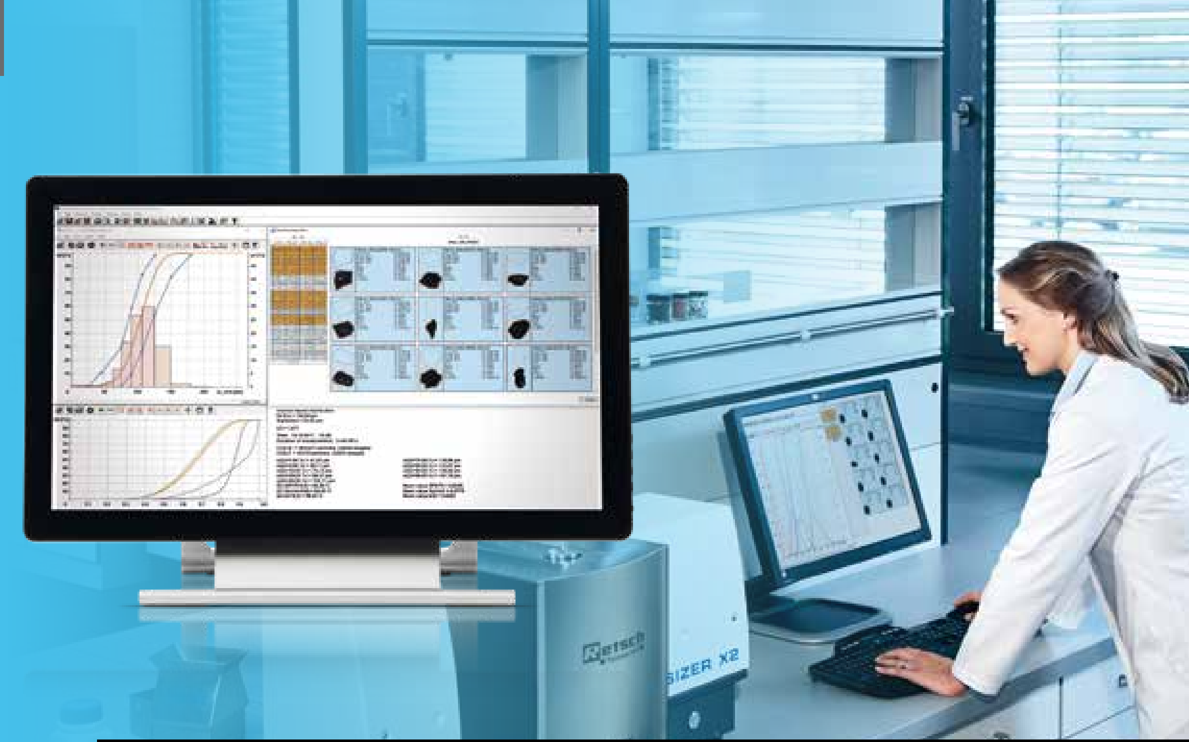
WHITE PAPER



Determination of Particle Shape with Dynamic Image Analysis

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Introduction

To qualitatively describe the shape of particles, the observer is often content with a mere visual inspection, in the case of fine samples probably with the aid of a microscope. Characterizations like "needle-shaped crystals", "compact granulate", "splintered grain", or "rounded sand" are quickly made and bring a corresponding picture to the mind of every reader. These descriptions are insufficient, however, when it comes to evaluating the suitability of a material for a specific application. If, for example, sand is intended to be used as a building material, the grains must not be too round. In this case, it is important to precisely quantify this roundness to reliably determine the suitability of the raw material. This is where quantitative particle shape analysis comes into play.

The measurement technique of Dynamic Image Analysis (DIA) is particularly suitable for this purpose, because it determines a variety of shape characteristics of each individual particle with great accuracy. It provides meaningful results in a short time by analyzing large quantities of material.

