AGGREGATES:
SIZE DISTRIBUTION

Key words: Aggregates, concrete, mortars, size distribution, test method

1 SCOPE AND FIELD OF APPLICATION

The method can be applied to determine the size distribution of aggregates in different materials such as hardened mortars and concrete. The maximum aggregate size which can be measured depends on the size of the measured image. The measurements can be performed using thin sections or other specimens where the aggregates can be distinguished from the background.

2 INFORMATIVE REFERENCES

NT BUILD 202 Concrete, hardened: sampling and treatment of cores for strength tests.
NT BUILD 381 Concrete, hardened: Air void structure and air content.

3 DEFINITIONS

Mean caliper diameter
The caliper diameter, H', is defined as the length of a 3D object in a certain direction as shown in Figure 1. If a 3D particle, e.g. a cube is placed between two parallel planes, the distance, H', between the planes will vary between the unit length, D, and √3D depending on the orientation of the cube. The mean caliper diameter (H') for a randomly orientated cube is 1.5D.

Feret diameter
The Feret diameter, F, is defined as the perpendicular distance between parallel lines, tangent to the perimeter at opposite sides of a 2D object in a certain direction as shown in Figure 2. When measuring the Feret diameter in several predetermined directions the obtained maximum value is the maximum Feret diameter (Figure 2).

The shape factor
The shape factor (Q) is defined as the mean shape of Na measured objects according to Equation 1.

\[
Q = \frac{4\pi \sum_{i=1}^{Na} \frac{A_i}{U_i^2}}{Na}
\]  

Where A is the area and U is the perimeter length of the objects. This shape factor varies between 0 and 1. For a sphere the factor is 1 and for a cube the mean shape factor is 0.668.

4 SAMPLING

If no sampling procedure is described in the test report, the sampling is performed in accordance with NT BUILD 381 or 202.
5 METHOD OF TEST

5.1 Principle

Determination of the size distribution of 3D particles using image analysis requires a number of steps:

1. Sampling and sample preparation
2. Acquisition and processing of images
   - Image acquisition
   - Image processing
     - Segmentation of edges and lines
     - Discrimination and thresholding
     - Binary image editing
3. Image measurement and statistical analysis
4. Stereological interpretation of measurement data.

This method is based on measurements of the maximum Feret diameter, Fm, of intersected 3D particles. The section where the analysed 2D surface intersects the 3D particles may be a thin section or a plane polished section. The total number of objects per unit area in size class i, \(N_{ai}\), is calculated from the following equation.

\[
N_{ai} = \sum_{j=i}^{k} P_j \cdot N_{vj} \cdot F_j \tag{2}
\]

where \(k\) is the number of classes and \(P_j\) is the probability that a 3D particle of size \(F_j\) will be observed as a 2D object in size class i. \(F_j\) is the geometrical mean size in class j. The objects are classified in a geometrical series and the numbering of the size classes starts with the largest size class.

5.2 Apparatus

The equipment for preparation depends on the equipment for measurements. Suitable equipment for preparing thin sections of mortar or concrete is described in NT BUILD 381.

Equipment for reproduction of an unbiased image of the measured specimen.

Equipment for automatic analysis with an accuracy in length determination of half the size of the lowest size class.

5.3 Preparation of test samples

The analysis shall be carried out on a plane surface. Suitable methods for achieving this for mortar or concrete specimens are described, for example, in NT BUILD 381. The test area must contain at least 1000 objects to be measured. It may be necessary to use more than one specimen (sub-samples) for one analysis to obtain the required number of objects.

5.4 Measurements

The distance between the picture elements shall be half the size of the smallest size class. At least the following parameters shall be measured.

The maximum Feret diameter of each object
The Feret diameter of the largest object
The size of the measured image
The area and the perimeter of each object.

The parameters area and perimeter are used to estimate the mean shape of the objects. Other parameters can be used provided they give relevant information on the shape of the objects.

A minimum 1000 objects shall be measured and classified in a geometric series with quotient 2.

5.5 Calculations

Calculation of number-based 3D distribution

In a system with 2D objects of various sizes divided by a geometric size, the number of 3D particles in each size class can be calculated by solving the system of equations below:

\[
\begin{bmatrix}
N_{v1} \cdot F_{1} \\
N_{v2} \cdot F_{2} \\
\vdots \\
N_{vn} \cdot F_{n}
\end{bmatrix}
= \begin{bmatrix}
P_1 \\
P_2 \\
\vdots \\
P_n
\end{bmatrix}
\begin{bmatrix}
N_{a1} \\
N_{a2} \\
\vdots \\
N_{an}
\end{bmatrix}
\tag{3}
\]

\(N_{vn}\) is the number of 3D objects in size class n. \(N_{an}\) is the number of 2D objects in size class n. The probabilities \(P_1, P_2, \ldots, P_n\) for spheres and cubes for a series with quotient 2 are listed in Table 1.

Table 1. The probability in % for a 3D object in size class j to be classified in different size classes, j, j+1, j+2 etc.

<table>
<thead>
<tr>
<th>Size class parameter</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>j</td>
<td>(P_1)</td>
</tr>
<tr>
<td>j+1</td>
<td>(P_2)</td>
</tr>
<tr>
<td>j+2</td>
<td>(P_3)</td>
</tr>
<tr>
<td>j+3</td>
<td>(P_4)</td>
</tr>
<tr>
<td>j+4</td>
<td>(P_5)</td>
</tr>
<tr>
<td>j+5</td>
<td>(P_6)</td>
</tr>
<tr>
<td>j+6</td>
<td>(P_7)</td>
</tr>
<tr>
<td>j+7</td>
<td>(P_8)</td>
</tr>
<tr>
<td>j+8</td>
<td>(P_9)</td>
</tr>
<tr>
<td>j+9</td>
<td>(P_{10})</td>
</tr>
</tbody>
</table>

Table 2. Volume of 3D objects for spherical and cubic shaped objects. \(d\) is the upper class limit of the actual size class.

<table>
<thead>
<tr>
<th>Shape of 3D objects</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical shape</td>
<td>(\pi d^3/12\sqrt{2})</td>
</tr>
<tr>
<td>Cubic shape</td>
<td>(0.433d^3/\sqrt{2})</td>
</tr>
</tbody>
</table>
Calculation of volume-based 3D distribution

The total volume, \( V_{v j} \), of aggregates in size class \( j \) is calculated by multiplying the number of 3D objects in each size class, \( N_{v j} \), by the volume of the objects according to Table 2.

5.6 Expression of results

The size distribution is stated as the number-based 2D and 3D size distribution and the volume-based 3D size distribution expressed in percentages without decimals.

6 REPORT

The test report shall include the following information, if relevant:

a) Name and address of the testing laboratory
b) Identification number of the test report
c) Name and address of the organisation or the person who ordered the test
d) The purpose of the test
e) Method of sampling and other circumstances (date and person responsible for the sampling)
f) Name and address of manufacturer or supplier of the tested object
g) Name or other identification of the object
h) Description of the tested object
i) Date of supply of the tested object
j) Date of the test
k) Test method
l) Any deviation from the test method
m) Test results
n) Size of the measuring frame and largest observed object
o) Number of measured objects
p) Distance between pixels
q) Uncertainty of the test result
r) Date and signature.