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European Assessment Document for

Belitic calcium sulfoaluminate and calcium sulfoaluminate based cement

This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers belitic calcium sulfoaluminate based cement (in the following referred to as BCSAC) and calcium sulfoaluminate based cement (in the following referred to as CSAC).

The BCSAC is a cement with rapid hardening features for the production of concrete, mortar and grouts according to EN 206[1]. This cement is not fully covered by harmonised standard EN 197-1 and EAD 150001-00-0301 "Calcium sulfoaluminate based cement" and EAD 150004-00-0103 "Rapid hardening sulfate resistant calcium sulfoaluminate based cement". Table 1.1.1 specifies the main clinker phases of various cements containing calcium sulfoaluminate.

Table 1.1.1: Comparison between the clinker phases of the belitic calcium sulfoaluminate based cement (BCSAC) and two different calcium sulfoaluminate cements (CSAC) which are covered in EAD 15 0001-00-0301 and EAD 15 0004-00-0301

Clinker	**Clinker Phase**		
	Belite	**Yeelimite**	**Other**
	% by mass		
Belitic calcium sulfoaluminate clinker (BCSAK)	≥ 35	20 – 40	≥ 25
Calcium sulfoaluminate clinker (CSAK) according to EAD 150001-00-0301	No Information	≥ 45	No Information
Calcium sulfoaluminate clinker (CSAK) according to EAD 150004-00-0301	No Information	≥ 50	No Information

Deviations for BCSAC and CSAC from common cement according to EN 197-1 are:

- BCSAC contains as constituent a BCSAK (50 – 98 % by mass) and not a Portland cement clinker.
- CSAC contains as constituent a CSAK (20 – 90 % by mass) and not a Portland cement clinker.
- Rapid setting feature implies initial setting time < 45 min which is considerably shorter than for EN 197-1 cements of ≥ 45 min.
- BCSAC and CSAC shows a very early (compressive) strength after 1 ≤ t ≤ 24 h and can be determined significantly earlier than EN 197-1 cements (2 days or 7 days).
- Sulfate (SO_3) content (> 4,0 % by mass) is higher than EN 197-1 cements of ≤ 4,0 % by mass.
- BCSAC and CSAC are not considered as low heat cement.
- BCSAC and CSAC are not considered as a pozzolanic cement.

One special feature of CSAC is the very early compressive strength < 24 h with strengths of more than 10 MPa after 8 hours. Concretes made with these cements can be stripped and loaded much earlier than concretes made with common cements, depending on the temperatures. For this reason, it is not necessary to determine the 2-d strength as covered by EN 197-1.

The characteristic "heat of hydration (LH)" as referred to in EN 197-1 is normally used when the cement is used for massive components in order to reduce increased component heating due to hydration. BCSA and CSAC cements are not suitable as LH cements as they show a higher heat of hydration than specified in EN 197-1, clause 7.2.3. BCSAC and CSAC are not used for massive components. For this reason, the characteristic "LH" is not taken into account as essential characteristic for BCSA and CSAC.

The characteristic "C_3A in clinker" cannot be determined for the BCSAK and CSAK, because C_3A is a clinker phase that is only formed during the production of Portland cement clinker. This phase can only be determined on Portland cement clinker. . Therefore, it is not referred to as an essential characteristic for BCSAC and CSAC in this EAD. In order to avoid negative effects of a high sulfate content of BCSAC or CSAC and the reactivity of C_3A due to additional Portland cement CEM I according to EN 197-1 in the

1 All undated references to standards in this EAD are to be understood as references to the dated versions listed in chapter 4.

concrete composition in the concrete plant, it is checked whether delayed ettringite formation can occur, see clause 2.2.13.

The characteristic "pozzolanicity" only applies to CEM IV according to EN 197-1. Thus, it is not referred to as an essential characteristic in this EAD.

The belitic calcium sulfoaluminate clinker (BCSAK) is made by sintering a precisely specified mixture of raw materials (raw meal, paste or slurry) containing elements, usually expressed as oxides, CaO, Al_2O_3, SiO_2, Fe_2O_3, SO_3 and small quantities of other materials. The BCSAK is composed mainly by $2CaO \cdot SiO_2$ (Belite) and by $C_4A_3\overline{S}$ or $C_4(A, F)_3\overline{S}$ (Yeelimite).

The content of Belite in the BCSAK is equal or greater than 35 % by mass and the content of Yeelimite in the BCSAK is in the range between 20 % and 40 % by mass.

The remaining parts consist of calcium sulfates and other compounds.

Table 1.1.2 gives the range of the composition for BCSAC.

Table 1.1.2: Range of the composition for BCSAC

BCSAK	50 – 98 % by mass
Cement CEM I and/or CEM II according to EN 197-1	0 – 25 % by mass
Calcium Sulfate (as defined in EN 197-1, clause 5.4)	0 – 20 % by mass
Limestone (as defined in EN 197-1, clause 5.2.6)	0 – 25 % by mass
Fly ash (as defined in EN 197-1, clause 5.2.4)	0 – 20 % by mass
Minor additional constituents (as defined in EN 197-1, clause 5.3)*	< 5 %* by mass
Additives (as defined in EN 197-1, clause 5.5) **	< 2 %** by mass
Organic additives (as defined in EN 197-1, clause 5.5)	< 0,2 % by mass
* The residue of BCSAK process can be integrated as minor additional constituent. ** EN 197-1, clause 5.5, specifies: The total quantity of additives shall not exceed 1,0 % by mass of the cement (except for pigments). The quantity of organic additives on a dry basis shall not exceed 0,2 % by mass of the cement. A higher quantity may be incorporated in cements provided that the maximum quantity, in % by mass, is declared on the packaging and/or the delivery note.	

The calcium sulfoaluminate clinker (CSAK) is made by sintering a precisely specified mixture of raw materials (raw meal, paste or slurry) containing elements, usually expressed as oxides, CaO, Al_2O_3, SiO_2, Fe_2O_3, SO_3 and small quantities of other materials. The CSAK is a hydraulic material which is composed mainly by $C_4A_3\overline{S}$ or $C_4(A,F)_3\overline{S}$ (Yeelimite). The content of Yeelimite in the CSAK is usually greater than 45% by mass, the remaining parts consisting of calcium silicates ($2CaO\ SiO_2$) and other compounds.

The content of Yeelimite in the CSAK shall be at least 45 % by mass.

The content of Yeelimite in the CSAC shall be at least 9 % by mass.

Table 1.1.3 gives the range of the composition for CSAC.

Table 1.1.3: Range of the composition for CSAC

CSAK	5 – 90 % by mass
Cement CEM I or CEM II according to EN 197-1	0 – 80 % by mass
Rapid setting cement according to EAD 150008-00-0301 "Rapid setting cement"	0 – 50 % by mass
Calcium sulfate (as defined in EN 197-1, clause 5.4)	0 – 30 % by mass
Limestone (as defined in EN 197-1, clause 5.2.6)	0 – 30 % by mass
Minor additional constituents (as defined in EN 197-1, clause 5.3) *	< 5 %* by mass
Additives (as defined in EN 197-1, clause 5.5) **	< 8 %** by mass
Of which organic additives (as defined in EN 197-1, clause 5.5)	< 0,5 %** by mass
* The residue of CSAK process can be integrated as minor additional constituent.	

** hEN 197-1, clause 5.5, specifies: The total quantity of additives shall not exceed 1,0 % by mass of the cement (except for pigments). The quantity of organic additives on a dry basis shall not exceed 0,2 % by mass of the cement. A higher quantity may be incorporated in cements provided that the maximum quantity, in % by mass, is declared on the packaging and/or the delivery note.

Hydraulic hardening of CSAC is primarily due to Yeelimite, but, when present in the composition, Portland cement and/or Rapid setting cement also participates in the hardening process.

This EAD version covers the following amendments in comparison to version 00:

- The content of Yeelimite in the CSAC is at least 9 % by mass instead of 10 % by mass.
- A further main constituent (Rapid setting cement according to EAD 150008-00-0301 "Rapid setting cement") is required for the production of CSAC.
- The minimum content of CSAK was reduced from 20 % by mass to 5 % by mass.
- All cements according to EN 197-1 can be used for the manufacturing of CSAC.
- All clauses have been amended with the exception of clause 2.2.17 "Content, emission and/or release of dangerous substances".
- The clauses 2.2.2 "Calcium sulfoaluminate (Yeelimite) content in the cement" and 2.2.4 "Cement composition" have been shifted to new clauses 3.4.2 and 3.4.3.

Two new clauses 2.2.13 "Delayed Ettringite Formation" and 3.4.1 "Control of raw materials by manufacturer" have been added. The assessment methods for "Effect of high temperature on mortar hardened under standard condition (clause 2.2.9)" and "Effect of high temperature on mortar at early age (clause 2.2.11)" have been modified. The tests shall now also be carried out at a temperature of 5 °C to assess the influence of low temperatures on strength and strength development.

Consequently, the titles of clause 2.2.9 "Effect of different storage temperatures on mortar which hardened under standard conditions" and clause 2.2.11 "Effect of different curing temperatures on mortar at early age" have been adapted.

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations, e.g., with regard to the intended end use conditions, having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA as long as the details of the assessment methods as laid down in this EAD are respected.

1.2 Information on the intended use(s) of the construction product

1.2.1 Intended use(s)

The BCSAC and CSAC are cements for production of concrete, mortar, grouts and other mixes including in particular cast-in-situ and prefabricated structural concrete in accordance with EN 206 and screed material in accordance with the harmonised standard EN 13813.

BCSAC and CSAC are not intended to be used for the fabrication of massive concrete components such as dam walls. BCSAC and CSAC are especially characterized by a rapid hardening and/or low shrinkage.

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of concrete incorporating BCSAC or CSAC for the intended use of 50 years when installed in the works (provided that the BCSAC or CSAC are subject to appropriate installation). These provisions are based upon the current state of the art and the available knowledge and experience

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[2].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

1.3 Specific terms used in this EAD

BCSAC	Belitic calcium sulfoaluminate cement
BCSAK	Belitic calcium sulfoaluminate clinker
CEM	All common cements according to EN 197-1
CEM I	Portland cement according to EN 197-1
CEM II	Portland composite cement according to EN 197-1
CS	Calcium sulfate according to EN 197-1, clause 5.4
CSA	Calcium sulfoaluminate
CSAC	Calcium sulfoaluminate based cement
CSAK	Calcium sulfoaluminate clinker
RSC	Rapid setting cement according to EAD 150008-00-0301
L or LL	Limestone according to EN 197-1, clause 5.2.6
V or W	Fly ash according to EN 197-1, clause 5.2.4

Symbols:

A	=	Total air content [% by volume]
A_{300}	=	Micro air content [% by volume]
Cl^-	=	Chloride [% by mass]
C_{dcr}	=	Direct carbonation resistance
C_{rsc}	=	Carbonation resistance determined in a storage chamber
$D_{nss,90}$	=	Chloride diffusion coefficient (unsteady state) after 90 days [$m^2\ s^{-1}$]
$E_{d,0}$	=	Dynamic Modulus of Elasticity [kN/mm²] after pre-storage respectively before storage of the specimens in saturated $Ca(OH)_2$-solution and 4,4 % $Na_2(SO)_4$-solution
$E_{d,CH,(ti,T)}$	=	Dynamic Modulus of Elasticity [kN/mm²] after storage in saturated $Ca(OH)_2$-solution after a storage time t_i = 14, 28, 56, 91 and 182 days and storage temperature (T) of 5 °C and 20 °C
$E_{d,NS,(ti,T)}$	=	Dynamic Modulus of Elasticity [kN/mm²] after storage in 4,4 % $Na_2(SO)_4$-solution after a storage time t_i = 14, 28, 56, 91 and 182 days and storage temperature (T) of 5 °C and 20 °C
$E_{d,w,(ti,T)}$	=	Dynamic Modulus of Elasticity [kN/mm²] after storage for t_i = 0, 14, 28, 56, 91 and 180 days at a storage temperature (T) of 5 °C and 20 °C in demineralised water
FT_{beam}	=	Freeze thaw resistance without de-icing agent – Beam test
FT_{CiF}	=	Freeze thaw resistance without de-icing agent – CiF-Test
FT_{Slab}	=	Freeze thaw resistance without de-icing agent – Slab-Test
FTS_{CDF}	=	Freeze thaw resistance with de-icing agent – CDF-Test
FTS_{Slab}	=	Freeze thaw resistance with de-icing agent – Slab-Test
IST	=	Initial setting time [min]
IR	=	Insoluble residue [% by mass]
$\bar{L}$	=	Spacing factor [mm]

