Warsaw University of Technology

Faculty of Civil Engineering

Department of Building Materials Engineering

BUILDING MATERIALS

LABORATORY TASK

Testing the technical characteristics of aggregate for lightweight concrete

Authors:

Joanna Sokołowska, Ph.D.

Kamil Załęgowski, Ph.D.

Table of content

1. Aim of the task

Understanding the types of aggregates for construction purposes and testing the bulk density and shape index of aggregate for lightweight concrete.

2. Theoretical background

2.1. Definitions according to standards PN-EN 12620 and PN-EN 1097-3

Aggregate – granular material used in construction; aggregate can be natural, artificial or recycled.

Natural aggregate – aggregate of mineral origin, which, apart from mechanical treatment, has not been subjected to any other treatment.

Aggregate of continuous grading curve – aggregate which is a mix of coarse and fine aggregates.

Artificial aggregate – aggregate of mineral origin, obtained as a result of an industrial process involving thermal or other modification.

Recycled aggregate – aggregate resulting from the processing of inorganic material previously used in construction.

Fillers – aggregate, most of which passes through a 0.063 mm sieve, which can be added to building materials to obtain certain properties.

Aggregate size – the aggregate designation by determining the lower (d) and upper (D) sieve dimensions, expressed as d/D.

Fine aggregate – aggregate with grain size D equal to 4 or less.

Coarse aggregate – aggregate with grain size D equal to 4 mm or larger and d equal to 2 mm or larger.

Natural aggregate of fraction 0/8 mm – aggregate of natural glacial and/or river origin with grain size D equal to 8 mm or less.

Dust – aggregate fraction with grain dimensions passing through a 0.063 mm sieve.

Aggregate category – the level of aggregate properties expressed as a range of values or a limit value.

Aggregate grading – grain size distribution, expressed as a percentage of mass passing through the specified set of sieves.

Bulk density in a loose state – the quotient of the uncondensed mass of dry aggregate filling a given container to the volume of that container.

2.2. Introduction

Aggregates for construction purposes can be classified by origin, density and use. Depending on the origin, aggregate is distinguished:

- natural – from natural mineral deposits, only mechanically treated; it is obtained from mineral resources that occur in nature, in particular, such as: gravel, sand, crushed gravel, crushed aggregate from rocks, natural gravel,
- artificial – generally lightweight, mineral aggregates obtained as a result of an industrial process involving thermal treatment or other modification; examples are aggregates obtained as a result of burning clay raw materials.
- recycled – resulting from the processing of material previously used in construction, e.g. from concrete or reinforced concrete; materials for their production are obtained from demolition,
- aggregate mixes.

Depending on the density of grains, aggregates are distinguished:

- heavy aggregate – density (in a dry state) equal to or greater than 3000 kg/m^3,
- ordinary aggregate – density (in a dry state) greater than 2000 kg/m^3 and lower than 3000 kg/m^3,
- lightweight aggregate – density (in a dry state) equal to or lower than 2000 kg/m^3 bulk density in a loose and dry state equal to or lower than 1200 kg/m^3.

According to standard PN-EN 12620 the size of aggregate for construction purposes are determined by the dimensions of the lower (*d*) and upper (*D*) sieves and expressed as *d*/*D*. This marking allows the presence of a certain amount of grains that remain on the upper sieve (oversize grains) and a certain amount of beans that can pass through the lower sieve. Depending on the grain size, aggregate is distinguished:

- fine – aggregate with grain size up to 4 mm (D ≤ 4 mm, d = 0 mm),
- coarse – aggregate with grain size from 4 to 63 mm (D ≥ 4, d ≥ 2 mm),
- fillers – most of the grains pass through the sieve 0.063 mm; it can be added to building materials to get the demanded properties.

Aggregates for construction purposes, depending on the properties, are divided into categories, defined as the level of aggregate properties expressed by the range of its value or its limit value,

while there is no relationship between the categories specified for different properties. The division of aggregates into categories indicates their diverse quality and is an indicator of its applicability. Aggregate categories are distinguished, among others, due to: grain size (Table 1), flatness index value, shape index value (Table 2), shell content in coarse aggregate, dust content, Los Angeles coefficient value, impact resistance, resistance to abrasion, polishing resistance, frost resistance or chemical requirements.

