SI-RT-03

Revision B

Imaging Parameters Reference Table

The purpose of this document is to provide a listing and definitions for the Particle Morphology Parameters available in the Microtrac PartAn Software

Listing of Microtrac Morphological Parameters by Primary Characterization Groups			
Size	**Shape/Form**	**Surface Roughness**	**Intensity**
Da**	Sphericity**	Convexity**	Transparency**
Dp	Circularity**	Solidity	Curvature
FLength**	Roundness	Concavity	
FWidth**	Krumbein Roundness		
FThickness** (3D Only)	Extent		
ELength	Ellipse Ratio		
EWidth	W/L Aspect Ratio**		
EThickness (3D Only)	L/W Aspect Ratio**		
Actual Area	T/L Aspect Ratio (3D Only)		
Actual Perimeter	L/T Ratio (3D Only)		
Volume	T/W Ratio (3D Only)		
Surface Area	W/T Ratio (3D Only)		
CHull Area	Ellipticity		
CHull Perimeter			
CHull Surface Area	Angularity		
Sieve (3D Only)	Rectangularity (3D Only)		
Cylinder Diameter (3D Only)	Compactness		
Cylinder Length (3D Only)			
Fiber Length			
Fiber Width			

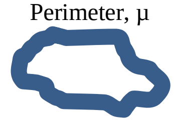
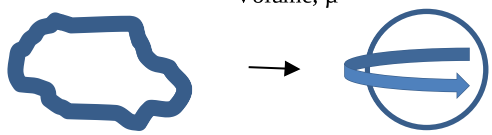
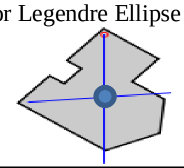
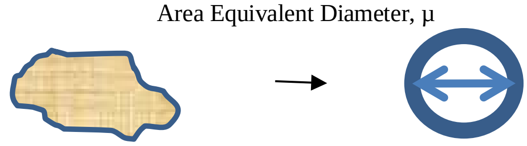
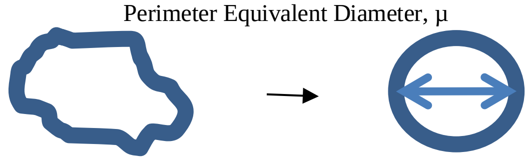
Note 1: The letter "F" refers to Feret calculations. The letter "E" refers to Legendre Ellipse calculations. See explanations on following pages for more details.

Note 2: Values containing Thickness (T) are not available in PartAn SI or Sync Hybrid Analyzers (2D). Thickness is only available in PartAn 3D models.

***** Often used parameter***

General Parameter Terminology

This table describes the basic parameters of the measured particles.

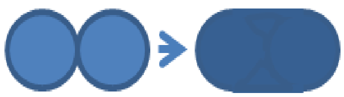
Notation	Description, units
Actual Area = A	Area, μ^2 
Actual Perimeter = P	Perimeter, μ 
Volume	Volume, μ^3 
Centroid	Center of gravity or the x/y point on image (only used for Legendre Ellipse calculations) 
Da $Da = (4A/\pi)^{1/2}$	Area Equivalent Diameter, μ 
Dp $Dp = P/\pi$	Perimeter Equivalent Diameter, μ 

***** Often used parameter***

MICROTRAC MRB PARTICLE CHARACTERIZATION

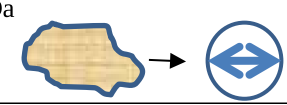
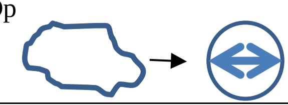
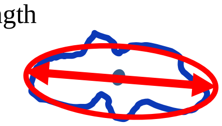
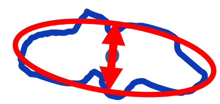
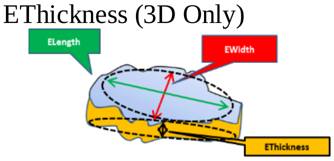
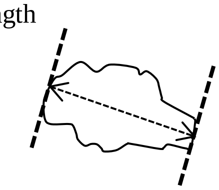
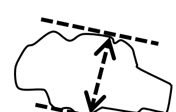
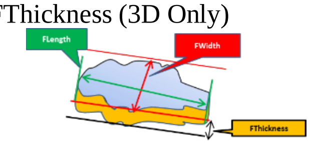
General Parameter Calculations

General parameters indicate dimensions of the outside of particles. Basic Size Parameters used for other calculations