2 The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

L	=	Liquid absorption [% by mass]
LOI	=	Loss on ignition [% by mass]
$M_{nss,35}$	=	Chloride "non-steady-state migration coefficient" at a specimen age of 35 days [10^{12} m^2/s]
$M_{nss,97}$	=	Chloride "non-steady-state migration coefficient" at a specimen age of 97 days [10^{12} m^2/s]
P_n	=	Loss of mass (scaling) after n freeze-thaw-cycles [% by mass]
$R_{c,t\,h}$	=	Compressive strength at t hours (The point in time t is the earliest possible time for demoulding the specimens (without destroying the specimens) for testing the compressive strength [MPa or N/mm^2]
$R_{c,28d}$	=	Compressive strength at a specimen age of 28 days [MPa or N/mm^2]
RDM	=	Relative dynamic modulus of elasticity [%]
$RDM_{FF,n}$	=	Relative dynamic modulus of elasticity measured with fundamental transverse frequency after n freeze-thaw cycles [%]
$RDM_{UPTT,n}$	=	Relative dynamic modulus of elasticity measured with ultrasonic pulse transit time after n freeze-thaw cycles [%]
S	=	Soundness [mm]
SO_3	=	Sulfate content [% by mass]
S_n	=	Mass of scaled material after n freeze-thaw cycles [kg/m^2]
d	=	Days
d_c	=	Carbonation depth [mm]
k_c	=	Carbonation rate [mm/ $\sqrt{d}$]
v_c	=	Carbonation speed [mm/ $\sqrt{d}$]
w_0	=	Weight of the specimen [g] after pre-storage after pre-storage respectively before storage of the specimens in saturated $Ca(OH)_2$-solution and 4,4 % $Na_2(SO)_4$-solution
$w_{CH(ti,T)}$	=	Weight of the specimen [g] after storage in saturated $Ca(OH)_2$-solution after a storage time t_i = 14, 28, 56, 91 and 182 days and storage temperature (T) of 5 °C and 20 °C
$w_{NS(ti,T)}$	=	Weight of the specimen [g] after storage in 4,4 % $Na_2(SO)_4$-solution after a storage time t_i = 14, 28, 56, 91 and 182 days and storage temperature (T) of 5 °C and 20 °C
$w_{w,(ti,T)}$	=	Weight of the specimen [g] stored for t_i = 14, 28, 56, 91 and 182 days at a storage temperature (T) of 5 °C and 20 °C in demineralised water
ΔL	=	Mean value of the expansion of the length [mm/m]
$\Delta l_{CH(ti,T)}$	=	Mean value of the length difference (storage in saturated $Ca(OH)_2$-solution after a storage time t_i = 14, 28, 56, 91 and 182 days and storage temperature (T) of 5 °C and 20 °C) of 3 specimens [mm/m]
$\Delta l_{NS(ti,T)}$	=	Mean value of the length difference (storage in 4,4 % Na_2SO_4-solution after a storage time t_i = 14, 28, 56, 91 and 182 days and storage temperature (T) of 5 °C and 20 °C) of 3 specimens [mm/m]
$\Delta l_{w,(ti,T)}$	=	Mean value of the length stored for t_i = 14, 28, 56, 91 and 180 days at a storage temperature (T) of 5 °C and 20 °C in demineralised water
$\Delta l_{ti,T}$	=	Expansion [mm/m] after a storage time t_i = 14, 28, 56, 91 and 182 days at a storage temperature (T) of 5 °C and 20 °CΔm_n = Water uptake of the specimen after n freeze-thaw cycles [%]
Δm_n	=	Water absorption of the specimens after n freeze thaw cycles [%]
Δm_{56}	=	Water absorption of the specimens after 56 freeze thaw cycles [%]
ε_d	=	Expansion of (drying) shrinkage [µm/m]
$\varepsilon_{L,n}$	=	Dilation of the specimen after n freeze-thaw cycles [%]
f_{C28}	=	Concrete compressive strength after 28 days [MPa or N/mm^2]

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of belitic calcium sulfoaluminate cement (BCSAC) and calcium sulfoaluminate based cement (CSAC) are assessed in relation to the essential characteristics.

Table 2.1.1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Very early (compressive) strength ($1 \leq t \leq 24$ h)	2.2.1	Level ($R_{c,th}$ [MPa or N/mm²])
2	Standard (compressive) strength (28 days)	2.2.2	Class ($R_{c,28d}$ [MPa or N/mm²])
3	Initial setting time	2.2.3	Description (IST [min])
4	Soundness	2.2.4	Description (S [mm])
5	Sulfate content (as SO_3)	2.2.5	Description (SO_3 [% by mass])
6	Chloride content	2.2.6	Description (Cl^- [% by mass])
7	Insoluble residue	2.2.7	Level (IR [% by mass])
8	Loss on ignition	2.2.8	Level (LOI [% by mass]]
Aspects of durability with relevance only for the essential characteristics linked with BWR1			
9	Effect of different storage temperatures on mortar which hardened under standard conditions	2.2.9	Level [MPa], description
10	Shrinkage of concrete	2.2. 10	Method Shr_C: Level [ε_d: µm/m]; description and/or Method Shr_M: Level [ε: mm/m or µm/m]
11	Effect of different curing temperatures on mortar at early age	2.2.11	Level [MPa], description
12	Sulfate resistance (external sulfate attack)	2.2.12	Method SR_{FPM}: Description and Level ($\Delta l_{NS(ti,T)}$; $\Delta l_{CH(ti,T)}$; $\Delta l_{ti,T}$: [mm/m]; $E_{d,NS,(ti,T)}$, $E_{d,CH,(ti,T)}$ and $E_{d,0}$: [kN/mm²]; $W_{NS(ti,T)}$, $W_{CH(ti,T)}$ and W_0: [g]) and/or Method SR_{SPM}: Level [ΔL: %] and/or description
13	Delayed ettringite formation	2.2.13	Level [$E_{d,w,(ti,T)}$: kN/mm²; $l_{w,(ti,T)}$: mm; $W_{w,(ti,T)}$: g] and/or description
14	Carbonation of concrete	2.2.14	Method C_{dcr}: Level [d_C: mm; v_C: mm/ $\sqrt{d}$] and/or description [; and/or Method C_{rsc}: Level [d_C: mm; k_c: mm/ $\sqrt{d}$]
15	Resistance to chloride penetration	2.2.15	Method M_{nss}: Level [$M_{nss,35}$; $M_{nss,97}$: 10^{-12} m²/s] and/or Method $D_{nss,90}$: Level [D_{nss}: m²s^{-1}]

No	Essential characteristic	Assessment method	Type of expression of product performance
16	Freeze-thaw resistance without de-icing agent	2.2.16	Method FT_{Slab}: Description; Level [S_n: kg/m²; $\varepsilon_{L,n}$: %; f_{C28} = MPa] and/or Method FT_{beam}: Description; Level [Δm_n: %; $RDM_{FF,n}$ and $RDM_{UPTT,n}$: %] and/or Method FT_{CiF}: Description; Level [S_n: kg/m²; $RDM_{UPTT,n}$: %; f_{C28} = MPa] and/or Method FT_{cube}: Description; Level [L: %; P_n: % by mass, f_{C28} = MPa]
17	Freeze-thaw resistance with de-icing agent	2.2.17	Method FT_{Slab}: Description; Level [S_n: kg/m²; Description; $\varepsilon_{L,n}$: %; A: % by volume; A_{300}: % by volume; $\bar{L}$: mm; f_{C28} = MPa] and/or Method FTS_{CDF}: Description; Level [S_n: kg/m²; $RDM_{UPTT,n}$: %; A: % by volume; A_{300}: % by volume; $\bar{L}$: mm; f_{C28} = MPa]
Basic Works Requirement 2: Reaction to Fire			
18	Reaction to fire	2.2.18	Class
Basic Works Requirement 3: Hygiene, health and the environment			
19	Content, emission and/or release of dangerous substances	2.2.19	Level

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

2.2.1 Very early (compressive) strength (1 ≤ t ≤ 24 h)

The early (compressive) strength shall be determined in accordance with EN 196-1, clause 9.2, at a specimen age of t[3] hours (1 h ≤ t ≤ 24 h).

Tests are made on mortars as described in EN 196-1, clause 6. Due to the very early setting time, the addition of a retarding admixture makes the preparation of the specimens easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

The very early (compressive) strength at t[3] hours (1 h ≤ t ≤ 24 h) ($R_{c,t\,h}$) shall be given in the ETA.

2.2.2 Standard (compressive) strength (28 days)

The standard (compressive) strength shall be determined in accordance with EN 196-1, clause 9.2, at a specimen age of 28 days.

Tests shall be made on mortars as described in EN 196-1, clause 6. Due to the very early setting time the addition of a retarding admixture makes the preparation of the specimens easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

The three classes of standard strength depend on the 28 days - compressive strength and shall be

Strength class	28 days-compressive strength [MPa]	
32,5 N	≥ 32,5	≤ 52,5
32,5 R		
42,5 N	≥ 42,5	≤ 62,5
42,5 R		
52,5 N	≥ 52,5	-
52,5 R		

according to EN 197-1, clause 7.1, table 3.

The standard (compressive) strength ($R_{c,28d}$) at 28 days and the class of standard (compressive) strength shall be stated in the ETA.

2.2.3 Initial setting time

The initial setting time (IST) shall be determined in accordance with EN 196-3, clause 6, with the reference method.

The initial setting time (IST) shall be stated in the ETA.

3 The point in time is the earliest possible time for demoulding the specimens (without destroying the specimens) for testing the compressive strength.

2.2.4 Soundness

The soundness (expansion) (S) shall be determined in accordance with EN 196-3, clause 7.

Due to the very early setting time the addition of a retarding admixture makes the preparation of the specimens easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

The soundness (expansion) (S) shall be less or equal than 10 mm according to EN 197-1, clause 7.1, table 3.

The soundness (expansion) (S) shall be stated in the ETA.

2.2.5 Sulfate content (as SO_3)

The sulfate content, expressed as SO_3, shall be determined according to EN 196-2, clause 4.4.2.

The sulfate content, expressed as SO_3, shall be stated in the ETA.

2.2.6 Chloride content

The chloride content Cl^- shall be determined according to EN 196-2, clause 4.5.16.

The chloride content (Cl^-) shall be less or equal than 0,10 % by mass according to EN 197-1, clause 7.3, table 4. The chloride content (Cl^-) shall be stated in the ETA.

2.2.7 Insoluble residue

If the BCSA or CSAC are manufactured with a Portland cement CEM I according to EN 197-1, the insoluble residue (IR) shall be determined according to EN 196-2, clause 4.4.3.

The insoluble residue (IR) shall be stated in the ETA.

2.2.8 Loss on ignition

If the BCSA or CSAC are manufactured with a Portland cement CEM I according to EN 197-1, the loss on ignition (LOI) shall be determined according to EN 196-2, clause 4.4.1.

The loss on ignition (LOI) shall be stated in the ETA.

2.2.9 Effect of different storage temperatures on mortar which hardened under standard conditions

The effect of the hardening process shall be tested on mortar prisms with BCSAC or CSAC and with a Portland cement (CEM I) according to EN 197-1 as a reference cement.

For the assessment mortar prisms (40 mm x 40 mm x 160 mm) shall be made according to EN 196-1 with BCSAC or CSAC and with the Portland cement (CEM I) as a reference cement according to EN 197-1 (both mortars with w/c = 0,5) cured under standard conditions for 28 days.

