application note

# Particle size and shape measurement using image analysis

## What exactly is particle size and shape?

This paper describes how particle size and particle shape is calculated and illustrates how image analysis can be used to measure both.

## What is particle size?

Describing a 3D particle is often a more complex matter than it first appears. For practicality or ‘management purposes’ it is convenient to describe particle size as one single number. However, unless the particle is a perfect sphere (which is rare in ‘real-world’ samples) there are many ways to describe the size of a particle. This is the basic challenge of particle size analysis – how do we describe a 3-dimensional object with one number only?

Image analysis captures a 2-dimensional image of the 3D particle and calculates various size and shape parameters from this 2D image. One of the principle diameters calculated is CE diameter (Circle Equivalent diameter) which is the diameter of a circle with the same area as the 2D image of the particle. Of course different shaped particles will have an influence on this CE diameter but, importantly, it is a single number that gets larger or smaller as the particle does and it is objective and repeatable.

## CE diameter

The 3D image of the particle is captured as a 2D image and converted to a circle of equivalent area to the 2D image. The diameter of this circle is then reported as the CE diameter of that particle (see Fig.1).

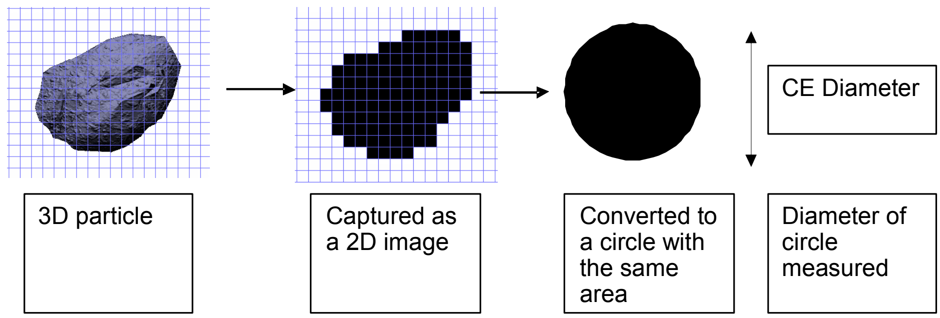


**Figure 1:** Calculation of CE diameter

Of course a single value from one particle is unlikely to be the much sought-after “single number for management purposes”. It is unlikely to be statistically significant as the single value depends upon which individual particle is chosen. A number of particles which are representative of your sample as a whole have to be measured and statistical parameters generated.

A more appropriate single characterisation number would be the mean of all the CE diameters for example. Once a distribution is generated all statistical parameters such as mean, median, mode, standard deviation, D10, D90 percentiles etc can be easily calculated.

Many real-world samples are broadly shaped like a “Normal” or “Gaussian” distribution. This allows us to apply statistical methods in order to evaluate confidence parameters and make recommendations on the minimum number of particles to analyze to achieve a reasonable level of statistical significance.

## What is particle shape and why is it important?

If describing a 3D particle size is complex then quantifying shape is even more complicated! There are an almost infinite number of ways to describe a complex shape and in doing so we seem to be deviating from our stated objective of reducing a sample to one quantifiable number. So why measure shape?

Measuring size alone is sometimes insufficiently sensitive to identify important but subtle differences between samples. Some batches of samples may differ by such a small amount that this difference is lost during the translation to a circle-equivalent or spherical-equivalent diameter. For example consider the 3 shapes below.

All these 3 shapes have the same area = 4 square units. When they are converted to a circle equivalent diameter they give the same result – a circle equivalent diameter of 2.257 units.