Table 1. Basic requirements for aggregate particle size according to standard PN-EN 12620

Aggregate	Size	Percentage of mass passing through					Category G
		$2D$	$1,4D$	D	d	$d/2$	
Coarse	$D/d \leq 2$ or $D \leq 11,2$ mm	100	$98 \div 100$	$85 \div 99$ $80 \div 99$	$0 \div 20$	$0 \div 5$	$G_C85/20$ $G_C80/20$
	$D/d > 2$ mm or $D > 11,2$	100	$98 \div 100$	$90 \div 99$	$0 \div 15$	$0 \div 5$	$G_C90/15$
Fine	$D \leq 4$ mm and $d = 0$ mm	100	$95 \div 100$	$85 \div 99$	-	-	G_F85
Natural 0/8	$D = 8$ mm and $d = 0$ mm	100	$98 \div 100$	$90 \div 99$	-	-	$G_{NG}90$
Continuous grading	$D \leq 45$ mm and $d = 0$	100	$98 \div 100$	$90 \div 99$ $85 \div 99$	-	-	G_A90 G_A85

Tab.2. Categories of maximal SI values

Shape index	Category SI
≤ 15	SI_{15}
≤ 20	SI_{20}
≤ 40	SI_{40}
≤ 55	SI_{55}
> 55	$SI_{Declared}$
No requirement	SI_{NR}

3. Practical tasks

3.1. 3.1. Testing the grading of aggregate for concrete according to PN-EN 933-1

3.1.1. Materials and equipment

- Set of sieves,
- bottom and cover for the sieve,
- sieving device,
- trays and brushes,
- analytical scale,
- buckets of the proper size,
- aggregate mix.

3.1.2. Task completion

The test consists in separating the aggregate mix using a set of sieves into several fractions classified by decreasing sizes. The dimensions of the sieve mesh size and the number of sieves are selected depending on the type of specimen and the accuracy required.

The mass of the aggregate analytical specimen with a volumetric density between 2000 kg/m^3 and 3000 kg/m^3 should comply with the requirements given in Table 3.

Table 3. Mass of the aggregate analytical specimen for grading determination

Aggregate size D [mm] (max)	Mass of the analytical specimen [kg] (min)
63	40
32	10
16	2,6
8	0,6
≤ 4	0,2

Note 1: For other grain sizes, the minimal mass of the analytical specimen may be interpolated from the masses given in Table 1.

Note 2: If the mass of the analytical specimen does not comply with Table 3, and the particle size does not meet the requirements of PN-EN 933-1 standard, this should be stated in the report.

Note 3: In the case of aggregates with a grain density less than 2000 kg/m^3 or more than 3000 kg/m^3, an appropriate correction of the mass of the analytical specimen given in Table 3 should be performed on the basis of the density ratio in order to prepare the analytical specimen of approximately the same volume as ordinary aggregates.

The reduction of the specimen should ensure that the mass of the analytical specimen is larger than the minimum, but not of an exactly predetermined size.

The aggregate analytical specimen should be dried to constant mass by heating at $(110 \pm 5)°C$, then cooled and weighed, and the mass recorded as M_1.

For some aggregates, drying at $110°C$ may cause strong binding of the grains, which will limit their separation during subsequent washing and/or sieving. For such aggregates, the procedure described in Appendix B of PN-EN 933-1 standard should be applied.

Put the dry specimen onto a set of sieves, consisting of several sieves arranged from top to bottom according to decreasing mesh size. Shake the sieve set mechanically or manually, and then, to make sure all material has been sieved, remove the sieves one by one and shake each manually, starting from the sieve with the largest mesh size (avoiding loss of material!). Transfer all the material that passed through the sieve to the next sieve of the set and continue sieving.

The sieving process can be considered complete when the mass of retained material does not change by more than 1.0% after 1 minute of sieving.

To avoid overdosing during sieving, the fraction remaining on each sieve after sieving, expressed in grams, should not exceed:

$$\frac{A \cdot \sqrt{d}}{200}$$

where: A – sieve area in mm^2, d – sieve mesh size in mm.

If any fraction exceeds this amount, use one of the following procedures:
  a) divide fractions into smaller portions than the maximum and sieve them one after the other,
  b) using a specimen divider or quartering, divide the portions of the specimen passing through the next largest sieve and continue the sieve analysis on the reduced analytical specimen, taking into account in the subsequent calculations the correction resulting from the reduction of the specimen.

Weigh the material remaining on the sieve with the largest hole size and record its mass as R_1. Repeat the same operation for each of the sieves located lower, and the masses remaining on them are written as R_2, R_3 ... R_n. Weigh the material remaining on the bottom and record its mass as P. Record all masses in the test data sheet – an example of the results sheet is presented in Table 4.