The number of specimens is given in the following table

Specimen's age [d]	28	35 (28+7)				56 (28+28)				90 (28+62)				Σ
Storage temperature [°C]	20	5	20	40	60	5	20	40	60	5	20	40	60	-
BCSAC	3	3	3	3	3	3	3	3	3	3	3	3	3	39
CEM I	3	3	3	3	3	3	3	3	3	3	3	3	3	39

After 24 hours all specimens are demoulded from the formworks and stored at a temperature of (20 ± 2) °C and at a relative air humidity of ≥ 95 % for 27 days until testing (specimen age: 28 days).

Afterwards the compressive strength shall be determined according to EN 196-1 on 3 prisms per series (with BCSAC or CSAC and with CEM I). The 28-days-compressive strength is the reference value for mortar with BCSAC or CSAC and for mortar with CEM I.

The remaining prisms (3 prisms per series and storage period respectively storage temperature) shall be stored for further 7 days (= 35 days), 28 days (= 56 days) and 62 days (= 90 days) at a temperature of (5 ± 2) °C, (20 ± 2) °C, (40 ± 2) °C and (60 ± 2) °C and a relative air humidity of ≥ 95 %.

After 7 days, 28 days and 62 days, 3 prisms shall be taken per series and storage temperature to determine the compressive strength according to EN 196-1.

The compressive strength (mean values) for each storage temperature and storage period shall be compared for mortar with BCSAC or CSAC and for mortar with "CEM I".

The determined compressive strengths (mean values) for each series (with BCSAC or CSAC and with CEM I) shall be stated in the ETA as levels and/or diagram.

2.2.10 Shrinkage of concrete

2.2.10.1 Method Concrete - Shr_C – Reference test method

The shrinkage of concrete with BCSAC or CSAC shall be determined according to EN 12390-16.

For the assessment at least 3 specimens with the dimensions 75 mm x 75 mm x 280 mm shall be prepared.

The shrinkage shall be tested on concrete I, see Table 2.2.10.1.1.

Table 2.2.10.1.1: Composition of concrete for the determination of shrinkage

	Composition per m³ fresh concrete
concrete I	c = 320 kg BCSAC or CSAC g = ….. kg aggregates [1] $\frac{w}{c} = 0,60$ with w = effective water

[1] Aggregates according to EN 12620 with the following grading curve shall be used:

Size [mm]	0,25	0,5	1	2	4	8	16
Passing [% by mass]	6	14	22	32	46	68	100

The specimens shall be stored for (24 ± 2) hours in the mould, protected from drying at (20 ± 2) °C and > 95 % relative air humidity.

After demoulding, the concrete prisms shall be stored in water with (20 ± 2) °C for 6 days in water at a water temperature of (20 ± 2) °C. Immediately after demoulding (24 hours) and 6 days from demoulding, the weight and length of the prisms shall be determined according to EN 12390-16.

At a specimen age of 7 days the prisms shall be removed from water and the surface is wiped dry with a damp cloth. The prisms shall then be stored at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) % until testing.

Afterwards the weight and length of the prisms (w_0, l_0) shall be determined according to EN 12390-16.

Afterwards the weight and length of the prisms shall be determined after 7 days, 14 days, 21 days, 28 days, 53 days, 83 days, 113 days and 173 days of storage at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) %.

During each measurement step the presence of cracks or any other faults of the surfaces shall be checked and recorded.

The shrinkage of the concrete prisms at 180 days respectively the expansion of (drying) shrinkage (ε_d), together with the information that the performance has been determined with the "Method Concrete", shall be given in the ETA, together with a description of any cracks detected during the checks as above.

2.2.10.2 Method Mortar- Shr_M – Alternative test method

The shrinkage of mortar with BCSAC or CSAC shall be determined according to EN 12617-4, clause 6, with measurement studs Type 1.

The mortar shall be made according to EN 196-1 with BCSAC or CSAC.

The shrinkage is measured after 1, 3, 7, 14, 28 (and 56) days from demoulding.

The change in length shall be calculated in relation to the initial reading (L_0) taken after 24 h. The movement strain ε shall be expressed as the change in length (ΔL) over the gauge length (L_g), in units of mm/m, expressed to the nearest 0,01 mm/m.

$$\text{strain } \varepsilon = \frac{\Delta L \cdot 1000}{L_g} \text{ [mm/m or µm/m]}$$

The strain ε of the mortar prisms at 28 and 56 days together with the information that the performance has been determined with the "Method Mortar" shall be given in the ETA, together with a description of any cracks detected during the checks as above.

2.2.11 Effect of different curing temperatures on mortar at early age

The effect of temperature on setting and hardening behaviour shall be tested on mortar prisms with BCSAC or CSAC and with a Portland cement (CEM I) according to EN 197-1 as reference cement.

For the assessment mortar prisms (40 mm x 40 mm x 160 mm) shall be made according to EN 196-1 with BCSAC or CSAC and with the Portland cement (CEM I) as reference cement (both mortars made with w/c = 0,5).

The number of specimens for the tests is given in the following table.

Specimen's age	8 h	24 h				48 d				72 d				Σ
Storage temperature [°C]	20	5	20	40	80	5	20	40	80	5	20	40	80	-
BCSAC or CSAC	3	3	3	3	3	3	3	3	3	3	3	3	3	39
CEM I	3	3	3	3	3	3	3	3	3	3	3	3	3	39

The specimens shall be cured in a moist air cabinet maintained at a temperature of (20 ± 2) °C and a relative air humidity of ≥ 95 % for 8 hours.

Afterwards the compressive strength after 8 hours shall be determined according to EN 196-1 on 3 prisms per series (with BCSAC and with CEM I or with CSAC and with CEM I). The compressive strength after 8 hours is the initial value for mortar with BCSAC or CSAC and for mortar with CEM I.

The remaining prisms (3 prisms per series and storage period respectively storage temperature) shall be stored at a temperature of (5 ± 2) °C, (20 ± 2) °C, (40 ± 2) °C and (80 ± 2) °C and a relative humidity of ≥ 95 % up to a specimen age of 24 hours, 48 hours and 72 hours.

At a specimen age of 24 hours, 48 hours and 72 hours, 3 prisms shall be taken per series and storage temperature to determine the compressive strength according to EN 196-1.

The determined compressive strengths (mean values) for each series (with BCSAC or with CSAC and with CEM I) shall be stated in the ETA as levels and/or diagram.

2.2.12 Sulfate resistance (external sulfate attack)

2.2.12.1 Method Flat prism - SR_{FPM} – Reference test method

The sulfate resistance (external sulfate attack) of BCSAC or CSAC shall be determined by the flat prism method (FPM) given in Annex A on mortar specimens aged up to 26 weeks in a solution of Na_2SO_4, and in a solution of saturated calcium hydroxide ($CaOH_2$). Differences of expansion and of Relative Dynamic Modulus of elasticity (RDM) of the product specimens aged in the two solutions at various ages shall be calculated. Some further reference sulfate resistant cements according to EN 197-1 - for example CEM I-SR and/or CEM III/B, C-SR and/or CEM IV/A, B-SR - shall be tested at the same time and under the same conditions in order to compare the sulfate resistance performance of BCSAC or CSAC with the reference cements.

The sulfate resistance of BCSAC or CSAC shall be determined by the flat prism method (**SR_{FPM}**) given in **Annex A** on mortar specimens aged up to 26 weeks in 4,4 % Na_2SO_4-solution and in saturated calcium hydroxide $Ca(OH)_2$-solution.

The mean values of the length difference [mm/m] for each tested cement (BCSAC or CSAC) and two reference cements (SR-cements according to EN 197-1), test solution (4,4 % Na_2SO_4-solution and saturated $Ca(OH)_2$-solution), storage temperature (T = 5 °C and 20 °C) and storage time (t_i = 14, 28, 56, 91 and 182 days (182 days only for a storage at 20 °C)), together with the information that the performance has been determined with the "Method Flat prism" shall be given in the ETA, see also Annex A:

$\Delta l_{NS,(ti,T)}$

$\Delta l_{CH,(ti,T)}$

The calculated expansion of the length [mm/m] for each tested cement, storage temperature (T = 5 °C and 20 °C) and storage time (t_i = 14, 28, 56, 91 and 182 days (182 days only for storage at 20 °C)), together with the information that the performance has been determined with the "Method Flat prism", shall be given in the ETA, see also Annex A:

$\Delta l_{ti,T}$

The mean value of the dynamic modulus of elasticity for each tested cement, storage solution (4,4 % Na_2SO_4-solution and saturated $Ca(OH)_2$-solution), storage temperature (T = 5 °C and 20 °C) and storage time (t_i = 14, 28, 56, 91 and 182 days (182 days only for storage at 20 °C) and also the initial measurement (after pre-storage t = 0), together with the information that the performance has been determined with the "Method Flat prism", shall be given in the ETA, see also Annex A:

$E_{d,NS,(ti,T)}$, $E_{d,CH,(ti,T)}$ and $E_{d,0}$

The mean value of mass of the specimens for each tested cement, storage solution (4,4 % Na_2SO_4-solution and saturated $Ca(OH)_2$-solution), storage temperature (T = 5 °C and 20 °C) and storage time (t_i = 14, 28, 56, 91 and 182 days (182 days only for storage at 20 °C)) and also the initial measurement (after pre-storage t = 0), together with the information that the performance has been determined with the "Method Flat prism" shall be given in the ETA, see also Annex A:

$w_{NS,(ti,T)}$, $w_{CH,(ti,T)}$ and w_0

In addition, a detailed description of the specimens in view of cracks (e.g., photo) after testing – if any - shall be stated in the ETA together with the information that the product has been assessed using the "Method Flat prism".

2.2.12.2 Method Square prism - SR_{SPM} – Alternative test method

The sulfate resistance of BCSAC or of CSAC shall be determined by the test method given in **Annex B**.

The mean value of the expansion of length of the flat prisms stored in distilled water and sulfate solution (**ΔL**) and storage period as well as for each tested cement, together with the information that the performance has been determined with the "Method Square prism", shall be stated in the ETA.

2.2.13 Delayed ettringite formation

If the BCSAC or CSAC is to be used in combination with Portland cement CEM I according to EN 197-1 for the production of concrete, the delayed ettringite formation must be determined using the "reduced flat prism method" described in **Annex C** on mortar samples that have been stored in demineralized water for up to 26 weeks. The test shows that no harmful delayed ettringite formation can be occurred. The test shall be carried out on mortar samples made with BCSAC or CSAC and the selected cements, see also **Annex C**.

The mean value of length ($l_{w,(ti,T)}$), the mean value of the dynamic modulus of elasticity ($E_{d,w,(ti,T)}$) and the mean value of the mass of flat prisms ($w_{w,(ti,T)}$) stored for 180 days in demineralised water at a storage temperature of (5 ± 2) °C and (20 ± 2) °C and a detailed description of the specimens (e.g., photo) in view of cracks – if any – shall be stated in the ETA.

2.2.14 Carbonation of concrete

2.2.14.1 Method Carbonation resistance determined in a storage chamber – C_{rsc} – Reference test method

The carbonation resistance of concrete made with BCSAC or CSAC shall be measured according to EN 12390-10 by using a storage chamber (see clauses 5.4 and 6.2 and Annex A of EN 12390-10).

The carbonation resistance shall be tested on concrete IIa (concrete made with BCSAC or CSAC) and concrete IIb (reference concrete), see Table 2.2.14.1.1.

Table 2.2.14.1.1: Composition of concrete for the determination of carbonation depth

	Composition per m³ fresh concrete
Concrete IIa	c = 350 kg BCSAC or CSAC g = kg aggregates [1] w = 175 l water $\left(\frac{w}{c} = 0{,}50\right)$ with w = effective water
Concrete IIb	c = 350 kg CEM I 52,5R g = kg aggregates [1] w = 175 l water $\left(\frac{w}{c} = 0{,}50\right)$ with w = effective water

[1] Aggregates according to EN 12620 with the following grading curve shall be used:

Size [mm]	0,125	0,25	0,5	1	2	4	8	16	32
Passing [% by mass]	5	9	14	20	30	43	62	89	100

Following specimens shall be produced:

- 2 beams (400 mm x 100 mm x 100 mm) for each concrete for determination of the carbonation depth,
- 3 cubes with the dimensions of 150 mm x 150 mm x 150 mm or cylinders with a diameter of d = 150 mm and a height of h = 300 mm for each concrete for determination of the compressive strength.