General Parameter	2D Description For Individual Particle	3D Calculation from Series of Tracked Individual Particle	Result Presentation
Actual Area	**Area** = Area of the projected image	Average area of the sequence of 3D images.	**Area:** Basic size parameter and used in other subsequent calculations
Convex Hull Area	**CHull Area**= Area of the convex hull of the image. The convex outline of a projected shape having concavities. If a rubber band is placed around the image, it will describe the Convex Hull. The area is then calculated. 	Average convex hull area of the sequence of 3D images.	**CHull Area:** Not normally used as a parameter, but is a basic size parameter and used in other subsequent calculations.
Actual Perimeter	**Perimeter** = Perimeter of the projected image for 2D.	Average perimeter of the sequence of 3D images.	**Perimeter:** Basic size parameter and used in other subsequent calculations
Convex Hull Perimeter	**CHull Perimeter** = Perimeter of the convex hull of the image. If a rubber band is placed around the image, it will describe the Convex Hull. The perimeter is then calculated. 	Average convex hull perimeter of the sequence of 3D image shapes.	**CHull Perimeter:** Not normally used as a parameter, but is a basic size parameter and used in other subsequent calculations
Legendre Ellipse	Determination of the moments of inertia of the shape coordinates. $\sigma_{xx} = \frac{1}{n}\sum (x_i - \bar{x})^2$ $\sigma_{yy} = \frac{1}{n}\sum (y_i - \bar{y})^2$ $\sigma_{xy} = \frac{1}{n}\sum (y_i - \bar{y})(xi - \bar{x})$ Definition of intermediate terms. $\alpha = \frac{1}{2}(\sigma_{xx} + \sigma_{yy})$ $\beta = \sqrt{\alpha^2 - \sigma_{xx}\sigma_{yy} + \sigma_{xy}}$ Determination of the lengths of the axes of an ellipse with equivalent inertia. Length of the major axis: **ELength** $= 4\sqrt{\alpha + \beta}$ Length of the minor axis: **EWidth** $= 4\sqrt{\alpha - \beta}$		

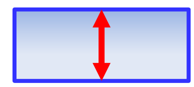
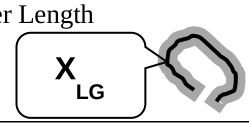
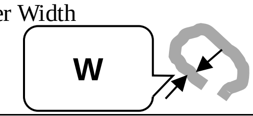
***** Often used parameter***

Size Parameter Calculations

Size Parameter	2D Calculation for Individual Particle	3D Calculation from Series of Tracked, Individual Particles	Result presentation
Area Equivalent diameter**	Da $= (4\text{Area}/\pi)^{1/2}$	Area = average Area in sequence of 3D images	Da 
Equivalent perimeter diameter	Dp $=$ Perimeter $/\pi$	Perimeter = average Perimeter in sequence of 3D images	Dp 
Legendre Ellipse Length	Measured length of the major axis of a Legendre ellipse whose center is the centroid of the particle shape. The moments of the Legendre ellipse and shape are the same up to the second order.	ELength = max ELength in sequence of 3D images *Note that "E" values are based upon the Legendre ellipse.*	ELength 
Legendre Ellipse Width	Measured length of the minor axis of a Legendre ellipse whose center is the centroid of the particle shape. The moments of the Legendre ellipse and shape are the same up to the second order.	EWidth = maximum EWidth in sequence of 3D images *Note that "E" values are based upon the Legendre ellipse.*	EWidth 
Legendre Ellipse Thickness	Not available in 2D.	EThickness = minimum EWidth in sequence of 3D images *Note that "E" values are based upon the Legendre ellipse.*	EThickness (3D Only) 
Feret Length**	FLength = Maximal distance between parallel tangents	FLength = maximum FLength in sequence of 3D images	FLength 
Feret Width**	FWidth = Minimal distance between parallel tangents	FWidth = maximum FWidth in sequence of 3D images	FWidth 
Feret Thickness**	Not available in 2D.	FThickness = minimum FWidth in sequence of 3D images	FThickness (3D Only) 
Sieve	Not available in 2D.	Sieve = (Sieve Coeff x FWidth) + ((1- Sieve Coeff) x FThickness) (3D only)	Sieve - Sieve data required

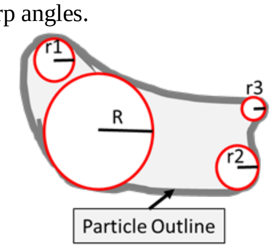
***** Often used parameter***

Size Parameter Calculations

Size Parameter	2D Calculation for Individual Particle	3D Calculation from Series of Tracked, Individual Particles	Result presentation
Cylinder Diameter	Not available in 2D.	CylDia = Distance parallel to shortest edges of the above Rectangularity minimum rectangle (3D only)	CylDia – Used when cylinder calculation option is selected 
Cylinder Length	Not available in 2D.	CylLength = Distance parallel to longest edges of the above Rectangularity minimum rectangle (3D only)	CylLength – Used when cylinder calculation option is selected 
Fiber Length	$X_{LG} = \frac{1}{4}\left(P + \sqrt{(P^2 - 16A)}\right)$ A= Area LG = length	*Not available* in 3D	Fiber Length 
Fiber Width	$W = A/X_{LG} - X_{LG}$	*Not available* in 3D.	Fiber Width 

