Your Concrete Answer: Size and Shape Analysis of Cement

Relevant for: Building materials, Concrete, Litesizer DIA 500, Dynamic Image Analysis, Size and Shape Analysis

The size and shape of cement particles strongly influence the properties of the final product, such as the flowability and water demand. Litesizer DIA 500 captures images at up to 144 frames per second and calculates particle size and shape distributions in only a few seconds.

1 Introduction

Cement is the most used material in the construction industry, accounting for the production of over 4 billion tons per year (1). It is an inexpensive and easy-to-produce material that consists of a complex mixture of inorganic components, such as silicates and aluminates. The hardening of the cement is mainly due to hydration, which means the combination of water with the different cement components.

There are five different types of cement, namely CEM I to CEM V. The most relevant for general construction are CEM I and CEM II. CEM I is a pure Ordinary Portland Cement (OPC), while CEM II is a mixture of OPC and additives such as fly ash, slag, or limestone, up to a maximum additive content of 35% (2).

Within each type, there are three grades, based on the 28-day compressive strength of the concrete that they produce. The grades are 32.5, 42.5, and 52.5. The cement is also classified according to its strength development: R indicates an early strength gain and N stands for normal strength development. For example, a cement CEM I 42.5 N is pure OPC giving a strength of 42.5 MPa with “normal” strength gain.

Besides the usual Portland cement, special formulations are often needed, such as quick-setting cement. This special type of cement starts the hardening process only a few minutes after being mixed with water and is usually set in less than one hour. Quick-setting cement is mainly composed of OPC and aluminum sulfate as a catalyst for the hydration process.

Moreover, the cement's quality is strongly dependent upon the size and shape of its particles, which affect its surface area, compression strength, and curing time. Particles that are too fine cause an exothermal setting in the final product, while particles that are too large do not fully hydrate. Complementary to particle size, particle shape is a critical parameter to monitor. Cement flowability and water demand may vary drastically for regular (spherical) and irregular particles (3; 4; 5).

Here, we show the application of Litesizer DIA 500 – the Anton Paar Dynamic Image Analyzer – to evaluate different cement types from different manufacturers. Litesizer DIA 500 (Figure 1) uses a high frame-rate camera to capture the image of a large number of individual particles in a short time. The result is both particle size and shape distribution in a few seconds.

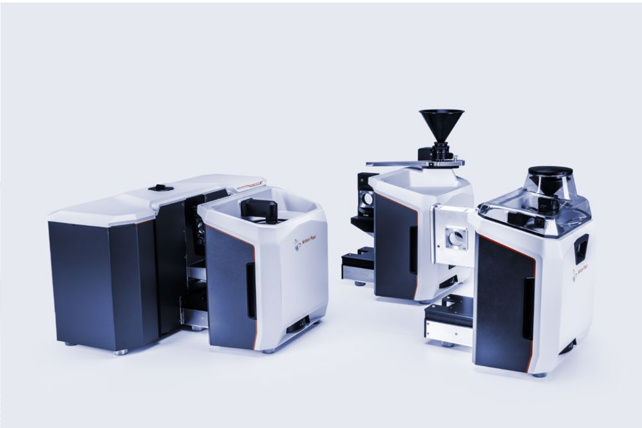


Figure 1: Litesizer DIA 500 Particle Analyzer and its three dispersion units: Liquid Flow, Free Fall, and Dry Jet (from left to right)

2 Experimental

The cement samples were analyzed with Litesizer DIA 500 equipped with the Dry Jet dispersion unit (Figure 2), which is the dispersion unit for deagglomerating dry materials using compressed air up to 4.6 bar.

Figure 2: Dry Jet dispersion unit

Five different cement types were selected to reflect different compositions and target applications (Table 1). The cement samples were analyzed as purchased and no previous treatment was performed.

Sample	Type	Manufacturer
Cement A1	CEM I 42.5 N	Manufacturer A
Cement A2	CEM I 52.5 N	Manufacturer A
Cement A3	Quick-setting cement	Manufacturer A
Cement B1	CEM II/AM (SL) 42.5N	Manufacturer B
Cement C1	Quick-setting cement	Manufacturer C

Table 1: Types of cement evaluated

The measurement conditions used for sample dispersion and image acquisition are displayed in Table 2.

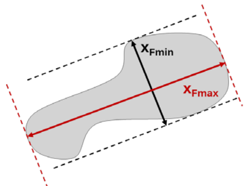
Parameter	Settings
Magnification mode	Zoom
Frame rate	50 fps
Air pressure	0.5 – 1.5 bar
Measurement time	10 – 60 s

Table 2: Measurement settings

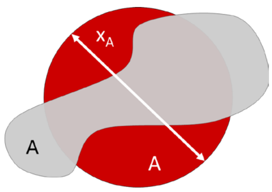
3 Results and Discussion

3.1 Overall size and shape results

Different size models can be used to describe a particle, e.g., the Feret diameter, which is the distance between two planes parallel and tangent to the contour of the particle. The minimum and maximum distances between these planes are named minimum and maximum Feret diameter (x_{Fmin} and x_{Fmax}).