Due to the very early setting time of some formula, the addition of a retarding admixture makes the preparation of the samples easier. If used, the nature and the dosage of the retarding admixture shall be given in the ETA.

After manufacturing the test specimens shall be stored for 24 hours in a damp room ((20 ± 2) °C and a relative air humidity of > 95 %). After demoulding the formworks, the specimens shall be stored immersed in water at a temperature of (20 ± 2) °C until an age of 7 days.

After 7 days the specimens shall be stored until testing at a temperature of (20 ±2) °C and a relative humidity of (65 ± 5) % in a climate-controlled chamber containing a CO_2 content close to the local normal climate, see EN 12390-10, for the climate clause 5.4 and for the chamber Annex A.

Measurements of carbonation depth d_c shall be performed after83 and 173 days. It is recommended to continue the tests on the same samples for 267, 358, 540 and 723 days in order to verify the obtained results after 173 days and improve the knowledge.

The compressive strength of concrete II a with BCSA or CSAC and of concrete IIb (CEM I) after 7 ($f_{C,7}$) and 28 days ($f_{C,28}$) shall be determined according to EN 12390-3 and shall be stated in the ETA.

The mean value of the carbonation depth (d_C) and the rate of carbonation k_c after 83 and 173 days for the concrete with BCSAC or CSAC (concrete IIa) and with the CEM I 52,5 R (concrete IIb), together with the information that the performance has been determined with the "Method Carbonation resistance determined in a storage chamber", shall be stated in the ETA.

2.2.14.2 Method Direct Carbonation Resistance of fine concrete - C_{dcr} – Alternative test method

The carbonation depth of concrete made with BCSAC or CSAC shall be measured according to EN 12390-10.

The carbonation depth shall be tested on 18 prisms (40 mm x 40 mm x 160 mm) with aggregates according to EN 12620 with a maximum size grain of 8 mm. 12 prisms for testing the compressive strength and 6 prisms for the determination of the carbonation depth are needed.

The carbonation resistance shall be tested on (fine) concrete III, see Table 2.2.14.2.1.

Table 2.2.14.2.1: Composition of (fine) concrete for the determination of carbonation depth

	Composition for 3 specimens
concrete III	c = 450 g BCSAC or CSAC g = 1350 g aggregates [1] w = 225 g water $\left(\frac{w}{c} = 0{,}50\right)$ with w = effective water

[1] Aggregates according to EN 12620 with the following grading curve shall be used:

Size [mm]	0,25	0,5	1	2	4	8
Passing [% by mass]	8	21,5	36	46,5	67,5	100

The specimens shall be prepared according to EN 196-1, clause 6. except the consideration of the gap of (3±1 mm) between the bowl and the blade that cannot be respected by the size grading of the sand.

Due to the very early setting time the addition of a retarding admixture makes the preparation of the specimens easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

After demoulding the specimens shall be stored immersed in water at a temperature of (20 ±2) °C, half of the specimens (9) until an age of 7 days (set no. carb1) and the other half (9) until an age of 28 days (set no. carb2).

Afterwards the specimens shall be stored at a temperature of (20 ± 2) °C and at a relative air humidity of 65 % and ambient CO_2 content (commonly 350 to 450 p.p.m.).

The carbonation depth shall be determined after 14, 28, 56, 98 and 140 days according to EN 12390-10, clause 7. It is recommended to continue the tests on the same samples for 1, 2 and 5 years in order to verify the obtained results after 140 days and improve the knowledge.

Furthermore the compressive strength shall be determined according to EN 196-1, clause 9.2:

- on the set of specimens no 1 (6 specimens), at the age of 35 days (after 7 days pre-storing in water and 28 days at a temperature of (20 ± 2) °C and at a relative air humidity of (65 ± 5) %) and at the age of 147 days (after 7 days pre-storing in water and 140 days at a temperature of (20 ± 2) °C an at a relative air humidity of (65 ± 5) %);
- on the set of specimens no 2 (6 specimes), at the age of 35 days (after 28 days pre-storing in water and 7 days at a temperature of (20 ± 2) °C and at a relative air humidity of (65 ± 5) %) and at the age of 168 days (after 28 days pre-storing in water and 140 days at a temperature of (20 ± 2) °C and at a relative air humidity of (65 ± 5) %).

Record the depth of carbonation after aging in water and after each aging step in air at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) % and ambient CO_2. The carbonation speed v_c shall be calculated by linear regression with:

$d_C = d_0 + v_C \cdot \sqrt{t_C}$ and then: $v_C = (d_C - d_0)/\sqrt{t_C}$ expressed in mm / $\sqrt{d}$

with:

d_0 = carbonation depth at time t = 0 ; this specific parameter depends on the storage and will be lower at a later start of carbonation.

d_c = carbonation depth (mm) at time t_C

t_c = duration of carbonation (days)

v_c = carbonation speed (in mm/$\sqrt{\text{day}}$)

Annex D contains tables and diagrams for the assessment of the carbonation resistance.

The determined carbonation depth together with the compressive strength and the calculated carbonation speed of prisms shall be inserted in the diagrams and figures given in **Annex D**.

The mean values of the carbonation depth d_c, and carbonation speed v_c, together with the information that the performance has been determined with the "Method Carbonation Direct Carbonation Resistance of fine concrete", shall be stated in the ETA as level and/or diagrams.

2.2.15 Resistance to chloride penetration

The following methods are equivalent.

2.2.15.1 Method Chloride migration coefficient - M_{nss}

The resistance to chloride penetration of concrete with the BCSAC or CSAC shall be determined according to EN 12390-18.

The resistance to chloride penetration shall be tested on concrete IV, see Table 2.2.15.1.1.

Table 2.2.15.1.1: Composition of concrete for the determination of the resistance to chloride penetration

	Composition per m³ fresh concrete
Concrete IV	c = 320 kg BCSAC or CSAC g = ….. kg aggregates[1] $\frac{w}{c} = 0,50$ with w = effective water

[1] Aggregates according to EN 12620 with the following grading curve shall be used:

Size [mm]	0,25	0.5	1	2	4	8	16
Passing [% by mass]	6	14	22	32	46	68	100

6 cylinders with a diameter of 100 mm and a length of 200 mm shall be made in accordance to EN 12390-2.

The specimens shall be stored for 24 hours in the mould at a temperature of (20 ± 2) °C and a relative air humidity > 95 %. After demoulding the specimens shall be stored in water at a temperature of (20 ± 2) °C until testing. At a specimen age of 28 days respectively 90 days 3 specimens shall be taken from the water.

In the middle of each cylinder a 50 ±2 mm thick slice shall be cut out. Measure the thickness of each slice with a slide calliper and read to 0,1 mm.

Note 2.2.15.1: The term 'cut' here means to saw perpendicularly to the axis of a core or cylinder, using a water-cooled diamond saw.

Afterwards the slices shall be stored immersed in water until testing at a specimen age of 35 days respectively 97 days. The test shall start at the specimen age of 35 days respectively 97 days.

The mean value of the chloride "non-steady-state migration coefficient" ($\mathbf{M_{nss,35};\ M_{nss,97}}$) of concrete with BCSAC or CSAC at a specimen age of 35 and 97 days, together with the information that the performance has been determined with the "Method Chloride migration coefficient", shall be stated in the ETA.

2.2.15.2 Method Chloride diffusion coefficient - D_{nss}

The resistance to chloride penetration of concrete with BCSAC or CSAC and with Portland cement as reference shall be determined in accordance EN 12390-11 by the chloride diffusion coefficient.

The resistance to chloride penetration shall be tested on concrete IIa (concrete made with BCSAC or CSAC) and concrete IIb (reference concrete), see Table 2.2.14.1.1.

At least 2 cylinders with a diameter of 100 mm and a length of 300 mm or 2 cubes with a length of 100 mm or 150 mm for each concrete shall be produced according to EN 12390-2.

The specimens shall be stored for 24 hours in the mould at a temperature of (20 ± 2) °C and a relative air humidity > 95 %. After demoulding the specimens shall be stored in water at a temperature of (20 ± 2) °C until testing. At a specimen age of 28 days the specimens shall be taken from the water.

The chloride diffusion coefficient after 90 days ($\mathbf{D_{nss,90}}$) of the two concretes, together with the information that the performance has been determined with the "Method Chloride diffusion coefficient", shall be stated in the ETA.

2.2.16 Freeze-thaw resistance without de-icing agent

2.2.16.1 Method Slab-Test - FT_{Slab} - Reference test method

The freeze-thaw resistance of concrete with BCSAC or CSAC shall be determined according to CEN/TS 12390-9, clause 5 ("Slab-test"). Additionally, the internal structural damage shall be determined according to CEN/TR 15177, clause 8.3.1.

Both test methods shall be applied on concrete IV (see Table 2.2.15.1.1). The "Slab-Test" shall be performed with de-mineralized water as freezing medium.

Furthermore, the compressive strength ($f_{C,28}$) of concrete IV shall be determined according to EN 123903 after 28 days and stated in the ETA.

The following test specimens are required to perform the tests:

- 4 specimens (50 ±2 mm x 150 mm x 150 mm) cut from 4 cubes with the dimension of 150 mm x 150 mm x 150 mm,
- 3 specimens for the determination of the compressive strength (cubes: 150 mm x 150 mm x 150 mm or cylinders: d = 150 mm, h = 300 mm) after 28 days.

After manufacturing the test specimens shall be stored for 24 hours in a damp room (temperature of (20 ± 2) °C and a relative air humidity of > 95 %). After demoulding the formwork, the specimens shall be immersed in water (20 ± 2) °C) until the age of 7 days. Afterward the specimens shall be stored for further 21 days at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) %.

The scaling S_n shall be measured after 7, 14, 28, 42 and 56 freeze-thaw cycles. The dilation $\varepsilon_{L,n}$ shall be measured after 0, 7, 14, 28, 42 and 56 freeze-thaw cycles.

The values of the surface scaling ($\mathbf{S_n}$), and the dilation $\boldsymbol{\varepsilon}_{L,n}$ after 7, 14, 28. 42 and 56 freeze-thaw cycles, together with the information that the performance has been determined with the "Method Slab test", shall be stated in the ETA, together with the compressive strength ($f_{C,28}$) as above and any information on visual defects of the specimens as, e.g., photos.

2.2.16.2 Method Beam-Test - FT_{beam} – Alternative test method

The freeze-thaw resistance of concrete (internal structural damage) with BCSAC or CSAC shall be determined according to CEN/TR 15177, clause 7 ("Beam-test").

The freeze-thaw resistance ("Beam-Test") shall be tested on concrete IIa, see Table 2.2.14.1.1.

The following test specimens are required to perform the test:

- 4 beams (specimen dimension: 400 mm x 100 mm x 100 mm)

After manufacturing the test specimens shall be stored for 24 hours in a damp room ((20 ± 2) °C and a relative air humidity of > 95 %). After demoulding, the specimens shall be immersed in water ((20 ± 2) °C) until the age of 7 days. Afterward the specimens shall be stored for further 21 days at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) %.

The test procedure and preparation of the specimens are described in detail in CEN/TR 15177, clause 7.

For the freeze-thaw resistance - internal damage according to CEN/TR 15177 - the dynamic modulus of elasticity ($RDM_{FF,n}$ and $RDM_{UPPT,n}$) shall be measured after 0, 7, 14, 28 and 56 freeze-thaw cycles.

The water absorption ($\mathbf{\Delta m_n}$) of the test specimens after n freeze-thaw cycles shall be determined.

The development of the relative dynamic modulus of elasticity ($\mathbf{RDM}_{FF,n}$ and $\mathbf{RDM}_{UPPT,n}$) and the mean value of the water absorption ($\mathbf{\Delta m_n}$) after 0, 7, 14, 28 and 56 freeze-thaw cycles, together with the information that the performance has been determined with the "Method Beam test", shall be given in the ETA together with any information on visual defects of the specimens as, e.g., photos.

2.2.16.3 Method CiF-Test - FT_{CiF} - Alternative test method

The freeze-thaw resistance of concrete with the BCSAC or CSAC shall be determined according to CEN/TS 12390-9, clause 7 ("CF-Test"), to determine the loss of material (scaling). The internal structural damage (i) shall be determined according to CEN/TR 15177, clause 9.3.1 (Relative Dynamic Modulus of elasticity – RDM).