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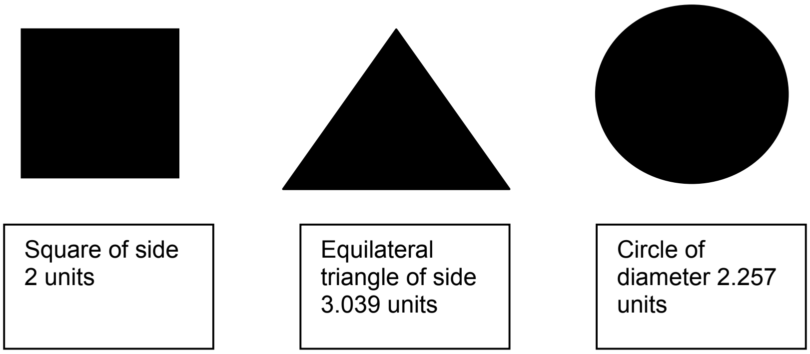



**Figure 2:** 3 very different shapes of identical CE diameter

This highlights the main disadvantage of measuring size only – very different shaped samples could be characterized as identical simply because they have similar projected 2D areas. Particle shape often has a significant influence on final product performance parameters such as flowability, abrasive efficiency, bio-availability etc so some way of characterizing shape is required.

## Three commonly used shape factors – circularity, convexity and elongation

One measure of shape is to quantify the 'closeness' to a perfect circle. For this we use the parameter Circularity which is defined as follows:

$$Circularity = 4\pi A / P^2$$

Where A is the particle area and P is its perimeter.

Circularity is a ratio of the perimeter of a circle with the same area as the particle divided by the perimeter of the actual particle image. There are alternative definitions of Circularity but the definition shown above has a squared term in the numerator and denominator in order to sensitize the parameter to even the most subtle variations in the area-perimeter relationship. For this we refer to this parameter more accurately as HS Circularity (for High Sensitivity).

Circularity has values in the range 0-1. A perfect circle has a circularity of 1 while a very 'spiky' or irregular object has a circularity value closer to 0. Circularity is sensitive to both overall form and surface roughness. Study the shapes below – notice how circularity is affected by both overall form and symmetry, and surface roughness.

Circularity is a good measure of what, in human terms, we could describe as "deviation from a perfect circle". However it is important to remember that it is unlikely that one single shape descriptor will perfectly discriminate and characterise all applications and different combinations of shapes.

Notice that the long ellipse shape (Figure 3, top right) has exactly the same circularity as the compact, spiky shape (Figure 3, bottom left).

Hence a variety of shape parameters have been developed to be used as a 'toolkit' – different applications will require different tools. For example an application concerned with perfectly spherical particles and measuring, perhaps for QC purposes, the deviation from perfectly spherical would use circularity as the discriminating parameter. However, circularity would not be appropriate for an application with both 'spiky' and elliptical particles present.

Two other commonly used shape parameters are convexity and elongation.

### Convexity

Convexity is a measure of the surface roughness of a particle and is calculated by dividing the "convex hull perimeter" by the actual particle perimeter. The easiest way to visualize the "convex hull perimeter" is to imagine an elastic band placed around the particle. Convexity also has values in the range 0-1. A smooth shape has a convexity of 1 as the convex hull perimeter is exactly the same as the actual perimeter. A very 'spiky' or irregular object has a convexity closer to 0 as the actual

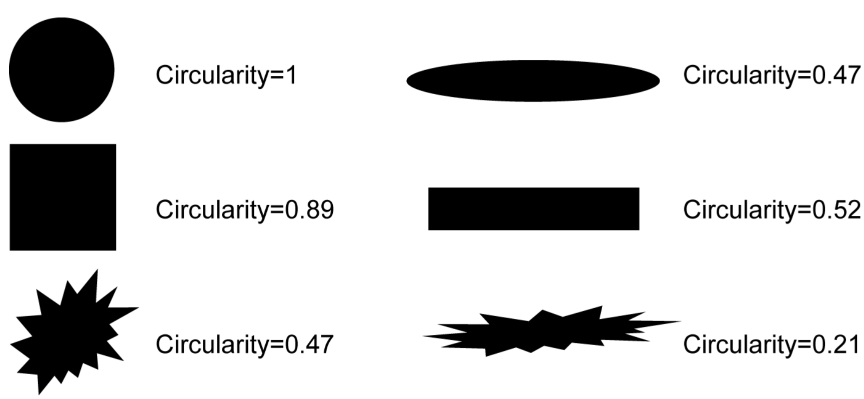



**Figure 3:** Illustration of circularity shape descriptor

perimeter is greater than the convex hull perimeter due to the fine surface features.