3.1.3. Results

Calculate the masses of material remaining on each sieve as a percentage of the dry mass of the specimen M_1.

Calculate the total output percentage of aggregate dry material passing through each sieve. The obtained results of aggregate particle size testing should be compared with the requirements regarding the particle size for the aggregate category (see Table 1) and the requirements regarding recommended limiting curves given on Fig.1 or Fig.2.
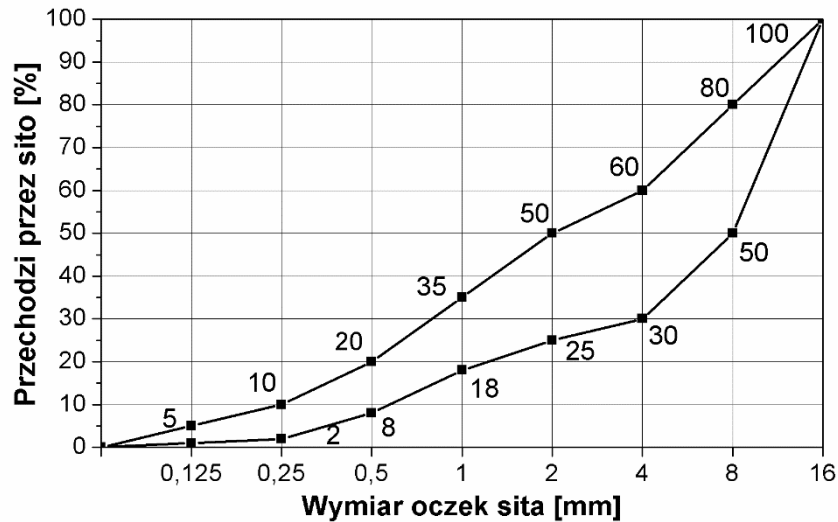

Fig.1. Cumulative size distribution limiting curves for aggregate for concrete with a grain size up to 16 mm recommended in PN-88/B-06250
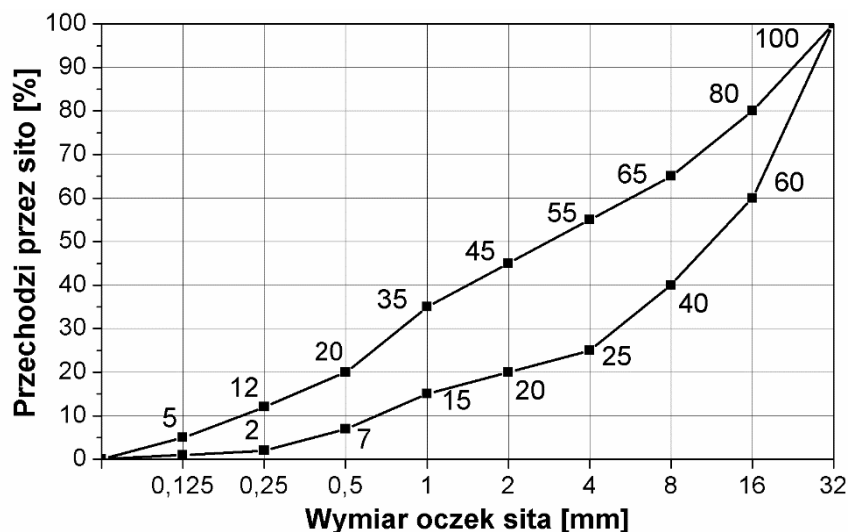

Fig.2. Cumulative size distribution limiting curves for aggregate for concrete with a grain size up to 32 mm recommended in PN-88/B-06250

3.1.4. Elaboration of results

The results should be presented in the form of a table (see Table 4) and in graphically, in the form of a particle size distribution curve in accordance with PN-EN 933-1 (graph of the relationship between the sum of masses passing through the sieve in % and the sieve mesh size in mm, Fig. 3). Put on the prepared graph the appropriate boundary curves of aggregate grain for ordinary concrete (see Fig. 1 or Fig. 2).