Both test methods shall be applied on concrete IV (see Table 2.2.15.1.1). The "CF"-Test shall be performed with de-mineralized water as freezing medium.

The compressive strength ($f_{C,28}$) of concrete IV shall be determined according to EN 12390-3 after 28 days and stated in the ETA.

The following test specimens are required to perform the tests:

- 5 specimens with a total testing surface of 0,08 m² and a height of the specimen of 70 mm (specimen dimension: 150 mm x 150 mm x 70 mm)
- 3 specimens for the determination of the compressive strength (cubes: 150 mm x 150 mm x 150 mm or cylinders: d = 150 mm, h = 300 mm) after 28 days

After manufacturing the test specimens shall be stored for 24 hours in a damp room (temperature of (20 ± 2) °C and a relative air humidity of > 95 %). After demoulding the formwork, the specimens shall be immersed in water (20 ± 2) °C) until the age of 7 days. Afterward the specimens shall be stored for further 21 days at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) %.

Between 21st and 26th day after demoulding the specimen lateral surfaces shall be either covered with aluminium foil glued with butyl rubber or sealed with a solvent-free epoxy resin. Immediately after this treatment the specimens shall be returned to the climate chamber, see also CEN/TS 12390-9, clause 7.3.

The freeze–thaw test shall start after a specimen age of 28 days with the re-saturation of the specimens.

Following dry storage, the specimens shall be placed in the test containers on the (5 ± 0,1) mm high spacers with the test surface downwards, see CEN/TS 12390-9, Figure 8. Subsequently, the freezing medium shall be poured into the container to a height of (10 ± 1) mm without wetting the specimen's top.

During the capillary suction the test container shall be closed. The capillary suction period shall be seven days at a temperature of (20 ± 2) °C. Check and adjust the liquid level above at regular intervals, depending on the suction capacity of the material during capillary suction.

The weight gain of the specimens shall be measured:

$\Delta w = w_{after,7d} - w_{before,28d}$

with:

Δw: water absorption / capillary suction [g]

$w_{after,7d}$: weight of the specimen after 7 days water suction [g]

$w_{before,28d}$: weight of the specimen after 28 days [g]

The capillary suction of water of each specimen shall be measured and recorded.

The scaling ($\mathbf{S_n}$) shall be measured after 7, 14 and 28 freeze-thaw cycles. The dynamic modulus of elasticity ($\mathbf{RDM}_{UPTT,n}$) shall be measured after 0, 7, 14, and 28 freeze-thaw cycles.

The results of the surface scaling ($\mathbf{S_n}$) after 7, 14 and 28 freeze-thaw-cycles and the relative dynamic modulus of elasticity ($\mathbf{RDM_{UPTT,n}}$) after 0, 7, 14 and 28 freeze-thaw cycles, together with the information that the performance has been determined with the "Method CiF-Test", shall be stated in the ETA, together with the compressive strength ($f_{C,28}$) and any information on visual defects of the specimens as, e.g., photos.

2.2.16.4 Method Cube-Procedure - FT$_{cube}$ - Alternative test method

The freeze-thaw resistance of concrete with BCSAC or CSAC shall be determined according to CEN/TS 12390-9, clause 6 ("cube procedure").

The freeze-thaw resistance ("cube procedure") shall be tested on concrete V, see Table 2.2.16.4.1.

Table 2.2.16.4.1: Composition of concrete for determination of the freeze-thaw resistance without de-icing agent

	Composition per m³ fresh concrete
Concrete V	c = 300 kg BCSA or CSAC g = ….. kg aggregates [1] $\frac{w}{c} = 0{,}60$ with w = effective water

[1] Aggregates according to EN 12620 with the following grading curve shall be used:

Size [mm]	0,125	0,25	0,5	1	2	4	8	16	32
Passing [% by mass]	1,5*)	5	23	35	45	56	70	85	100

*) Recommended value

The following test specimens are required to perform the tests:

- 3 cubes (150 mm x 150 mm x 150 mm) or 3 cylinders (d = 150 mm, h = 300 mm) for testing of compressive strength after 28 days
- 4 cubes (100 mm x 100 mm x 100 mm) for the cube test

After manufacturing the test specimens shall be stored for 24 hours in a damp room ((20 ± 2) °C and a relative air humidity of > 95 %). After demoulding, the specimens shall be immersed in water ((20 ± 2) °C) until the age of 7 days. Afterward the specimens shall be stored for further 20 days at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) %. The cube test shall start when the specimens are 27 days old, see CEN/TS 12390-9, clause 6.

The scaling shall be measured after 10, 25, 50, 75 and 100 freeze-thaw cycles.

The compressive strength ($f_{C,28}$) shall be determined according to EN 12390-3 after 28 days and stated in the ETA.

The scaling (**P_n**) after 10, 25, 50, 75 and 100 freeze-thaw-cycles, the fluid absorption (**L**) and any information on visual defects of the specimens as, e.g., photos, together with the information that the performance has been determined with the "Method Cube-Procedure", shall be stated in the ETA.

2.2.17 Freeze-thaw resistance with de-icing agent

2.2.17.1 Method Slab–Test - FTS_{Slab} – Reference test method

The freeze-thaw resistance with de-icing agent of concrete with BCSAC or CSAC shall be determined according to CEN/TS 12390-9, clause 5 ("Slab-Test"). The internal structural damage shall be determined according to CEN/TR 15177, clause 8.3.1.

Both test methods shall be applied on concrete VI, see Table 2.2.17.1.1. The "Slab-Test" shall be performed with a 3 %-NaCl-solution as freezing medium.

Table 2.2.17.1.1: Composition of concrete for the determination of the freeze-thaw resistance with de-icing agent

	Composition per m³ fresh concrete
Concrete VI	c = 320 kg BCSAC or CSAC g = ….. kg aggregates [1] Concrete with air entraining agent. (The air content of the fresh concrete shall be 4,5 ± 0,5 Vol.-%.) $\frac{w}{c} = 0{,}50$ with w = effective water

[1] Aggregates according to EN 12620 with the following grading curve shall be used:

Size [mm]	0,25	0,5	1	2	4	8	16
Passing [% by mass]	6	14	22	32	46	68	100

The following test specimens are required to perform the tests:

- 4 specimens (50 ±2 mm x 150 mm x 150 mm) cut from 4 cubes with the dimensions 150 mm x 150 mm x 150 mm,
- 3 cubes with the dimensions 150 mm x 150 mm x 150 mm or cylinders with a height of h = 300 mm and a diameter of d = 150 mm for the determination of the compressive strength after 28 days,
- 2 specimens for the determination of the air void parameters (specimen dimensions: 150 mm x 150 mm x 150 (40) mm).

The description of the specimen preparation for the Slab-Test is given in CEN/TS 12390-9, clause 5.

For the determination of the compressive strength the specimens shall be immersed in water after demoulding until an age of 7 days. Afterwards the specimens shall be stored at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) % until testing.

The compressive strength of concrete V ($f_{C,28}$) shall be determined according to EN 12390-3 after 28 days and stated in the ETA.

The scaling S_n shall be measured after 7, 14, 28, 42 and 56 freeze-thaw cycles. The dilation $\varepsilon_{L,n}$ shall be measured after 0, 7, 14, 28, 42 and 56 freeze-thaw cycles.

The air void parameters (A, A_{300}, $\bar{L}$) shall be determined according to EN 480-11 on concrete V.

The values of the surface scaling (**S_n**) after 7, 14, 28, 42 and 56 freeze-thaw cycles and the dilation **$\varepsilon_{L,n}$** after 7, 14, 28. 42 and 56 freeze-thaw cycles, together with the information that the performance has been determined with the "Method Slab-Test", shall be stated in the ETA, together with the compressive strength ($f_{C,28}$) air void parameters (**A, A_{300},** $\bar{L}$) and any information on visual defects of the specimens as, e.g., photos.

2.2.17.2 Method CDF-Test - FTS_{CDF} – Alternative test method

The freeze-thaw resistance with de-icing agent of concrete with the BCSAC or CSAC shall be determined according to CEN/TS 12390-9, clause 7 ("CDF-Test"). The internal structural damage shall be determined according to CEN/TR 15177, clause 9.3.1 (Relative Dynamic Modulus of elasticity – RDM)

The freeze-thaw resistance with de-icing agent ("CDF-Test") shall be tested on concrete VI, see Table 2.2.17.1.1. The test shall be performed with a 3 %-NaCl-solution as freezing medium.

The following test specimens are required to perform the tests:

- 5 specimens with a total testing surface of 0,08 m² and a height of the specimens of 70 mm (specimen dimensions: 150 mm x 150 mm x 150 (70) mm)
- 3 cubes with the dimensions 150 mm x 150 mm x 150 mm or cylinders with a height of 300 mm and a diameter of d = 150 mm for the determination of the compressive strength after 28 days
- 2 specimens for the determination of the air void parameters (specimen dimensions: 150 mm x 150 mm x 150 (40) mm)

After manufacturing the test specimens shall be stored for 24 hours in a damp room at a temperature of (20 ± 2) °C and a relative air humidity of ≥ 95 %. After demoulding, the specimens shall be immersed in water at (20 ± 2) °C until the age of 7 days. Afterward the specimens shall be stored for further 21 days at a temperature of (20 ± 2) °C and a relative air humidity of (65 ± 5) %.

Between 21st and 26th day after demoulding the specimen lateral surfaces shall either be covered with aluminium foil glued with butyl rubber or sealed with a solvent-free epoxy resin. Immediately after this treatment the specimens shall be returned to the climate chamber, see also CEN/TS 12390-9, clause 7.3.

The freeze–thaw test shall start after 28 days with the re-saturation of the specimens.

Following dry storage, the specimens shall be placed in the test containers on the (5 ± 0,1) mm high spacers with the test surface downwards, see CEN/TS 12390-9, Figure 8. Subsequently, the freezing medium shall be poured into the container to a height of (10 ± 1) mm without wetting the specimen's top.

During the capillary suction the test container is closed. The capillary suction period shall be seven days at a temperature of (20 ± 2) °C. Check and adjust the liquid level above at regular intervals, depending on the suction capacity of the material during capillary suction. The weight gain of the specimens shall be measured:

$\Delta w = w_{after,7d} - w_{before,28d}$

with:

Δw: water absorption / capillary suction [g]

$w_{after,7d}$: weight of the specimen after 7 days water suction [g]

$w_{before,28d}$: weight of the specimen after 28 days [g]

The capillary suction of water of each specimen shall be measured and recorded.

The scaling (**S_n**) shall be measured after 7, 14 and 28 freeze-thaw cycles. The dynamic modulus of elasticity (**RDM**$_{UPTT,n}$) shall be measured after 0, 7, 14 and 28 freeze-thaw cycles.

The capillary suction of water of each specimen shall be measured and reported for further information.

The compressive strength of concrete V ($f_{C,28}$) shall be determined according to EN 12390-3 after 28 days and stated in the ETA.

The air void parameters (A, A_{300}, $\bar{L}$) shall be determined according to EN 480-11 on concrete V after 28 days.

The results of the surface scaling (**S_n**) after 7, 14 and 28 freeze-thaw cycles and the relative dynamic modulus of elasticity (**$RDM_{UPTT,n}$**) after 0, 7, 14 and 28 freeze-thaw cycles, together with the information that the performance has been determined with the "Method CDF-Test", shall be stated in the ETA, together with the compressive strength ($f_{C,28}$), the air void parameters (**A, A_{300},** $\bar{L}$) and any information on visual defects of the specimens as, e.g., photos.

2.2.18 Reaction to fire

Considering the limitations for organic additives in the composition of the products as stated in tables 1.1.4 and 1.1.5 BCSAC and CSAC are considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire, in accordance with the provisions of Decision 96/603/EC as amended by Commission Decision 2000/605/EC and 2003/424/EC, without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of the products is class A1.