***** Often used parameter***

Shape Parameter Calculations

Shape Parameter	2D Calculation for Individual Particle	3D Calculation from Series of Tracked, Individual Particles	Result presentation
Ellipse Ratio	**Ellipse Ratio** = EWidth / ELength (2D)	**Ellipse Ratio** = EThickness/ELength. (3D) Minimum EWidth / ELength *Note that "E" values are based upon the Legendre ellipse.*	Measure of overall form. As it decreases, measures of circularity decrease. Ratio of Width to Length, 0 to 1 (square to circle). Uses Legendre ellipse calculation.
Ellipticity	**Ellipticity** = 1/Ellipse Ratio (2D)		Measure of overall form. Inverse of Ellipse Ratio
Compactness	**Compactness** = $(4\text{Area}/\pi)^{1/2}$ / FLength	Area = average Area of a sequence of 3D images FLength = max FLength in the series of images	Less sensitive but more robust, than Roundness Values 0 to 1 (circle).
Roundness	**Roundness** = 4Area / π $(\text{FLength})^2$	Area = average Area of a sequence of 3D images = FLength = max FLength in the series of images	Measure of proximity to circle, 0 to 1 (circle). Sensitive to elongated deviations from a circle. Overall shape indicator.
Krumbein Roundness	<u>Krumbein RND –</u> Krumbein RND = avg$(r_1,r_2,r_3,\ldots,r_n)$ / R R = Radius of largest inscribed circle in the shape. r_1, r_2, r_3, …. , r_n = radius of all turns in the shape (where r_n is less than R) Uses: Proppants and materials showing protrusions and sharp angles such as abrasives.	Average of a sequence of 3D images General explanation: The largest circle that can be inscribed in the particle is determined. Turns in the particle shape are identified and the radius of each is calculated. The average of the radii of all turns is calculated. The average is divided by the radius of the inscribed circle. A perfect, circularly shaped particle will provide a value of 1.	Calculation used for proppants and materials having protrusions and sharp angles. 
T/L Aspect Ratio	*<u>Not available</u>* in 2D.	T/L Aspect Ratio = FThickness / FLength (3D) = Minimum FWidth / Maximum FLength in the series of images	FThickness and FLength from the sequence of 3D images of the same particle. Value range = 0 to 1 where 1 represents sphere.
L/T Ratio	*<u>Not available</u>* in 2D.	**L/T Ratio** = FLength / FThickness (3D) = Maximum FLength / Minimum FWidth in the series of images	FLength and FThickness from the sequence of 3D images of the same particle. Value range = 1 to infinity where 1 represents sphere.
W/L Aspect Ratio **	**W/L Aspect Ratio** = FWidth / FLength (2D)	**W/L Ratio** = FWidth / FLength (3D) = Maximum FWidth/ maximum FLength in the series of images	For 2D, FLength and FWidth are from one particle image. 3D uses from the sequence of 3D images of the same particle. Value range = 0 to 1 where 1 represents sphere.

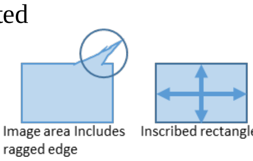
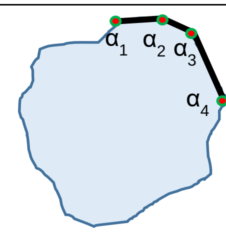
***** Often used parameter***