This article introduces the shape parameters that are characterized particularly well by DIA. In the second part the use of the shape analysis with the devices of the CAMSIZER series will be illustrated by some practical examples.

Describing particle shape

The term "shape" encompasses different geometric properties of the particles studied. Some parameters describe the outer shape of the grains, including, for example, the aspect ratio (width divided by length, macroshape).
If finer structures are analyzed, such as curvature of the corners or surface roughness, it is called meso- or microshape. The shape analysis is described in ISO 9276-6.
From the multitude of ways of describing the particle shape, the user must select the one(s) that best reflects the sample material. This depends on the type of application, accessibility for the measuring system, and on the robustness, uniqueness, and manageability of the shape parameter. For some parameters different definitions are found in the literature. These definitions and the characteristics of the used measuring technique should be taken into consideration.

Determination of particle shape by dynamic image analysis

In dynamic image analysis, a camera system detects a stream of moving particles. The particle images are recorded as shadow projections and are analyzed in real time (Fig. 1). Hence, a high-resolution size and shape distribution is available after only a few minutes measurement time. This result is based on the evaluation of thousands, hundreds of thousands, or even millions of individual particles, depending on the sample and measuring system.

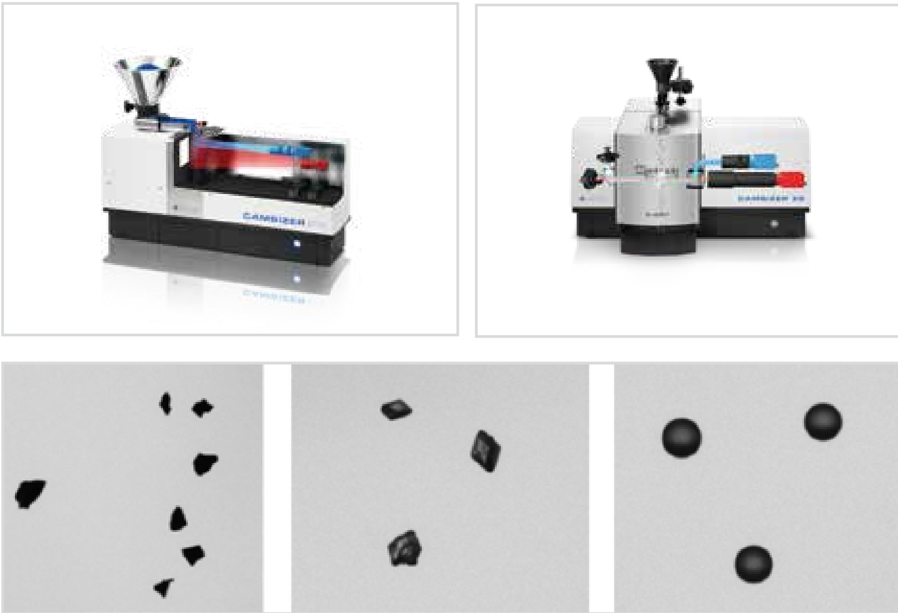

Fig. 1: Two state-of-the-art DIA instruments - CAMSIZER P4 (left) and CAMSIZER X2 (right) from Retch Technology. The P4 model is suitable for the rapid analysis of free-flowing bulk materials in a size range of 20 µm to 30 mm, the X2 model is optimized for fine, powdery sample materials in a size range from 0.8 µm to 8 mm.
Particle images: Activated carbon (left), sugar crystals (center), expandable polystyrene, EPS (right).

Particle shape definitions

Values for shape parameters lie in a range between 0 and 1 with values equal or close to 1 characterizing a nearly spherical, regular, or isometric particle. In the following, the most commonly used shape parameters in DIA are introduced.

Aspect ratio (width / length)

The aspect ratio is the quotient of particle width and particle length (Fig. 2) and thus a description of the outer form or geometry (macroshape). For the determination of the aspect ratio different widths or length definitions can be used, e. g. minimum and maximum Feret diameter, chord measurements, or only ratios are considered in which width and length are perpendicular to each other. Therefore, the numbers may vary slightly depending on the method. Nevertheless, this is a very easy to determine, stable and robust shape parameter that can be reliably measured largely irrespective of the absolute particle size.