2.2.19 Content and/or release of dangerous substances

2.2.19.1 General

The performance of the BCSAC or CSAC related to the emissions and/or release and, where appropriate, the content of dangerous substances shall be assessed on the basis of any information provided by the manufacturer[4] after identifying the release scenarios taking into account the intended use of the product and the Member States where the manufacturer intends his product to be made available on the market.

The identified intended release scenarios[5] for this BCSAC or CSAC and intended use with respect to dangerous substances are:

S/W1: Product with direct contact to soil, ground- and surface water,

S/W2: Product with indirect contact to soil, ground- and surface water.

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4 The manufacturer may be asked to provide to the TAB the REACH related information which shall accompany the DoP with (cf. Article 6(5) of Regulation (EU) No 305/2011).
The manufacturer is **not** obliged:
- to provide the chemical constitution and composition of the product (or of constituents of the product) to the TAB, or
- to provide a written declaration to the TAB stating whether the product (or constituents of the product) contain(s) substances which are classified as dangerous according to Directive 67/548/EEC and Regulation (EC) No 1272/2008 and listed in the "Indicative list on dangerous substances" of the SGDS, taking into account the installation conditions of the construction product and the release scenarios resulting from there.

Any information provided by the manufacturer regarding the chemical composition of the products may not be distributed to EOTA or to TABs.

5 Scenario S/W1 is applicable for products which are in contact with soil or water in a way that dangerous substances could be released directly out of the product.
Scenario S/W2 is applicable for products which can be leached by rain (e.g., external claddings) and could release dangerous substances which can have an impact on soil and water.

2.2.19.2 Leachable Substances

For the intended use covered by the release scenario S/W1 the performance of the product concerning leachable substances has to be assessed. A leaching test with subsequent eluate analysis shall take place, each in triplicate.

Elution test specimens shall be made of concrete with the following composition:

Cement: BCSAC or CSAC, c = 280 kg/m^3

Water / cement ratio: 0,60

Aggregate: Gravel/Sand according to EN 12620 with the following grading curve:

Size [mm]	0,25	0,5	1	2	4	8	16
Passing [% by mass]	6	14	22	32	46	68	100

Concrete cubes[6] with dimensions of 100 mm x 100 mm x 100 mm shall be made in accordance with EN 12390-2 (form oil shall not be used).

The specimens shall be stored for (24 ± 2) hours in the mould, protected from drying at (20 ± 2) °C and a relative air humidity of ≥ 95 %.

After demoulding the formworks, the test specimens shall be airtight packaged and stored at a temperature of (20 ± 2) °C. The test specimens shall generally be stored for 56 days. The requirements for storage are fulfilled, when the cubes, for instance, are immediately double-wrapped in plastic foil (at least 0,3 mm thick), and all free edges of the plastic foil are stuck down with adhesive tape.

The eluate shall be produced by a tank test according to EN 16637-2. The eluates taken after 6 hours, 24 hours, 54 hours, 4 days, 9 days, 16 days, 36 days and 64 days shall be analysed for the following environmentally relevant parameters:

a) antimony, arsenic, barium, lead, cadmium, chromium (total), chromate (Cr VI), cobalt, copper, molybdenum, nickel, mercury, thallium, vanadium, zinc,
b) chloride (Cl^-), sulfate (SO_4^{2-}), fluoride (F^-),
c) TOC, pH-value, electrical conductivity, colour and turbidity.

antimony, arsenic, barium, lead, cadmium, chromium (total), chromate (Cr VI), cobalt, copper,

The parameters shall be analysed with standardised test methods according to table 2.2.19.2.1.

Table 2.2.19.2.1: Analytical test methods

Parameter	**Test method**
antimony (Sb), arsenic (As), barium (Ba), lead (Pb), cadmium (Cd), total chromium (Cr), chromate VI (Cr), cobalt (Co), copper (Cu), molybdenum (Mo), nickel (Ni), mercury (Hg), thallium (Ti), vanadium (V), zinc (Zn), chloride (Cl^-), sulfate (SO_4^{2-}), fluoride (F^-)	EN 17195
TOC, pH-value, electrical conductivity	EN 17332
Colour	EN ISO 7887
Turbidity	EN ISO 7027-1

Measured concentration of the leaching test according to EN 16637-2 of hardened concrete shall be recorded per step for each parameters a) and b) in µg/L and mg/m^2. Additionally, the cumulatively released quantities shall be expressed for each parameter in mg/m^2.

For parameters a) and b) the cumulatively released quantities expressed in mg/m² shall be given in the ETA.

6 Alternatively, cylinders with a diameter of 100 mm and a height of at least 100 mm can be used.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 97/555/EC, as amended by Commission Decision 2010/683/EU.

The system is 1+.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
1	Very early (compressive) strength t h (1 ≤ t ≤ 24 h)	2.2.1	Control plan	1	2/week[a)] 4/week[b)]
2	Standard (compressive) strength (28 days)	2.2.2	32,5 N, 32,4 R ≥ 30,0 MPa 42,5 N, 42,5 R ≥ 40,0 MPa 52,5 N, 52,5 R ≥ 50,0 MPa lower limit value[1)] Class	1	
3	Initial setting time	2.2.3	Control plan	1	2/week[a)] 4/week[b)]
4	Soundness (Expansion)	2.2.4	≤ 10 mm upper limit value[1)]	1	1/week[a)] 4/week[b)]
5	Sulfate content (as SO_3)	2.2.5	Control plan	1	2/week[a)] 4/week[b)]
6	Chloride content	2.2.6	≤ 0,10 % by mass upper limit value[1)]	1	2/month[a) c)] 1/week[b)]
7	Control of raw materials	3.4.1	Control plan	1	each batch
8	Calcium sulfoaluminate (Yeelimite) content in the cement	3.4.2*	Control plan	1	1/month[a)] 1/week[b)]
9	Belite content in the cement (Only for BCSAC)	3.4.3*	Control plan	1	
10	Composition of BCSA or CSAC	3.4.4*	Control plan		
11	Density	3.4.5	Control plan	1	
12	Fineness (Blaine)	3.4.6	Control plan	1	1/month[a)] 1/week[b)]

* Other methods than the one indicated may be used provided they give results correlated and equivalent to those obtained with the reference method

1) Limit values for single results according to EN 197-1, table 10

a) Routine situation according to EN 197-1, table 6

b) Initial period for a new type of cement according to EN 197-1, table 6

c) When none of the test results within a period of 12 months exceeds 50 % of the characteristic value the frequency may be reduced to one per month according to EN 197-1.

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for BCSAC or CSAC are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	Notified Body will ascertain that the factory production control with the staff and the equipment are suitable to ensure a continuous and orderly manufacturing if the BCSAC or CSAC.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer. Details on the procedure are given in EN 197-2.	According to Control plan	According to Contol plan	When starting the production or a new line
Continuous surveillance, assessment and evaluation of factory production control					
2	The Notified Body will ascertain that the system of the FPC and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw material, to the process and to the product as indicated in Table 3.2.1. Details on the procedure are given in EN 197-2.	According to Control plan	According to Control plan	1/year
Audit-testing of samples taken by the notified product certification body at the manufacturing plant or at the manufacturer's storage facilities					
3	Very early (compressive) strength t h (1 ≤ t ≤ 24 h)	2.2.1	Control plan	1	6/year[1)]
4	Standard (compressive) strength (28 days)	2.2.2	32,5 N, 32,4 R ≥ 30,0 MPa 42,5 N, 42,5 R ≥ 40,0 MPa 52,5 N, 52,5 R ≥ 50,0 MPa	1	
5	Initial setting time	2.2.3	Control plan	1	
6	Soundness (Expansion)	2.2.4	≤ 10 mm	1	
7	Sulfate content (as SO_3)	2.2.5	Control plan	1	
8	Chloride content	2.2.6	≤ 0,10 % by mass	1	
9	Control of raw materials	3.4.1	Control plan	1	
10	Calcium sulfoaluminate (Yeelimite) content in the cement	3.4.2*	Control plan	1	
11	Calcium sulfoaluminate (Yeelimite) content in the cement	3.4.2*	Control plan	1	
12	Belite content in the cement (Only for BCSAC)	3.4.3*	Control plan	1	
13	Composition of BCSA or CSAC	3.4.4*	Control plan	1	
14	Density	3.4.5	Control plan	1	
15	Fineness (Blaine)	3.4.6	Control plan	1	

* Other methods than the one indicated may be used provided they give results correlated and equivalent to those obtained with the reference method

1) In case BCSAC or CSAC is continuously dispatched. In case BCSA or CSAC is not continuously dispatched, minimum frequency of sampling is reasonably adapted.

3.4 Special methods of control and testing used for the assessment and verification of constancy of performance

3.4.1 Control of raw materials by manufacturer

The raw materials for the production of BCSAC or CSAC shall be subject to control by the manufacturer before acceptance. Check of raw materials shall include control of the inspection documents presented by the suppliers of the initial materials (comparison of the trade name, producer and internal requirements on the product characteristics).

3.4.2 Calcium Sulfoaluminate (Yeelimite) content in the cement

The calcium sulfoaluminate content in the cement, expressed as Yeelimite or $C_4A_3\bar{S}$, shall be determined from calcium sulfoaluminate content in the BCSAK or CSAK with XRD-analysis with Rietveld refinement.

The Yeelemite content in the BCSAK or CSAK shall be determined by quantitative X-ray diffraction analysis. The chemical composition of the cement raw materials (BCSAK or CSAK, if necessary further main cement constituents, calcium sulfate) and of the BCSAC or CSAC shall be determined in accordance with EN 196-2. On the basis of the previously determined chemical composition of the cement raw materials and the BCSAC, the BCSAK content or the CSAC, the CSAK shall be determined by regression calculation. The Yeelimite content of the BCSAC/CSAC shall be calculated from the BCSAK/CSAK content of the BCSAC/CSAC and the Yeelimite content of the BCSAK/CSAK.

3.4.3 Belite content in the cement

The Belite content (C_2S) in the cement shall be determined from Belite content in the BCSAK with XRD-analysis with Rietveld refinement, see clause 3.4.1.

3.4.4 Composition of BCSAC or CSAC

The composition of the BCSAC or CSAC shall be determined by an appropriate test method, see EN 197-1, clause 9, table 6, footnote i.

The composition of the main constituents of the BCSAC shall be in the following range:

BCSAK	50 - 98	[% by mass]
CEM I or CEM II	0 - 25	[% by mass]
L or LL	0 - 25	[% by mass]
V or W	0 - 20	[% by mass]
$CaSO_4$ ($C\bar{S}$)	0 - 20	[% by mass]

The composition of the main constituents of CSAC shall be in the following range:

CSAK	20 - 90	[% by mass]
CEM I or CEM II	0 - 80	[% by mass]
RSC	0 - 50	[% by mass]
$CaSO_4$ ($C\bar{S}$)	0 - 30	[% by mass]
L or LL	0 - 30	[% by mass]

3.4.5 Density

The density of the BCSAC or CSAC shall be determined according to EN 1097-7.

3.4.6 Fineness (Blaine)

The fineness of the BCSAC or CSAC shall be determined according to EN 196-6.