Shape Parameter Calculations

Shape Parameter	2D Calculation for Individual Particle	3D Calculation from Series of Tracked, Individual Particles	Result presentation
L/W Aspect Ratio **	**L/W Aspect Ratio** = FLength / FWidth (2D)	**L/W Ratio** = FLength / FWidth = Maximum FLength / Maximum FWidth in the series of images	For 2D, FLength and FWidth are from one particle image. For 3D, FLength and FWidth are from the sequence of 3D images of the same particle. Value range = 1 to infinity where 1 represents sphere.
T/W Ratio	*Not available* in 2D.	**T/W Ratio** = FThickness / FWidth (3D) = Minimum FWidth / Maximum FWidth in the series of images	FThickness and FWidth from the sequence of 3D images of the same particle. Value range = 0 to 1 where 1 represents sphere.
W/T Ratio	*Not available* in 2D.	**W/T Ratio** = FWidth / FThickness (3D) = Maximum FWidth / Minimum FWidth in the series of images	FWidth and FThickness from the sequence of 3D images of the same particle. Value range = 1 to infinity where 1 represents sphere.
Extent	**Extent** = Area / (FLength x FWidth) (2D)	**Extent** = Area / (FLength x FThickness) (3D) = Area / (Maximum FLength x Minimum FWidth)	Value of 1 describes the degree to which the actual area takes up maximum possible area based on product of the two largest perpendicular dimensions.
Sphericity**	**Sphericity** = $[4\pi \text{Area} /(\text{Perimeter}^2)]^{1/2}$ = Da/Dp	Area = average Area of a sequence of 3D images Perimeter = average Perimeter of a sequence of 3D images	Measure of the proximity to a circle Values range 0 to 1(value of 1 equals a perfect circle)
Circularity**	**Circularity** = Sphericity^2 $[4\pi \text{Area} / (\text{Perimeter}^2)]^2$ = $(\text{Da/Dp})^2$	Area = average Area of a sequence of 3D images Perimeter = average Perimeter of a sequence of 3D images	Measure of proximity to a circle. More sensitive, less robust, than Sphericity. Range of values 0 to 1 (value of 1 equals a perfect circle).
Solidity	**Solidity** = Area / CHull Area	Area = average Area of a sequence of 3D images CHull Area = average Convex Hull Area	Measure of surface roughness, 0 to 1. Value of 1 describes very smooth surface. Ratio of area of the particle to the area of the convex hull.
Concavity	**Concavity** = (CHull Area – Area) / CHull Area	Area = average Area of a sequence of 3D images CHull Area = average Convex Hull Area	Measure of surface roughness, 0 to 1. In this case, a value of 1 describes an extremely rough, spikey surface
Convexity**	**Convexity** = CHull Perimeter / Perimeter	Perimeter = average Perimeter of a sequence of 3D images	Measure of surface roughness, 0 to 1 (smooth). As roughness increases, measures of circularity decrease.

***** Often used parameter***

Shape Parameter Calculations

Shape Parameter	2D Calculation for Individual Particle	3D Calculation from Series of Tracked, Individual Particles	Result presentation
Rectangularity	*Not available* in 2D.	Rectangularity = Maximum ratio of Area of image in 3D row divided by Area of maximum rectangle that can be inscribed within that image. (3D only)	Rectangularity - Used when cylinder calculation option is selected 
Angularity	First the outline is reduced to be expressed by a fewer number of points. Angle at each point is calculated, $\alpha_1, \alpha_2 \ldots \alpha_n$ Change in angle at each point is calculated: $\beta_n = \alpha_n - \alpha_{n+1}$ Angularity Index is calculated, where e is 0, 10, 20 … 170 for class in $$AI = \frac{\sum_{e=0}^{e=170} eP(e)}{n}$$ Where $P(e)$ is the frequency of β_n in each interval 0-10, 10-20 … 170-180	**Reference:** Evaluation of Aggregate Imaging Techniques for the Quantification of Morphological Characteristics, Wang, Sun, Tutumluer, Druta (Paper Submitted August 1, 2012 for Presentation at the 2013 TRB Annual Meeting and Publication in the Transportation Research Record: Journal of the Transportation Research Board). **Uses:** Any material including aggregates used in and materials showing protrusions and sharp angles such as abrasives. **Range of values** 0 to 180. 180= many sharp edges. Value=0 for perfect circle.	 Particle shape, ***angularity***, and surface texture are critical properties in assessing aggregate usage for asphalt concrete. Fractured and flat and/or elongated particles are used in most specifications to assure quality.

Shape Parameter Notes: *Form indicators in that they diverge further from a sphere to other shapes. All are ratios that use the above values to elucidate shape features. For instance, Surface Roughness parameters (convexity, etc.) can identify poor flowability/compaction and agglomerated particles. This chart uses values from Appendix I table to provide special calculations to assist defining shape characteristics. 3D refers to 3Dimensional image data. 2D refers to 2Dimensional image data. When thickness (T) is applied to a formula, only 3D calculation is available.*