Circularity

Circularity is calculated from the ratio of the area (A) of the particle projection to its perimeter (P) using the formula in Fig. 2. Circularity can be understood as a measure of the similarity of the particle to a sphere. A rough particle surface leads to low numerical values of the parameter circularity. To be able to use this parameter meaningfully, accurate measurement of the circumference is required. This can, however, only be achieved sufficiently well with the adequate magnification. Hence, the measurement results for circularity depend on the particle size. This can largely be compensated by suitable correction factors but cannot completely be prevented. In addition, the circularity results of different optical systems with different magnification and optical design are difficult to compare. Circularity is therefore a less robust shape parameter than aspect ratio.

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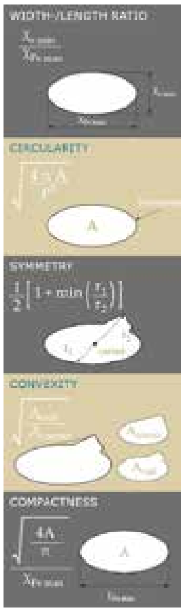

Fig. 2: Frequently used shape parameters in dynamic image analysis.

Symmetry

Symmetry is a measure of the eccentricity of the particle image. First, the centroid of the particle projection is determined, then the minimum ratio of two opposing semi axes through this point (Fig. 2) is calculated. From this ratio, the symmetry is determined, so that a perfectly symmetrical particle is given the value 1 (in each direction, the distance from centroid to perimeter is the same). Note that this is true for a circle as well as for many other polygons, e.g. rectangles!

Convexity

Convexity, concavity, or "solidity" describes the ratio of the real area of a particle projection to its convex hull. The convex hull is determined by compensating all the roughness with an envelope (Fig.2) which can best be imagined like a rubber band stretched around the particle image.

Compactness

Compactness is calculated from the ratio of the area of the particle image to the particle length. Just like circularity, compactness can also be interpreted as a similarity of the particle projection with a circle (for circles, compactness = circularity = 1). However, the compactness formula does not use the perimeter but the length of the particle which is more clearly defined metrologically and better accessible for the analyzers (Fig. 2). Compactness is therefore the more robust parameter and a good substitute for circularity.

Roundness

According to ISO 9276-6, roundness is based on the description of the curvature of the particle images. It is therefore a measure of the smoothness of the particle's corners. Various methods are presented in the literature; in this article we follow the definitions of Wadell (1932, 1935), Krumbein (1941) and Krumbein & Sloss (1963). These have been proven useful in sedimentology and for the analysis of raw sand and quartz grains but are also applicable to other issues. In each corner of the particle projection a circle is described, the mean radius of all corner circles is calculated and divided by the radius of the inscribed circle. At the time when these parameters were presented, no image analysis software existed, hence, a very time-consuming manual evaluation was inevitable. To reduce workload, model particles were printed on charts (Fig. 3) which were used to classify the particles during evaluation under the microscope. Consequently, this method is very susceptible to the user's individual perception. Moreover, these charts were altered and deteriorated by repeated copying, and are therefore rarely comparable.
Dynamic image analysis provides user-independent, reliable measurement data. However, the determination of the roundness requires a high magnification and is useful only for a particle size of more than 25 pixels.