4 REFERENCE DOCUMENTS

EN 196-1:2016	Methods of testing cement – Part 1: Determination of strength
EN 196-2:2013	Methods of testing cement – Part 2: Chemical analysis of cement
EN 196-3:2016	Methods of testing cement – Part 3: Determination of setting times and soundness
EN 196-6:2018	Methods of testing cement– Part 6: Determination of fineness
EN 197-1:2011	Cement - Part 1: Composition, specifications and conformity criteria for common cements
EN 197-2:2020	Cement - Part 2: Assessment and verification of constancy of performance
EN 206:2013+A2:2021	Concrete - Specification, performance, production and conformity
EN 480-11:2005	Admixtures for concrete, mortar and grout - Test methods - Part 11: Determination of air void characteristics in hardened concrete
EN ISO 7887:2011	Water quality - Examination and determination of colour
EN ISO 7027-1:2016	Water quality – Determination of turbidity – Part 1: Quantitative methods
EN 1097-7:2022	Tests for mechanical and physical properties of aggregates – Part 7: Determination of the particle density of filler - Pyknometer method
EN 12390-2:2019	Testing hardened concrete - Part 2: Making and curing specimens for strength tests
EN 12390-3:2019	Testing hardened concrete - Part 3: Compressive strength of test specimens
CEN/TS 12390-9:2016	Testing hardened concrete - Part 9: Freeze-thaw resistance with de-icing salts -, Scaling
EN 12390-10:2018	Testing hardened concrete - Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide
EN 12390-11:2015	Testing hardened concrete – Part 11: Determination of the chloride resistance of concrete, unidirectional diffusion
EN 12390-16:2019	Testing hardened concrete – Part 16: Determination of the shrinkage of concrete
EN 12390-18:2021	Testing hardened concrete - Part 18: Determination of the chloride migration coefficient
EN 12617-4:2002	Products and systems for the protection and repair of concrete structures - Test methods - Part 4: Determination of shrinkage and expansion
EN 12620:2002+A1:2008	Aggregates for concrete
EN 13813:2002	Screed material and floor screeds - Screed materials - Properties and requirements
EN 14146:2004-06	Natural stone test methods - Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency)
CEN/TR 15177:2006	Testing the freeze-thaw resistance of concrete - Internal structural damage
CEN/TR 16563:2013	Principles of the equivalent durability procedure
EN 16637-2:2023	Construction products – Assessment of release of dangerous substances – Part 2: Horizontal dynamic surface leaching test
EN 17195:2023	Construction products – Assessment of release of dangerous substances – Analysis of inorganic substances in eluates

EN 17332:2023	Construction products – Assessment of release of dangerous substances – Analysis of organic substances in eluates
EAD 150001-00-0301	Calcium sulphoaluminate based cement
EAD 150004-00-0301	Rapid hardening sulfate resistant calcium sulphoaluminate based cement
EAD 150008-00-0301	Rapid setting cement

ANNEX A: TESTING THE SULFATE RESISTANCE (EXTERNAL SULFATE ATTACK) - FLAT PRISM METHOD S_{FPM}

A.1 General description of the test method

The sulfate resistance shall be determined by the flat prism method (S_{FPM}) on mortar specimens aged up to 26 weeks in a Na_2SO_4-solution (NS), and in a saturated calcium hydroxide ($CaOH_2$)-solution (CH) at a storage temperature (T) of (5 ± 2) °C (T_5) and (20 ± 2) °C (T_{20}).

The length and the mass as well as the longitudinal resonance frequency for the determination of the dynamic modulus of elasticity of the specimens shall be determined at regular intervals (0, 14, 28, 56, 91 and 182 days).

With the measured length of the specimens after a storage time t_i, the length difference of the flat prisms for each storage solution (NS and CH) and storage temperature (T_5 and T_{20}) shall be calculated as mean value from 3 specimens ($\Delta l_{NS,(ti,T)}$ and $\Delta l_{CH,(ti,T)}$).

The difference in elongation between the sulfate storage($\Delta l_{NS,(ti,T)}$) and the reference storage ($\Delta l_{CH,(ti,T}$) for a storage time (t_i) and a storage temperature (T_5 and T_{20}) shall be given as expansion of the length ($\Delta l_{ti,T}$).

In addition, the mass of the specimens ($w_{NS,(ti,T)}$ and $w_{CH,(ti,T)}$) and the dynamic modulus of elasticity ($E_{d,NS,(ti,T)}$ and $E_{d,CH,(ti,T)}$) shall be determined at a storage time t_i for each storage solution (NS and CH) and storage temperature (T_5 and T_{20}).

Two further cements according to EN 197-1 (two different sulfate resisting common cements – SR-Cements) shall be included in the testing as reference cements. The results of the reference cements shall also be stated in the ETA.

A.2 Cements

The sulfate resistance shall be tested on specimens made of mortar according to EN 196-1 with BCSA or CSAC and with at least two different SR-cements according to EN 197-1.

A.3 Making of test specimens

Mortar shall be made from each cement (BCSA or CSAC and the two different cements according to EN 197-1 as reference cements) according to EN 196-1, clause 6, with a water/cement-ratio of 0,50.

Due to the very early setting time the addition of a retarding admixture makes the preparation of the specimens easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

From each mortar 24 flat prisms with the dimensions 10 mm x 40 mm x 160 mm (12 with and 12 without measuring pin) shall be made according to EN 196-1 and be compacted on the vibrating table.

A.4 Storage of test specimens

The specimens shall be stored for (48 ± 2) hours in the mould, protected from drying at a temperature of (20 ± 2) °C and a relative air humidity of ≥ 95 %.

After demoulding, identify and indelibly mark each flat prism, including an arrow pointing towards the "top" of each prism for the purpose of using a consistent orientation for the measurements. Then examine the flat prisms and record any defects.

After demoulding the flat prisms shall be pre-stored until the age of 14 days, on edge, standing on gratings in saturated calcium hydroxide ($Ca(OH)_2$)-solution at (20 ± 2)°C.

After pre-storage:

For the <u>sulfate storage (NS)</u>, 3 flat prisms with measuring pin and 3 flat prisms without measuring pin shall be stored on edge, standing on gratings in the 4,4 % Na_2SO_4-solution at (5 ± 2) °C (= sulfate storage 5 °C = NS,T_5) and at (20 ± 2) °C (= sulfate storage 20 °C = NS,T_{20}).

For the <u>reference storage (CH)</u>, 3 flat prisms with measuring pin and 3 flat prisms without measuring pin shall be stored standing on edge, standing on gratings in a saturated $Ca(OH)_2$-solution at (5 ± 2) °C (= reference storage 5 °C = CH,T_5) and at (20 ± 2) °C (= reference storage 20 °C = CH,T_{20}).

In all storages the ratio of volumes of solution/solid matter shall be 4:1.

During storage of the test specimens the containers shall be air-tight sealed.

The Na_2SO_4 solution shall be replaced every 14 days with a new Na_2SO_4 solution, temperature-controlled at (5 ± 2) °C respectively (20 ± 2) °C.

The saturated $Ca(OH)_2$-solution shall be checked every 14 days for its saturation. If needed, it has to be concentrated.

A.5 Initial measurement procedure

After pre-storage, the test specimens shall be dried with a damp cloth after removal from the test solution at a room temperature of (20 ± 2) °C and a relative air humidity of 65 %.

Immediately afterwards the initial measurements shall be carried out to prevent the samples from drying out.

The flat prisms shall be weighed with a balance to an accuracy of 0,01 g (w_0).

The length of the flat prisms (with measuring pins) (l_0) shall be measured on a dial gauge with an accuracy of 0,001 mm.

The dynamic modulus of elasticity of the flat prisms (without measuring pins) ($E_{d,0}$) shall be calculated from measurements of the longitudinal resonance frequency ($F_{L,0}$) in accordance with EN 14146, clause 8.2.

Photographs of the flat prisms shall be taken to document their external appearance, e.g., crack formation or spalling.

A.6 Further measurement procedure

After 14, 28, 56, 91 and 182[7] days of storage (t_i) in the respective test solutions (NS and CH) and storage temperature (T = 5 and 20), the test specimens shall be removed from the containers to determine the specimen length ($l_{NS,(ti,T)}$ and $l_{CH,(ti,T)}$), the mass ($w_{ti,T}$) and the longitudinal resonance frequency ($F_{L,NS(ti,T)}$ and $F_{L,CH(ti,T)}$) for the determination of the dynamic modulus of elasticity ($E_{d,NS(ti,T)}$ and $E_{d,CH(ti,T)}$).

For the tests, the test specimens shall be dried with a damp cloth after removal from the test solution at a room temperature of (20 ± 2) °C and a relative air humidity of 65 %.

Immediately afterwards the measurements shall be carried out to prevent the samples from drying out.

The flat prisms shall be weighed with a balance to an accuracy of 0,01 g ($w_{NS,(ti,T)}$ and $w_{CH,(ti,T)}$).

The length of the flat prisms (with measuring pins) ($l_{NS,(ti,T)}$ and $l_{CH,(ti,T)}$) shall be measured on a dial gauge with an accuracy of 0,001 mm.

The longitudinal resonance frequency of the flat prims ($F_{L,NS(ti,T)}$ and $F_{L,CH(ti,T)}$) shall be determined following EN 14146 to calculate the dynamic modulus of elasticity ($E_{d,NS(ti.T)}$ and $E_{d,CH(ti.T)}$).

In additions the external appearance of the flat prisms, e.g., crack formation or spalling shall be documented with a description and photos.

A.7 Analysis

The length difference of the flat prisms (with measuring pins) shall be calculated as mean value from 3 specimens for each storage time (t), storage solution (NS or CH) and storage temperature (T = 5 and 20) ($\Delta l_{NS(ti,T)}$ and $\Delta l_{CH(ti,T)}$) by the following formula:

$\Delta l_{NS(ti,T)} = (l_{NS(ti,T)} - l_0) \times 100/160$ [mm/m]

$\Delta l_{CH(ti,T)}) = (l_{CH(ti,T)} - l_0) \times 100/160$ [mm/m]

with:

l_0 = length of the flat prisms after pre-storage (t = 0) [mm]

$l_{NS(ti,T)}$ = length of the flat prisms at storage time (t_i) [mm] in Na_2SO_4-solution at a storage temperature of 5 °C and 20 °C (T)

$l_{CH(t,T)}$ = length of the flat prisms at storage time (t_i) [mm] in $Ca(OH)_2$-solution at a storage temperature of 5 °C and 20 °C (T)

t_i = storage time 14, 28, 56, 91 and 182[7] days

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7 Only for the storage temperature of 20 °C the tests are continued for another 91 days.

The expansion of length ($\Delta l_{ti,T}$) between the sulfate storage($\Delta l_{NS(ti,T)}$) and the reference storage ($\Delta l_{CH(ti,T)}$) for each storage time shall be calculated by the following formula:

$$\Delta l_{ti,T} = \Delta l_{NS(ti,T)} - \Delta l_{CH(ti,T)}$$

ANNEX B: TESTING THE SULFATE RESISTANCE (EXTERNAL SULFATE ATTACK) – SQUARE PRISM METHOD SR_{SPM}[8]

B.1 Apparatus and solution

B.1.1 Containers

Containers for storage of distilled water and sulfate solution shall have a capacity of 1,5 and 2,5 litres and measure at least 180 mm x 80 mm. Each container shall be capable of containing 1,0 ± 0,1 litres of liquid, so that the depth of the liquid reaches at least 25 mm. All the containers shall be fitted with light-proof lids and shall be manufactured in a material that does not react with its content.

It is allowed to put specimens of different cement types in a single container provided that the chemical composition of the cement is equivalent. In this case 1,0 ± 0,1 litres of liquid shall be used per three specimens.

B.1.2 Sulfate Solution

The sulfate solution shall have a concentration of 16 ± 0,5 g SO_4 per litre, and shall be prepared by adding Na_2SO_4 or $Na_2SO_4 \cdot 10\ H_2O$ of analytical purity to distilled water, or to water of the same purity.

B.2 Cements

The sulfate resistance shall be tested on specimens made of mortar according to EN 196-1 with BCSA or CSAC and with at least two different SR-cements according to EN 197-1.

B.3 Making of test specimens

The mortar shall be prepared in accordance with clause 6 of EN 196-1 standard using EN standard sand, distilled water or water of equal purity. 6 prisms from each mortar with the dimensions 20 mm x 20 mm x 160 mm with two stainless steel studs shall be made and demoulded in accordance with clauses 7 and 8 of EN 196-1.

Due to the very early setting time the addition of a retarding admixture makes the preparation of the specimens easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

B.4 Conditioning

The specimens shall be stored according to clause 8.3 of EN 196-1. Immediately after demoulding the specimens shall be placed in 2 containers (2 x 3 specimens). Each container shall be filled with 1 litre of distilled water.

The specimens shall be placed along each other with at least 5 mm space between them, at least 5 mm water above and at least 5 mm distance from the sides of the containers. The specimens must be placed on supports at least 2 mm clear from the bottom of the containers, so that the maximum contact between the specimens and the supporting surface is 200 mm^2.

The specimens shall be always remaining wet and never dry out during removal from the mould and labelling.

