for “q” is 50%.



Areal Material Ratio Curve



Application

Assuming a surface was worn or modified such that the resulting material area was 50%, **Sxp** (97.5%, 50%) indicates the depth of the remaining material to the lowest regions of the texture. Thus **Sxp** (97.5%,50%) may be used to determine the depth of material available after 50% or the surface has either been removed or deformed to a plateau-like structure. By changing the values of “p” and “q”, **Sxp** (p,q) may be used to control other aspects of the texture.

As another example, **Sxp** (90%, 10%) may be used to control the overall “peak-to valley” height of the surface by not accounting for the top 10% of the surface which may likely be easily deformed/worn and the bottom 10% which may be easily filled in during initial surface interactions.

• Parameters By Family • Parameters By Name • Parameters By Symbol

3D S Parameters - Hybrid Parameters

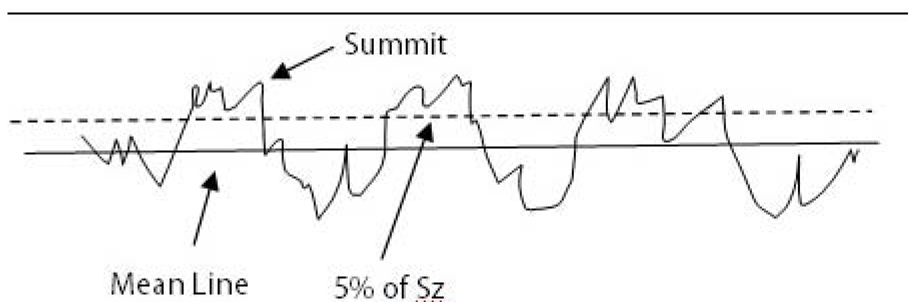
Sds (Summit Density)

Sds, the Summit Density, is the number of summits per unit area making up the surface. Summits are derived from peaks. A peak is defined as any point, above all 8 nearest neighbors. Summits are constrained to be separated by at least 1% of the minimum “X” or “Y” dimension comprising the 3D measurement area. Additionally, summits are only found above a threshold that is 5% of Sz above the mean plane.

(Note that Sds is not strictly defined in the ISO 25178-2 but was established earlier in the research which contributed to ISO 25178-2. Future sections of ISO 25178-2 may address parameters such as Sds as “Feature Parameters”.)

$$S_{ds} = \frac{Number - of - Peaks}{Area}$$

Surface with Sds ~ 2600 summits/mm



Although a 2D profile is shown here, it is understood that this criteria is applied to the 3D features of the surface.

Application

Sds is a key parameter when considering surfaces used in applications such as bearings, seals and electronic contacts. The manner in which the summits elastically and plastically deform under load is related to the **Sds** parameter. Depending on the application, a low **Sds** may result in higher localized contact stresses resulting in possible pitting and debris generation. In applications involving sliding components, a number of summits are needed to prevent optical contacting while maintaining a reasonable load distribution. Summit density may also be related to the cosmetic appearance of a surface once painted.

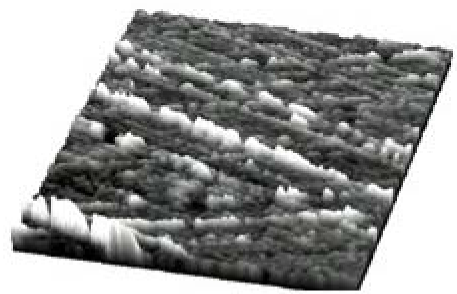
• **Parameters By Family** • **Parameters By Name** • **Parameters By Symbol**

3D Functional Parameters

Spk/Sk (Reduced Peak Height to Core Ratio), Svk/Sk (Reduced Valley Depth to Core Ratio), Spk/Svk (Reduced Peak Height to Reduced Valley Depth Ratio)

The ratios of the various areal material ratio parameters **Spk/Sk** , the Reduced Peak Height to Core Ratio, **Svk/Sk**, the Reduced Valley Depth to Core Ratio, and **Spk/Svk**, the Reduced Peak Height to Reduced Valley Depth Ratio may be helpful in further understanding the nature of a particular surface texture. In some instances, two surfaces with indistinguishable roughness average (**Sa**) may be easily distinguished by a ratio such as **Spk/Sk**. For example a surface with high peaks as opposed to a surface with deep valleys may have the same **Sa** but with vastly different **Spk/Sk** values.

Sa = 308 nm
Spk/Sk=0.25



Sa = 308 nm
Spk/Sk=1.07

Two surfaces with the same Sa but different Spk/Sk values.