One of the most relevant size models is the projected area equivalent diameter (x_A), which is the diameter of a sphere with the same projected area (A) as the particle's projection.



$$A=\pi r^2 = \frac{\pi {x_A}^2}{4}$$

$$x_A = \sqrt{\frac{4A}{\pi}}$$

The size model used for the particle size analysis in this report was x_A. All samples showed a monomodal broad particle size distribution with the major part of the population ranging from 5 µm to 60 µm (Figure 3).

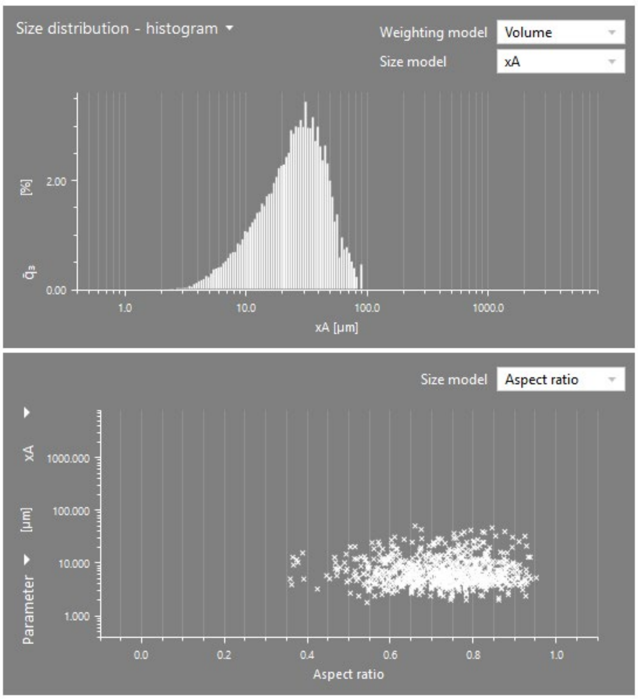


Figure 3: Single measurement result (Cement A1) as displayed immediately after the measurement is finished.

Representative particles' images and contours are immediately shown once the measurement is finished (Figure 4). All the individual particles are stored in a database and are easily accessed for further analysis.

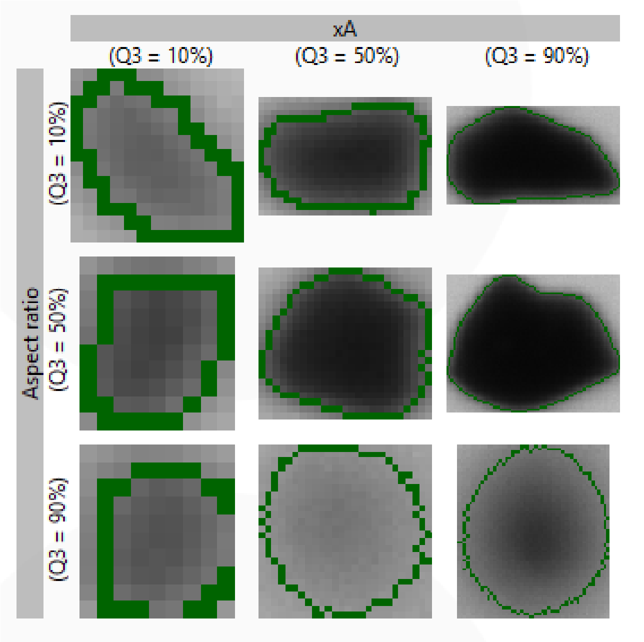
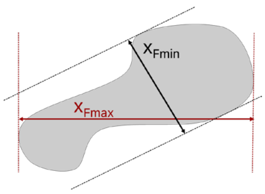


Figure 4: Representative particles' images and contours displayed in the Measurement Results View

The aspect ratio is the most commonly used shape parameter and relates to the minimum and maximum Feret diameters. It ranges from 0 (irregular particles) to 1 (sphere).



$$\text{Aspect ratio} = \frac{x_{Fmin}}{x_{Fmax}}$$

Additionally, the particles' shape can be evaluated by several other parameters, such as the ellipse ratio, compactness, etc. The choice of the most appropriate shape parameter depends on the characteristics of the particle and the field of application.

The particle size and particle size distribution are often used in the quality control of the cement production process. With Litesizer DIA 500, the shape analysis can also be used as a control parameter, as shown in Table 3 for the aspect ratio.

All samples contained particles with an aspect ratio mainly between 0.5 to 0.9. The quick-setting cement A3 had the biggest and most regular (spherical) particles, whereas the CEM I 52.5 N Cement A2 had the smallest particles in a narrower size range. These differences are helpful to predict the water demand and performance of cement.

3.2 Data Analysis and Export for Processing

In the Measurement Analysis, it is possible to evaluate simultaneously all the size and shape parameters of individual particles. The range of the parameters can be adjusted by the user (Figure 5) and the results can be recalculated if necessary. Besides, specific ranges can be set as default parameters for quality control and the creation of user-defined methods.