Study the shapes in Figure 4 – notice how convexity is unaffected by overall form – a smooth needle has the same convexity as a smooth circle.

### Elongation

Elongation is defined as [1-aspect ratio] or [1- width/length]. As the name suggests it is a measure of elongation and again has values in the range 0-1. A shape symmetrical in all axes such as a circle or square will have an elongation value of 0 whereas shapes with large aspect ratios will have an elongation closer to 1. Study the shapes in Figure 5 – notice how elongation is unaffected by surface roughness - a smooth ellipse has a similar elongation as a spiky ellipse of similar aspect ratio.

Along with the sensitivity gained from the ability to measure shape, image analysis provides two other important benefits: number-based resolution and recording of images. Both these provide the user with additional information which contributes to a deeper understanding of the product or manufacturing process.

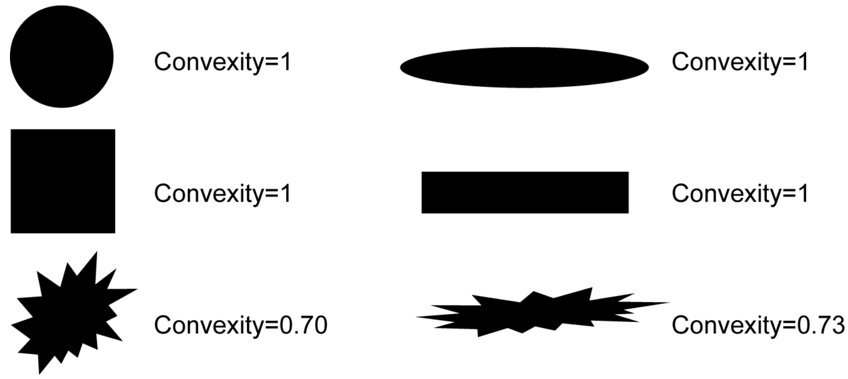



**Figure 4:** Illustration of convexity shape descriptor

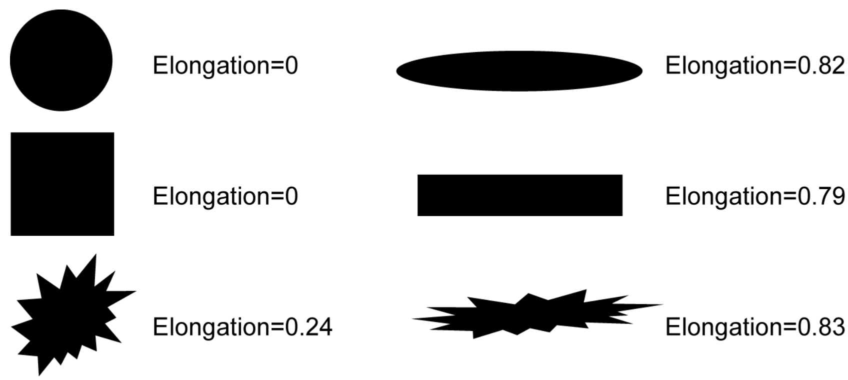
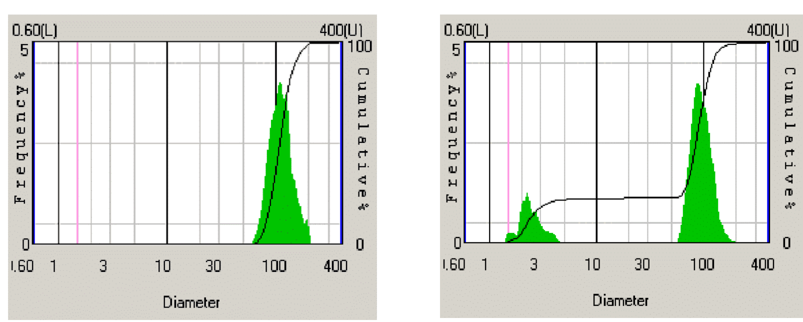



**Figure 5:** Illustration of elongation shape descriptor




Volume basis

Number basis

**Figure 6:** Number vs volume data display

## What does 'number-based' resolution mean?

Some applications, particularly those where the detection of small numbers of relatively small particles (fines) or the detection of foreign particles is important, require the resolution of a number-based system. Not all applications require this number-based sensitivity - if not it usually makes sense to benefit from the speed and convenience of ensemble methods.