Application

By considering the ratios such as **Spk/Sk**, **Svk/Sk** and **Spk/Svk** one may determine quantitatively the dominance of peak structures relative to valley structures. In typical tribological applications such as seals and bearings these ratios may be useful in differentiating surfaces that have similar surface roughness as measured by **Sa**. The ratios may be further thought of as a measure of the texture amplitude distribution normalized by the overall roughness magnitude and thus may be used to characterize the texture amplitude symmetry.

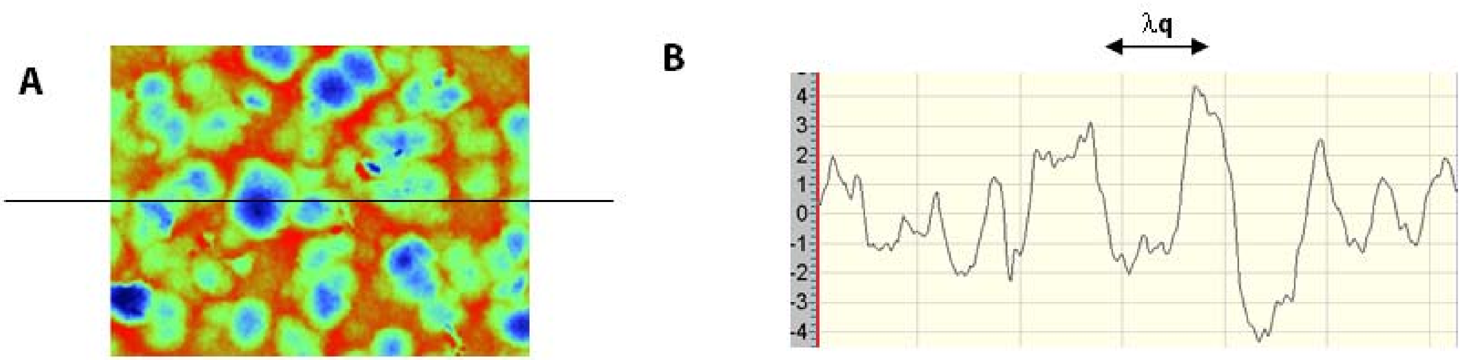
• Parameters By Family • Parameters By Name • Parameters By Symbol

2D (Profile) Stylus Parameters

Stylus (X,Y) λq

Stylus (X ,Y) λq , the Root Mean Square (rms) Profile Wavelength Along (X, Y), is a measure of the dominant spatial wavelength that comprises the surface weighted by the amplitude of the various spatial components. The evaluation of these parameters stems from Fourier analysis of the surface texture resulting in the following:

$$Stylus\ X\ \lambda q = 2\pi \frac{Stylus\ X\ Rq}{Stylus\ X\ \Delta q} \qquad Stylus\ Y\ \lambda q = 2\pi \frac{Stylus\ Y\ Rq}{Stylus\ Y\ \Delta q}$$



Depiction of the evaluation of the lq parameter. The contour plot (A) shows a line through the center over which the profile (B) is selected. After evaluation, a representation of λq is depicted in (B).

Application

The **λq** measurements along the X and Y directions provide a quantitative measure of the key spatial wavelengths that comprise the texture in the respective directions. A surface that has a high amplitude long wavelength wavy structure on which are superimposed small amplitude short wavelength texture features will have a **λq** representative of the long wavelength structure. However, as the amplitude of the shorter wavelength structure begins to approach that of the long wavelength structure, the measured **λq** will seek a value somewhere between the long wavelength and short wavelength values. **λq** is used when tool feed rates are under investigation and as a further means to differentiate surfaces/processes that yield similar amplitude parameters (e.g. **Ra**) but function differently. **λq** may be related to the appearance of a surface and also the real area of contact between loaded components.

• Parameters By Family • Parameters By Name • Parameters By Symbol

2D (Profile) Stylus Parameters

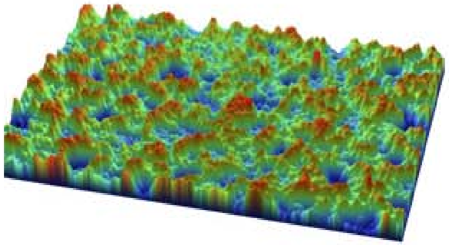
Stylus (X,Y) Δq

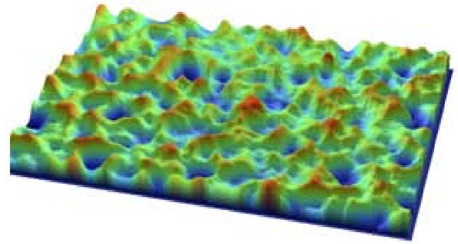
Stylus (X, Y) Δq is the Root Mean Square Slope Along (X,Y). The **Stylus X Δq** and **Stylus Y Δq** calculations find the rms (standard deviation) of the profile slope given by:

$$Stylus\ X\ \Delta q = \left(\frac{1}{Lx} \int_0^{Lx} \left(\frac{dZ(x)}{dx} - \left\langle \frac{dZ(x)}{dx} \right\rangle \right)^2 dx \right)^{1/2} \quad Stylus\ Y\ \Delta q = \left(\frac{1}{Lx} \int_0^{Lx} \left(\frac{dZ(y)}{dy} - \left\langle \frac{dZ(y)}{dy} \right\rangle \right)^2 dy \right)^{1/2}$$

From Fourier analysis, the surface texture is composed of a series of sine waves in all directions with different spatial frequencies (i.e. 1 /spatial wavelength) and amplitudes. The power spectrum is a measure of the amplitude of each sine wave for a particular spatial frequency, along a given direction. Thus for a 3D surface, the power spectrum would be displayed as a “3D” function in which the X and Y axes represent the various spatial frequencies for a given direction. The amplitude of the power spectrum (displayed on the Z axis) represents the amplitude of the sine wave at a particular spatial frequency direction. The angular power spectrum is found by integrating the amplitudes of each component sine wave as a function of angle.

The figures below demonstrate a crosshatched surface, the power spectral density of the surface and the angular power spectral density function.





Depiction of two surfaces with similar overall roughness but different surface texture slopes along the X and Y directions as a result of the presence or absence of finer spaced features.

Application

The **Δq** measurements along the X and Y directions provides a quantitative assessment of the rate of change of the surface heights over the profile length. Since the slope values are squared prior to integration, the polarity (i.e. positive or negative) of the slope is lost in the calculation. The **Δq** measurements may be useful in applications where a machining process is producing parts with nominally correct amplitude parameters (e.g. **Ra**) but has other functional or process problems. For machining operations, parameters associated with the materials or machine setup may be manifested in significant changes in the surface slopes, easily measured by **Δq**. The wetting characteristics of a surface and the surface area of a texture may be related to **Δq.**

• Parameters By Family • Parameters By Name • Parameters By Symbol

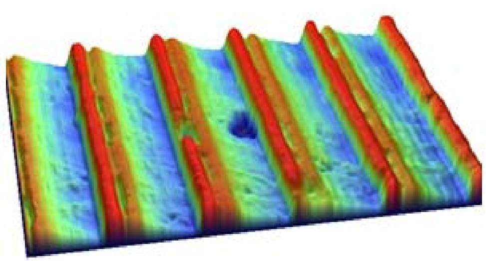
3D Legacy Parameters (WYKO 3D Parameters)

X Slope Rq and Y Slope Rq (X and Y Root Mean Squared Slope)

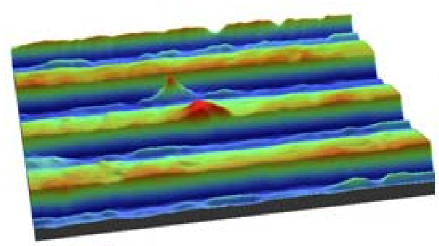
X Slope Rq and **Y Slope Rq**, the Root Mean Squared X Slope and Root Mean Squared Y Slope are found by calculating the standard deviation (i.e. rms) of the slopes of the surface along the X and Y directions respectively. The slope is found by taking the derivative of the surface profiles along each direction, using the lateral resolution of the measurement area as the point spacing. Analytically, **X Slope Rq** and **Y Slope Rq** are given by:

$$X\,Slope\,Rq = \left(\iint_a \left(\frac{\partial Z(x,y)}{\partial x} - \langle\frac{\partial Z(x,y)}{\partial x}\rangle\right)^2 dxdy\right)^{1/2} \qquad Y\,Slope\,Rq = \left(\iint_a \left(\frac{\partial Z(x,y)}{\partial y} - \langle\frac{\partial Z(x,y)}{\partial y}\rangle\right)^2 dxdy\right)^{1/2}$$

Where the brackets, <   >, represent the average value of all slopes in the relevant direction.



X Slope Rq = 9.28 deg
Y Slope Rq = 1.85 deg



X Slope Rq = 1.66 deg
Y Slope Rq = 9.10 deg

Application

Slopes may be used to investigate the behavior of various surface texture forming techniques in that material and process conditions may change the slopes considerably, whereas the height parameters such as **Ra** are relatively unaffected. The surface slope may also be useful in relating the nature of the surface when used in coating and visual appearance applications.