***** Often used parameter***

Surface Area and Volume Calculations

Surface Area / Volume Parameter	2D Calculation for Individual Particle	3D Calculation from Series of Tracked, Individual Particle	Result presentation
Surface Area (Sphere)	Surface Area = $\pi * (Da)^2$	Da calculated from average Area of the sequence of 3D images.	**Surface Area** (not a BET measurement)
CHull Surface Area (Sphere)	CHull Surface Area = $\pi*(Dca)^2$	Dca (CHull Area) calculated from the average CHull Area in the sequence of 3D images.	**CHull Surface Area-**
Volume	Calculated from the Area Equivalent Diameter, Da. **Volume** = $\pi\,(Da)^3 / 6$ (2D)	Calculated from actual 3D size parameters. **Volume** = FLength x FWidth x FThickness = Maximum FLength x Maximum FWidth x Minimum FWidth Best indication of volume since 3 dimensions being used.	**Volume**

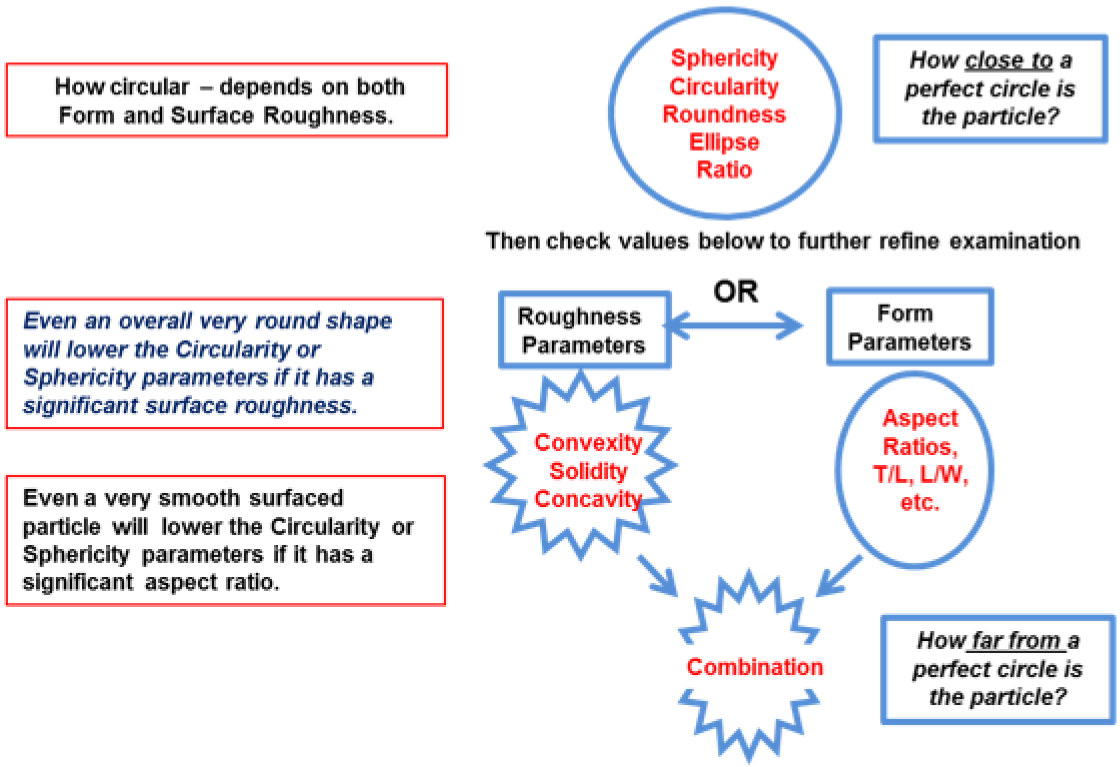
Intensity Parameter Calculations

Shape Parameter	Description
Transparency**	Transparency is the mean light intensity of the longest vertical line analyzed. The value is normalized to the range 0 to 1, with 0 being least transparent and 1 being the most transparent. See Particle Measurement section for more detail.
Curvature	The middle 50% of the line used to calculate Transparency (above) is fit to a parabolic function. The second order derivative of this function gives the Curvature value (concavity of the intensity gradient). On a scale of 0 to 1, any curvature values greater than 0.1 is very transparent, spherical particle.

***** Often used parameter***

Parameter Choice Decisions

A best practice for the development of data selection and specification setting is by starting with View Particles. Begin by selecting samples of "very good" and "very bad" product to facilitate the selection of the best parameters to use for SOP development. Additional selection of product having intermediate grades between "very good" and "very bad" will then be useful in further refinement of limits for optimal quality control.



<u>Setting Specifications / Selecting Data</u>

- Select "very good" and "very bad" product samples.
- Make measurements.
- Go to View Particles and determine what values allow discrimination between good and bad product.
- Obtain additional samples inside the range of "very good" and "very bad" product to further refine the acceptance values.

***** Often used parameter***