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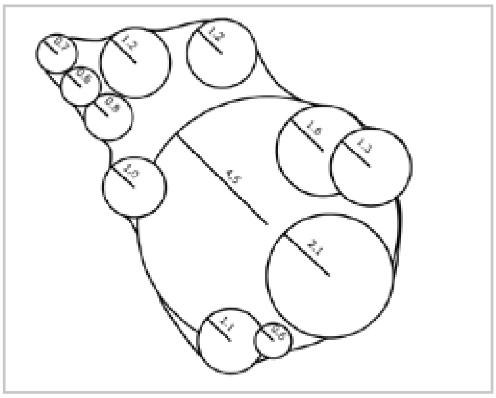

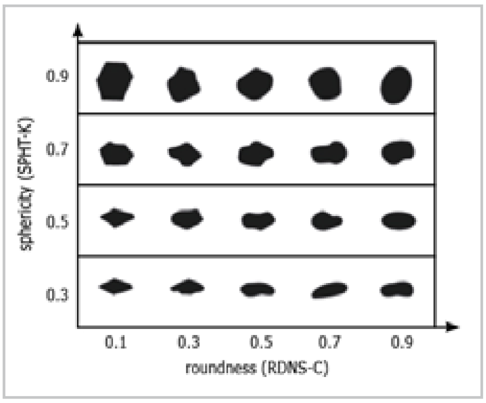

$$RDNS_C = \frac{\text{average radius (corners)}}{\text{radius (inner circle)}}$$

Fig. 3: Determination of roundness according to Wadell or Krumbein & Sloss. The chart on the right shows model particles that should allow the classification by roundness and sphericity in the microscopic evaluation. Note that "sphericity" after Krumbein means aspect ratio. A good example of the sometimes-confusing nomenclature when describing particle shape.

Examples of particle shape analysis

Broken spheres

In the chemical industry, catalyst materials are often applied to ceramic substrates. These carriers come in a variety of geometries like rods or tori, or spherical particles.
Due to mechanical stress the carriers may break which reduces the efficiency of the catalyst and produces an undesired fine fraction. With dynamic image analysis the percentage of broken particles can be precisely determined, allowing for continuous monitoring of the product quality (Fig. 4).

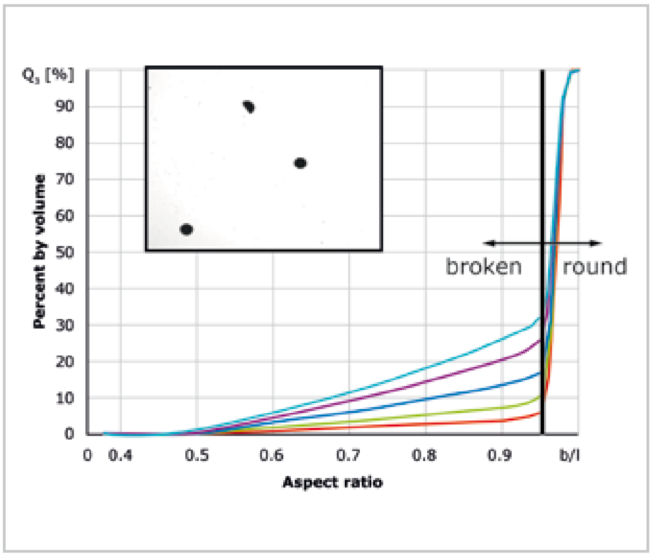

Fig. 4: Five analyses of a spherical catalyst carriers with different percentages of broken particles. Broken particles are easily identified as these have an aspect ratio smaller than 0.95. The percentage of these defective particles lies between 5% (red curve) and 32% (turquoise curve). The picture shows two complete and one broken sphere.

Metal Powders

Metal powders are usually produced by atomizing a melt. Depending on whether the cooling process happens in air or in liquid, very different particle shapes are the result. The shape has significant impact on the flowability and the bulk density of the powder. For additive manufacturing techniques like selective laser sintering, a round particle shape is desired. Dynamic image analysis is particularly suitable for predicting the suitability of a metal powder for different processes based on particle shape analysis (Fig. 5).