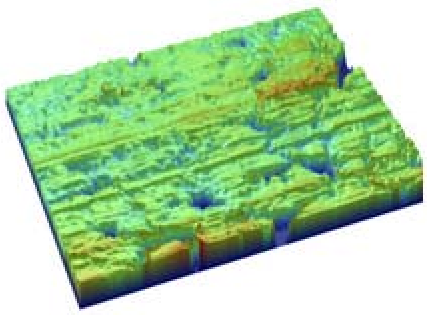
• Parameters By Family • Parameters By Name • Parameters By Symbol

3D S Parameters - Hybrid Parameters

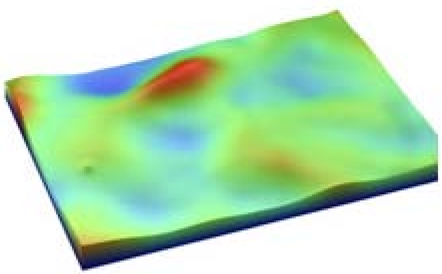
Sdq (Root Mean Square (RMS) Surface Slope)

Sdq is the Root Mean Square (RMS) Surface Slope comprising the surface, evaluated over all directions.

$$Sdq = \sqrt{\frac{1}{A}\int_0^{Lx}\int_0^{Ly}\left(\frac{\partial Z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial Z(x,y)}{\partial y}\right)^2 dydx}$$



Sa = 80 nm, Sdq=11.0 deg



Sa = 75 nm, Sdq=0.2 deg

Application

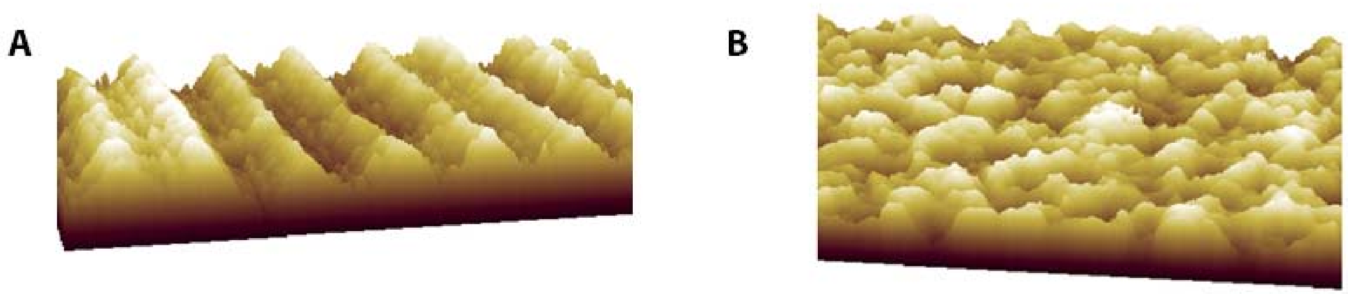
Sdq is a general measurement of the slopes which comprise the surface and may be used to differentiate surfaces with similar average roughness, **Sa**. **Sdq** may find application for sealing systems, surface cosmetic appearance and may be related to the degree of surface wetting by various fluids. **Sdq** is affected both by texture amplitude and spacing. Thus for a given **Sa,** a wider spaced texture may indicate a lower **Sdq** value than a surface with the same **Sa** but finer spaced features, as demonstrated above.

• Parameters By Family • Parameters By Name • Parameters By Symbol

2D (Profile) Stylus Parameters

Stylus X Ra/Stylus Y Ra, Stylus X Rz/Stylus Y Rz, Stylus X Δq/Stylus Y Δq, Stylus X λq/Stylus Yλq, Stylus X Pc/ Stylus Y Pc

The various **Stylus X/Stylus Y** ratios are found by dividing the corresponding Stylus X parameter(e.g. **Stylus X Ra**) by the corresponding Stylus Y Parameter (e.g. **Stylus Y Ra**). Thus the various ratios are unitless quantities.



A lathe- turned surface (A) for which Stylus X Ra/Stylus Y Ra is about 2.5 and a peened surface (B) where Stylus X λq/Stylus Y λq is about 1.0.