Ensemble particle sizing methods usually provide data on what is known as a 'volume-basis'. This means that the contribution each particle makes is proportional to its volume – large particles dominate the distribution and sensitivity to small particles is reduced as their volume is so much smaller than the larger ones.

Image analysis provides data on what is known as a 'number-basis'. This means that the contribution each particle makes to the distribution is the same - a very small particle has exactly the same ‘weighting’ as a very large particle.

For diagnostic or trouble-shooting purposes the presences of fines could be very important in order to fully understand the manufacturing process and the extra-sensitivity to fines of image analysis may be required.

## Recording of images

The ability to visualize images of individual particles provides the user with an extra level of verification that backs up quantitative data and helps optimize method development and sample preparation. This capability is particularly useful for ascertaining if an irregular shaped particle is a genuine primary particle or an agglomerate of smaller particles for example. Recorded images of all particles can then be sorted, filtered and classified according to the users’ requirements.

Figure 7 shows clear agglomeration of principally spherical particles. These can be identified visually from the images and also quantifiably by using a shape parameter such as circularity. All agglomerates will have a lower circularity value than primary spherical particles so sorting and filtering on circularity will quickly identify the level of agglomeration in a sample.

Figure 8 shows clear needle-shaped particles. These can be detected visually using the actual images and also statistically by using a shape parameter such as elongation.

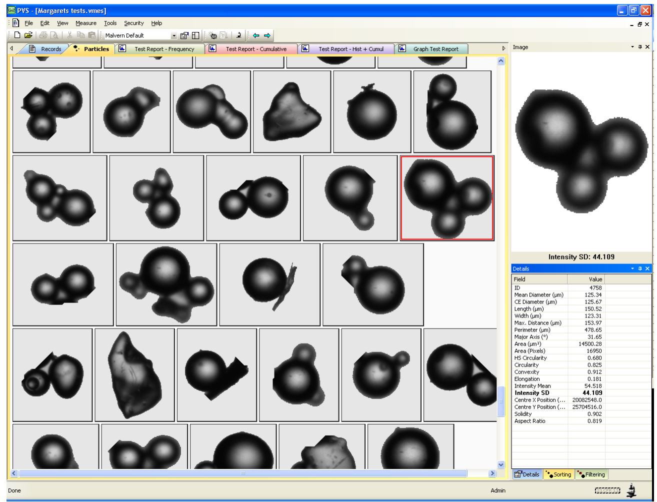


**Figure 7:** Particle image viewer showing agglomerates

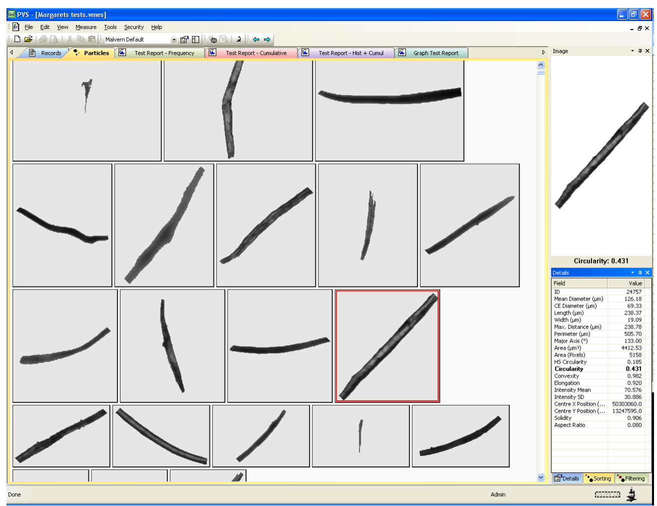


**Figure 8:** Particle image viewer showing needle-like particles