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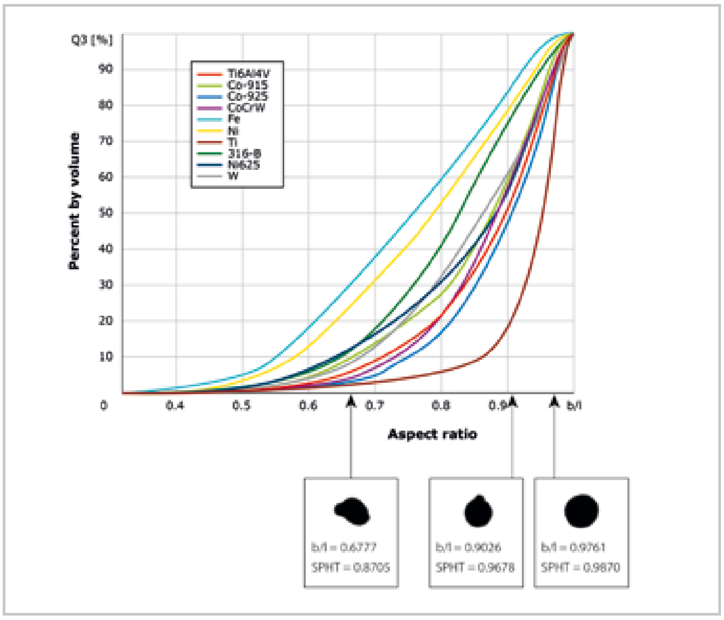

Fig. 5: Comparison of the aspect ratio for 10 different metal powders. Curves plotting on the left side of the diagram indicate irregular shape, curves plotting on the right side indicate regular particle shape. SPHT (sphericity) is circularity squared.
The Ti powder has the highest aspect ratio and is well suited for additive manufacturing. By means of image analysis, fused spheres can be identified very well.

Mixtures

If a sample has two components that are very similar in size, shape analysis may be the only chance to determine the proportion of the two components. An example of this would be a mixture of activated carbon and ion exchanger in water filters or a mixture of glass beads and grip agent, which is used for road markings. In both cases, the size of both components must be similar to avoid separation of the components (segregation in the container). However, since the particle shape is clearly different, the proportions can be exactly quantified using dynamic image analysis (Fig. 6).

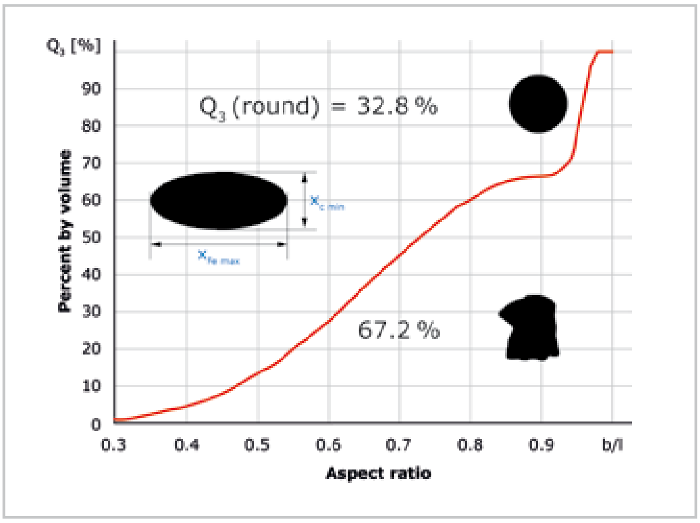

Fig. 6: Mixture of activated carbon (angular particles) and ion exchanger (round particles) from a water filter. The ion exchanger has shape values close to 1, whereas the activated carbon is much smaller than 1. In the mixture, a saddle point forms in the distribution where the mixing ratio can be read directly.