Application

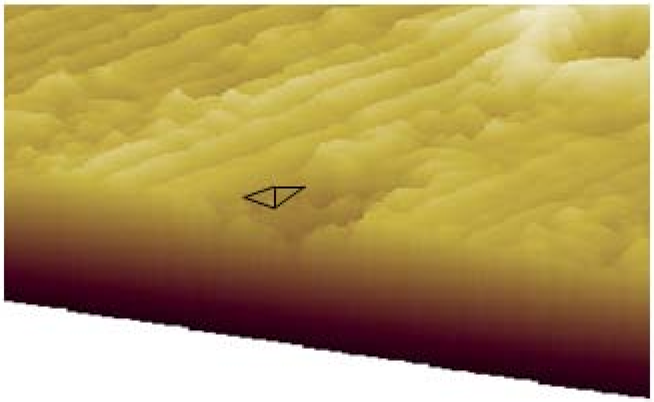
The ratio of the various Stylus X and Stylus Y parameters demonstrates the spatial isotropy of the surface texture. For example, the lathe-turned
surface (Figure A) has a high degree of anisotropy and thus the ratio of **Stylus X Ra/Stylus Y Ra** is greater than 1.00. A shot peened isotropic surface will tend to have Stylus X & Y ratios of about 1.00. The ratios may be used to assess the ability for a given surface finishing operation to remove remnants of a previous operation. The ratios may also be used to uncover any dominant surface directional paths that may contribute to fluid leakage.

• Parameters By Family • Parameters By Name • Parameters By Symbol

3D Legacy Parameters (WYKO 3D Parameters)

SAI (Surface Area Index)

SAI, the Surface Area Index, is the surface area at the lateral resolution of the measured/filtered surface as compared to that of a perfectly flat/smooth surface. The calculation involves fitting triangular patches between the measured points and adding up the total area of all patches. A ratio is then formed of the total surface area measured and the nominal flat area of measurement. This analysis is a precursor to a complete fractal analysis of the surface.[i] Since **SAI** is a ratio, it is a unitless quantity.



Depiction of the calculation of the Surface Area Index (SAI). Demonstrating only a few triangular patches whereas the complete analysis involves fitting patches over the complete image.

Application

The combination of different surface texture amplitudes and spacings are further manifested in the overall surface provided by the texture. The SAI parameter finds application for issues relating to surface wetting, fluid flow, coating adhesion, printing etc.

[i] C.A. Brown, P.D. Charles, W.A. Johnsen, S. Chester, fractal analysis of topographic data by the patchwork method, Wear 161 (1993) 61-67.

• Parameters By Family • Parameters By Name • Parameters By Symbol

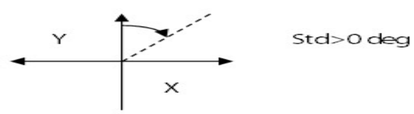
3D S Parameters - Spatial Parameters

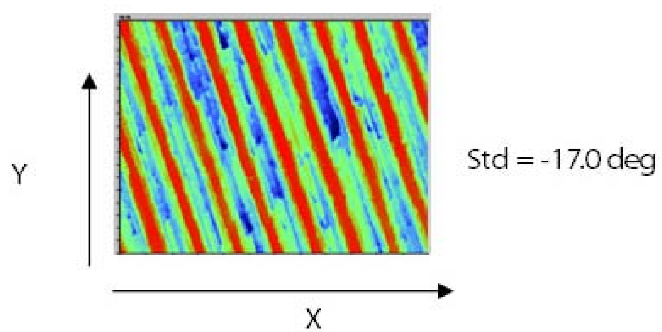
Std (Texture Direction)

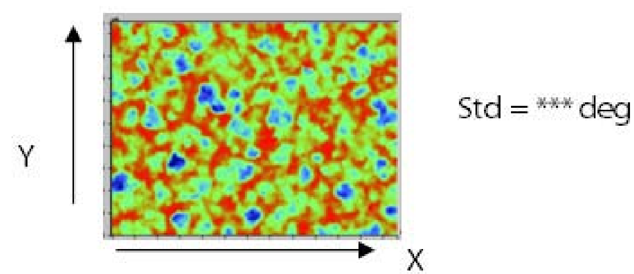
Std, the *texture direction*, is determined by the APSDF and is a measure of the angular direction of the dominant lay comprising a surface. **Std** is defined relative to the Y axis. Thus a surface with a lay along the Y axis will return a **Std** of 0 deg.

(Note that Std is not strictly defined in the ISO 25178-2 but was established earlier in the research which contributed to ISO 25178-2. Future sections of ISO 25178-2 may address parameters such as Std)

Std= Major direction of lay derived from APSDF







Since this surface is spatially isotropic there is no lay and thus Std is indeterminate

Application

Std is useful in determining the lay direction of a surface relative to a datum by positioning the part in the instrument in a known orientation. In some applications such as sealing, a subtle change in the surface texture direction may lead to adverse conditions. **Std** may also be used to detect the presence of a preliminary surface modification process (e.g. turning) which is to be removed by a subsequent operation (e.g. grinding followed by tumbling).