Tab.4. Results of sieving of aggregate for concrete according to standard PN-EN 933-1

Method	Dry sieving		
Type of aggregate			
Category of aggregate			
Mass M_1 [g]			
Sieve mesh size [mm]	Mass of material remaining on the sieve [g] R_i	Percentage of material remaining on the sieve [%] $R_i / M_1 \cdot 100$	Sum of masses passing through the sieve [%] $100 - \Sigma(R_i/M_1 \cdot 100)$
31,5	$R_1 =$	$A_1 =$	$100 - A_1 =$
16	$R_2 =$	$A_2 =$	$100 - (A_2 + A_1) =$
8	$R_3 =$	$A_3 =$	$100 - (A_3 + A_2 + A_1) =$
4	$R_4 =$	$A_4 =$	
2	$R_5 =$	$A_5 =$	
1	$R_6 =$	$A_6 =$	
0,5	$R_7 =$	$A_7 =$	
0,25	$R_8 =$	$A_8 =$	
0,125	$R_9 =$	$A_9 =$	
Material on the bottom	$P =$	$A_{10} =$	
Oversized grains [%]			
Undersized grains [%]			
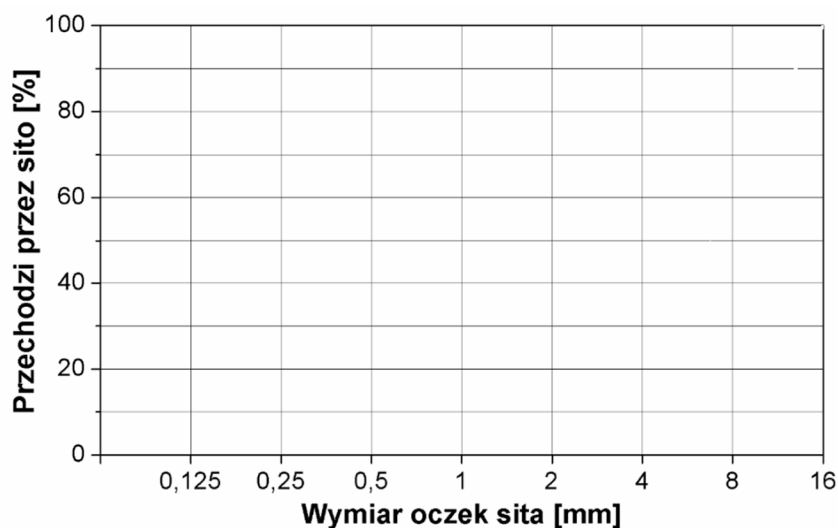
Rys.3. Obtained results in the form of relative and cumulative grain size distribution curve

3.2. Coarse aggregate grain shape index according to standard PN-EN 933-4

3.2.1. Materials and equipment

- Schultz caliper (see Fig. 4).
- analytical scale,
- plastic bowls,
- buckets of the right size,
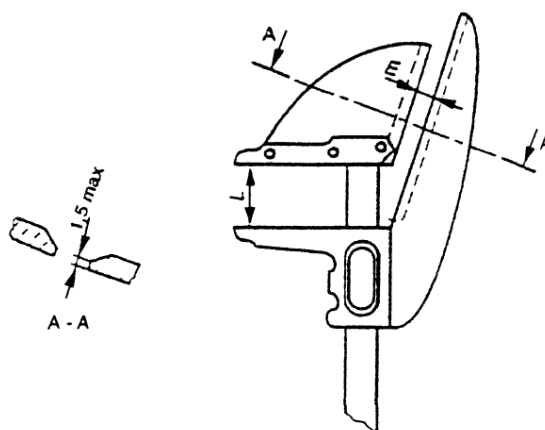- Natural aggregates of fractions 8/16 mm or 16/32 mm

Fig. 4. Schultz caliper

3.2.2. Task completion

The mass of analytical specimen of the aggregate with a volumetric density between 2000 kg/m^3 and 3000 kg/m^3 for testing the grain shape index should comply with the requirements given in Table 5.

Tab.5. Mass of analytical specimens for determining shape index of aggregate

Aggregate size D [mm] (max)	Mass of the analytical specimen [kg] (min)
63	45
32	6
16	1
8	0,1

Note 1: For other upper dimensions of aggregate D, proper masses of analytical specimens can be interpolated from the masses given in Table 5.

Note 2: In the case of aggregates with a grain density less than 2000 kg/m^3 or more than 3000 kg/m^3, an appropriate correction of the mass of the analytical specimen given in Table 5 should be performed on the basis of the density ratio in order to prepare the analytical specimen of approximately the same volume as ordinary aggregates.

The reduction of the specimen should ensure that the mass of the analytical specimen is larger than the minimum, but not of an exactly predetermined size.

The test should be carried out on each fraction with a grain size d/D, where $D \leq 2d$. In case of specimens of $D > 2d$ it should be divided into fractions of size d/D, where $D \leq 2d$ during the nest test procedure.