Roundness of sand grains

With an annual consumption of more than 40 billion tons, sand is the most widely used natural resource. A major part is found in building materials, but not every type of sand is suitable for this. Well-rounded grains, which are found for example in desert sand, are inappropriate for the construction industry. However, if the sand is to be used as a proppant material in hydraulic fracking, round grains are better suited than angular particles. The exact, user-independent measurement of the roundness by dynamic image analysis reliably characterizes the sand. Thanks to short measuring times of 2 - 5 minutes, high sample throughput and complete quality control are ensured. The comparability of the roundness values obtained by dynamic image analysis with the microscopic evaluation has been demonstrated (Vos, 2018).

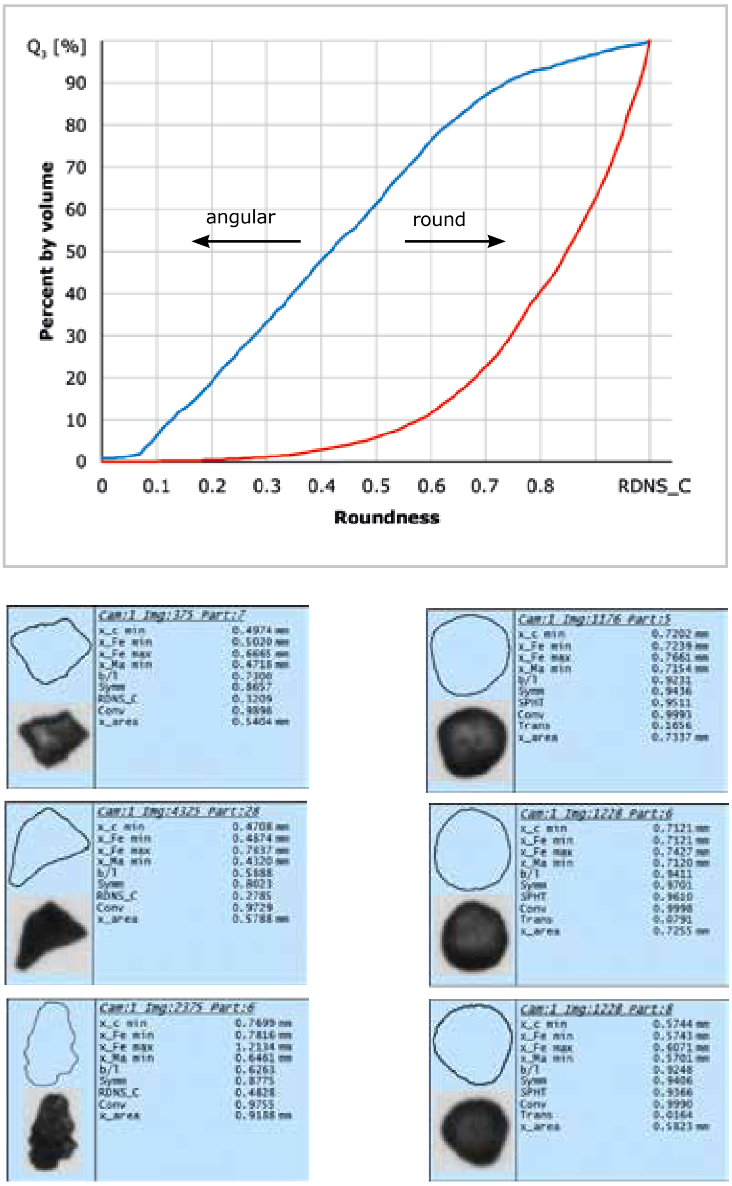

Fig. 7: Comparison of the roundness of two sand samples: Sample 1 (blue curve) consists of angular grains and has low roundness values. Sample 2 (red curve) consists of well-rounded grains with high roundness values. Particle images can be saved during analysis and then displayed. On the left some of the edgy grains, on the right some rounded grains are shown.

CONCLUSION

Dynamic Image Analysis is a highly accurate and reliable method for characterizing the particle size and particle shape of bulk solids and suspensions. Unlike other methods, image analysis alone delivers reliable and user-independent information about the particle shape. Since many properties of the sample material are influenced by the particle shape, the image analysis provides valuable information for assessing the product quality.

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