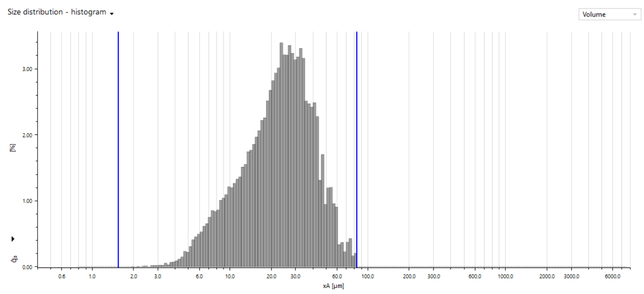


Figure 5: Size range selection (blue lines) of the volume-weighted particle size distribution (x_A) for Cement A1

Despite the high volume of generated information, all data is easily accessed and exported like for the other Anton Paar particle analysis instruments. This is useful for advanced users who intend to work with maximum flexibility on data visualization using data processing software. For instance, the difference in the particle size distribution between the samples can be seen in perspective with 3D representations created with external software (Origin 2023), as shown in Figure 6.

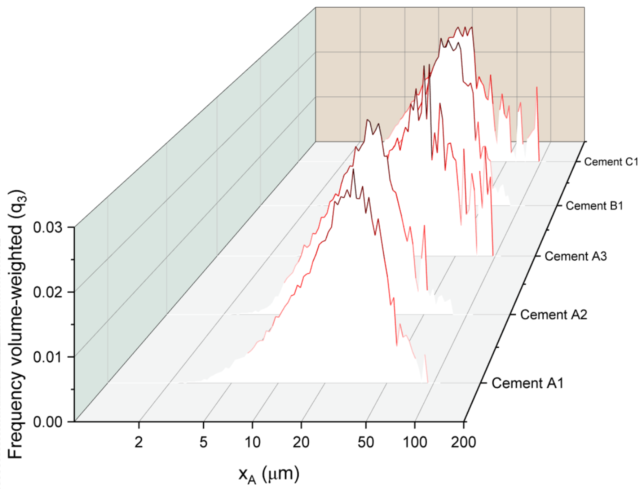


Figure 6: Particle size distribution of cement samples plotted with an external data processing software

Sample	Size (volume-weighted): xA			Shape (volume-weighted): Aspect ratio		
	Q_{10} / µm	Q_{50} / µm	Q_{90} / µm	Q_{10}	Q_{50}	Q_{90}
Cement A1	9.7 ± 0.1	25.9 ± 0.3	50.5 ± 0.9	0.565 ± 0.003	0.746 ± 0.004	0.875 ± 0.001
Cement A2	7.9 ± 0.1	18.8 ± 0.3	36.5 ± 1.7	0.606 ± 0.008	0.775 ± 0.007	0.890 ± 0.004
Cement A3	10.3 ± 0.2	25.7 ± 0.9	60.9 ± 8.9	0.609 ± 0.009	0.775 ± 0.007	0.895 ± 0.003
Cement B1	9.2 ± 0.3	23.8 ± 0.7	45.9 ± 2.3	0.551 ± 0.010	0.745 ± 0.005	0.877 ± 0.002
Cement C1	7.7 ± 0.2	19.0 ± 0.4	48.8 ± 7.0	0.579 ± 0.024	0.763 ± 0.015	0.885 ± 0.003

Table 3: Average size (x_A) and shape (aspect ratio) results for the measured cement samples

4 Summary

The fineness and shape of cement particles are important parameters in quality control as they influence the water demand, flowability, and performance of cement. Five cement samples were analyzed by Dynamic Image Analysis with Litesizer DIA 500 and both size and shape distributions were obtained. All the samples showed a broad monomodal size distribution mainly in the range from 5 µm to 60 µm. The shape of the particles was assessed by aspect ratio and compactness where one of the quick-setting cement samples showed the most regular (spherical) particles.

5 References

1. **Statista.** Cement production worldwide from 1995 to 2021. [Online]. Accessed in 2023. https://www.statista.com/statistics/1087115/global-cement-production-volume/.

2. **EAB Associates.** Types/Grades of Cement. [Online] https://www.eabassoc.co.uk/cement-type-grades.php.

3. *Effect of particle size distribution of fly ash–cement system on the fluidity of cement pastes.* **Lee, Seung Heun, et al.** 5, 2003, Cement and Concrete Research, Bd. 33.

4. *Particle Size Distribution and Rate of Strength Development of Portland Cement.* **Osbaeck, Bjarne und Johansen, Vagn.** 1989, Journal of the American Ceramic Society.

5. *A model investigation of the influence of particle shape on portland cement hydration.* **Bullard, Jeffrey W und Garboczi, Edward J.** 6, 2006, Cement and Concrete Research, Bd. 36.

Contact Anton Paar GmbH

Tel: +43 316 257-0

pc-application@anton-paar.com

www.anton-paar.com