Separate from the analytical specimen the dominant fraction with grain size d/D, where $D \leq 2d$, sieving according to PN-EN 933-1. Discard all grains smaller than d or larger than D. Note the mass of the dominant fraction d/D as M_1. Evaluate the length L and thickness E of each grain using a linear measuring instrument, where necessary. Move aside those grains whose dimension ratio $L/E > 3$. These grains are classified as irregular. The number of grains that require individual classification using the linear measuring instrument can be reduced by pre-separating grains with an L/E ratio significantly different from 3. Weigh the irregular grains and record their mass as M_2.

3.2.3. Evaluation of test results obtained for aggregate for concrete

Shape index SI should be calculated according to the formula

$$SI = \frac{M_2}{M_1} * 100$$

where: M_1 – mass of analytical specimen [g], M_2 – mass of irregular grains [g].

Note the grain shape index rounding to an integer number.

The marked shape index should be declared in accordance with the appropriate category specified in table 2, appropriate for the given application.

3.2.4. Elaboration of results

The results should be presented in the form of a table (see table 6):

Table 6. Example of table presenting results of shape index determination

Fraction of the tested specimen	
Mass of analytical specimen M_1	
Mass of irregular grains M_2	
Shape index SI	
Category of maximum SI value	

3.3. Bulk density in a loose state of lightweight aggregate according to standard PN-EN 1097-3

3.3.1. Materials and equipment

- Cylindrical container (see table 7).
- laboratory scale,
- buckets of the right size,
- Scraper at least 50 mm longer than the outside diameter of the container
- Lightweight aggregates specimens

Table 7. The minimum capacity of the container for testing bulk density in a loose state depending on the size of the aggregate

Aggregate size D [mm]	Volume [dm^3]
≤ 4	1,0
≤ 16	5,0
≤ 32	10,0
≤ 63	20,0

3.3.2. Task completion

The determination consists in examining the quotient of the uncondensed mass of dry aggregate filling a given container to the volume of that container.

The dry mass of aggregates filling a specific container is determined by weighing and the corresponding bulk density in the loose state is calculated.

Three test specimens should be prepared. The aggregate should be dried at temperature $(110 \pm 5)°C$ to constant mass. The mass of each specimen should be between 120% and 150% of the mass needed to fill the container. In the case of lightweight aggregates, the specimens can be tested after drying at $(110 \pm 5)°C$ until they reach moisture equilibrium at $(23 \pm 5)°C$ and relative humidity $(50 \pm 5)\%$. Weigh the empty, dry and clean container (mass m_1), place it on a horizontal surface and fill it with aggregate using a bucket until poured. When filling the container, minimize grain separation by placing the bucket on the upper edge. In no case should the edge of the bucket be higher than 50 mm from the edge of the container.

Carefully remove excess aggregate over the top of the container, making sure the surface is level. Level the surface using a scraper, being careful not to knead the surface.

Weigh the filled container and record its mass to the nearest 0,1% (mass m_2). The determination should be carried out for three samples..

Bulk density in a loose state ρ_{nl} should be calculated for each specimen according to the formula:

$$\rho_{nl} = \frac{m_2 - m_1}{V}$$

where: ρ_{nl} – bulk density in a loose state [kg/m^3], m_2 – mass of container filled with specimen [kg], m_1 – mass of empty container [kg], V container volume [dm^3]

Loose bulk density should be given as the arithmetic mean of the three values – accuracy up to the second decimal place in the case of ordinary aggregates and the third in the case of lightweight aggregates.

3.3.3. Evaluation of test results obtained for lightweight aggregate

The standards do not contain requirements for the bulk density of aggregates in the loose state.

3.3.4. Elaboration of test results obtained for lightweight aggregate

The results should be presented in the table (Table 8).

Table 8. Bulk density in a loose state of tested lightweight aggregates

	Material 1	Material 2
Type of aggregate		
Category of aggregate		
Container volume, V [dm^3]		
Container mass, m_1 [kg]		
Container and specimen mass, m_2 [kg]		
Bulk density in a loose state, ρ_{nl} [kg/dm^3]		

4. Laboratory report

The laboratory report should include:

I.   Subject, aim and scope of research (containing basic information about tested materials/products, test methods, requirements),

II. Tests results with proper units (results obtained in the laboratory prepared in the indicated manner, e.g. put in the proper tables),

III. Conclusions (bulleted statements formulated based on the results obtained),

IV. Bibliography (list of references to the literature or www used to prepare the report).