B.5 Testing procedure

At the age of 28 days the length of each specimen shall be measured. Before carrying out the measurements, the measuring apparatus must be calibrated using the reference bar. Not the result or adjust the measuring apparatus to the standard value. Remove one specimen at a time and clean the measuring points with a damp cloth. Note the measured value L(0).

After measuring each specimen, replace immediately 3 bars in the container with distilled water (set 1) while the 3 others are put into a new container containing 1 litre of sulfate solution (set 2) for the next storage period.

All the containers shall be stored with a sealed lid at (20 ± 2) °C.

The distilled water shall not be changed during the whole storage period but fill up the water level with additional water if necessary.

The sulfate solution shall be replaced every 28 days.

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8 This test method is identical to CUR 48 – 2010
Civiltechnisch Centrum Uitvoering Research en Regelgeving (Centre for Civil Engineering Research and Codes) - Recommendation 48 – Assessment of the suitability of new cements for use in concrete and of the equivalent performance of concrete with additions. Procedure, criteria and test methods

B.6 Test

Measure the length of the prisms L(t) in the same way after 4, 8, 12, 16, 20, 26, 29, 40 and 52 weeks in the container.

Photos of the specimens will be taken after every testing to illustrate the formations of the cracks. Record any visible degradation of the specimens

B.7 Analysis

For each storage period (t), measure the changes in the length of each specimen in relation to the length L(0), as a percentage of the standard length of 160 mm, round to an accuracy of 0,005 %. The percentage expansion of the prisms is to be calculated as mean value for the three specimens stored in distilled water and for the three specimens stored in the sulfate storage. The difference between the average of the three specimens stored in distilled water and the three specimens stored in the sulfate solution is recorded for each storage period.

ANNEX C: DELAYED ETTRINGIT FORMATION WITH THE REDUCED FLAT PRISM METHOD

C.1 General description of the test method

If the BCSAC or CSAC is to be used in combination with Portland cement CEM I according to EN 197-1 for the production of concrete, the delayed ettringite formation shall be determined by using the "reduced flat prism method" on mortar samples that have been stored in demineralized water for up to 26 weeks in order to check that there is no harmful delayed ettringite formation.

The internal damage shall be determined on mortar specimens stored for 180 days in demineralised water with the reduced flat prism method.

C.2 Cements

The delayed ettringite formation shall be tested on specimens made of mortar according to EN 196-1 with BCSA or CSAC and a mixture of BCSAC or CSAC with Portland Cement (CEM I) according to EN 197-1 with varied calcium aluminate content, e.g., CEM I-SR3 with C_3A-content < 3 % by mass (C1) and CEM I with C_3A-content > 9 % by mass (C2) and .

C.3 Making of test specimens

For the tests 4 mortars with a water/cement-ratio of 0,50 according to EN 196-1, clause 6, shall be made:

M1: 100 % BCSAC or CSAC

M2: x % BCSAC or CSAC and y % C1

M3: x % BCSAC or CSAC and y % C2

M4: 100 % C1

The composition of the mixture (ratio of BCSA (x) to CEM I (y) or CSAC (x) to CEM I (y)) depends on the maximum amount of CEM I in the mixture given by the manufacturer.

Due to the very early setting time the addition of a retarding admixture makes the preparation of the specimens with CSAC or CSAC easier. If a retarding admixture is used, the nature and the dosage of the retarding admixture shall be given in the ETA.

From each mortar 12 flat prisms with the dimensions 10 mm x 40 mm x 160 mm (6 with and 6 without measuring pin) shall be made according to EN 196-1, clause 6, and be compacted on the vibrating table.

C.4 Storage of test specimens

The specimens shall be stored for (48 ± 2) hours in the mould, protected from drying at a temperature of (20 ± 2) °C and a relative air humidity of ≥ 95 %.

After demoulding, identify and indelibly mark each flat prism, including an arrow pointing towards the "top" of each prism for the purpose of using a consistent orientation for the measurements. Then examine the flat prisms and record any defects.

After demoulding the flat prisms shall be stored for 180 days, on edge, standing on gratings in demineralised water at (5 ± 2) °C (3 prisms without pins and 3 prisms with pins) and at (20 ± 2) °C (3 prisms without pins and 3 prisms with pins).

The ratio of volumes of solution/solid matter shall be 4:1.

During storage of the test specimens the containers shall be air-tight sealed.

C.5 Initial measurement procedure

After demoulding, the test specimens shall be dried with a damp cloth after removal from the test solution at a room temperature of (20 ± 2) °C and a relative air humidity of 65 %.

Immediately afterwards the initial measurements shall be carried out to prevent the samples from drying out.

The flat prisms shall be weighed with a balance to an accuracy of 0,01 g (w_0).

The length of the flat prisms (with measuring pins) (l_0) shall be measured on a dial gauge with an accuracy of 0,001 mm.

The dynamic modulus of elasticity of the flat prisms (without measuring pins) ($E_{d,0}$) will be calculated from measurements of the longitudinal resonance frequency ($F_{L,0}$) in accordance with EN 14146, clause 8.2.

Photographs of the flat prisms shall be taken to document their external appearance, e.g., crack formation or spalling.

C.6 Further measurement procedure

At a storage duration of 14, 28, 56, 91 and 180 days (t_i) in demineralised water at a storage temperature (T = 5 and 20), the test specimens shall be removed from the containers to determine the specimen length ($l_{w,ti,T}$), the mass ($w_{w,ti,T}$) and the longitudinal resonance frequency ($F_{L,w\ (ti,T)}$) for the determination of the dynamic modulus of elasticity ($E_{d,w\ (ti,T)}$).

For the tests, the test specimens shall be dried with a damp cloth after removal from the test solution at a room temperature of (20 ± 2) °C and a relative air humidity of 65 %.

Immediately afterwards the measurements shall be carried out to prevent the samples from drying out.

The flat prisms shall be weighed with a balance to an accuracy of 0,01 g ($w_{w,ti,T}$).

The length of the flat prisms (with measuring pins) ($l_{w,ti,T}$) shall be measured on a dial gauge with an accuracy of 0,001 mm.

The longitudinal resonance frequency of the flat prims ($F_{L,w\ (ti,T)}$) shall be determined following EN 14146 to calculate the dynamic modulus of elasticity ($E_{d,w\ (ti.T)}$).

In additions the external appearance of the flat prisms, e.g., crack formation or spalling shall be documented with a description and photos.

C.7 Analysis

The length different of the flat prisms (with measuring pins) shall be calculated as mean value from 3 specimens for each storage duration ($t_{w,i}$) and storage temperature (T = 5 and 20) ($l_{w,ti,5}$ and $l_{w,ti,20}$) by the following formula:

$\Delta L_{w,(ti,T)} = (l_{w,(ti,T)} - l_0) \times 100/160$ [mm/m]

with:

l_0 = length of the flat prisms after demoulding (t = 0) [mm]

$l_{w,(ti,T)}$ = length of the flat prisms at storage time (t_i) [mm] in demineralised water at a storage temperature of 5 °C and 20 °C (T)

t_i = storage time 14, 28, 56, 91 and 180 days

ANNEX D: EVALUATION OF THE CARBONATION RESISTANCE - C_{DCR}

The carbonation depth and the carbonation speed of concrete with BCSAC or CSAC are compared to a database (Annex B of CEN/TR 16563). The basis for the four diagrams is formed by the data of various standard cements compiled in the two tables. The determined values from the carbonation test are entered in the diagrams. The position of the new data points can be used to assess whether the binder is inside or far outside the data cloud for common cements.

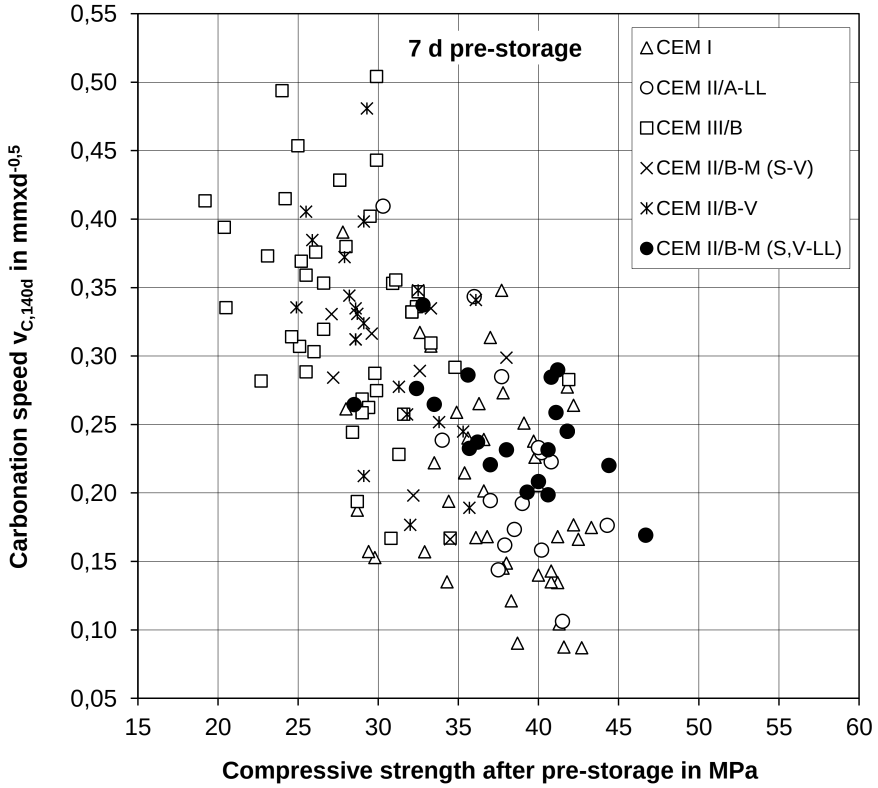
The following Tables and Figures result from cement testing for the verification of the carbonation behaviour of different cements (CEM I, CEM II/A-LL, CEM III/B, CEM II/B-M (S-V), CEM II/B V, CEM II/B-M (SV-LL)) and are given as database.

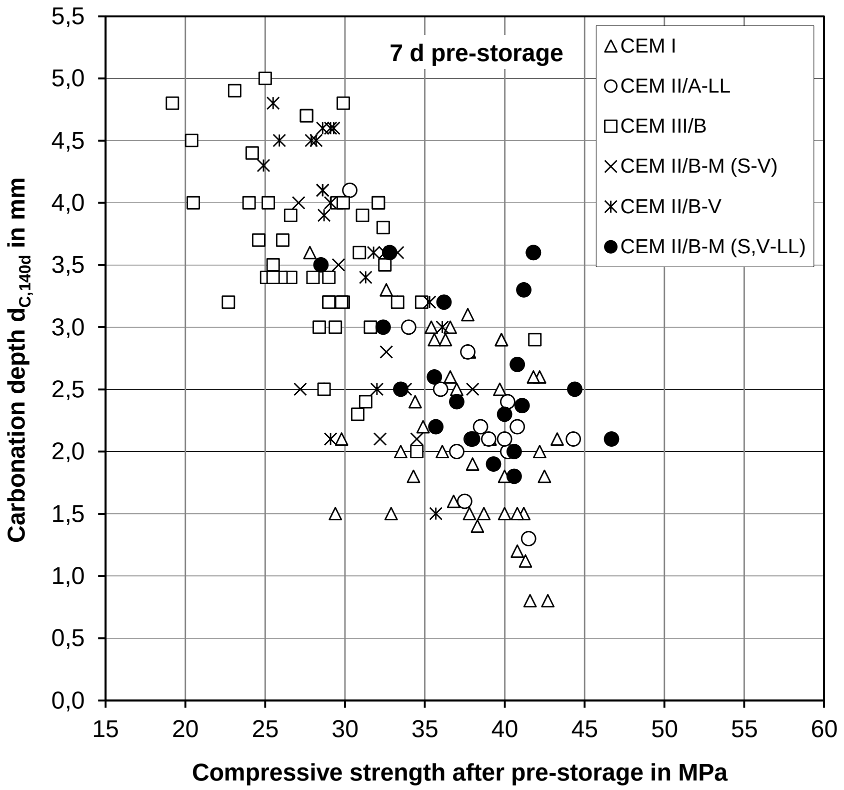
Carbonation test on concrete (w/c = 0,50) - **7** days pre-storage

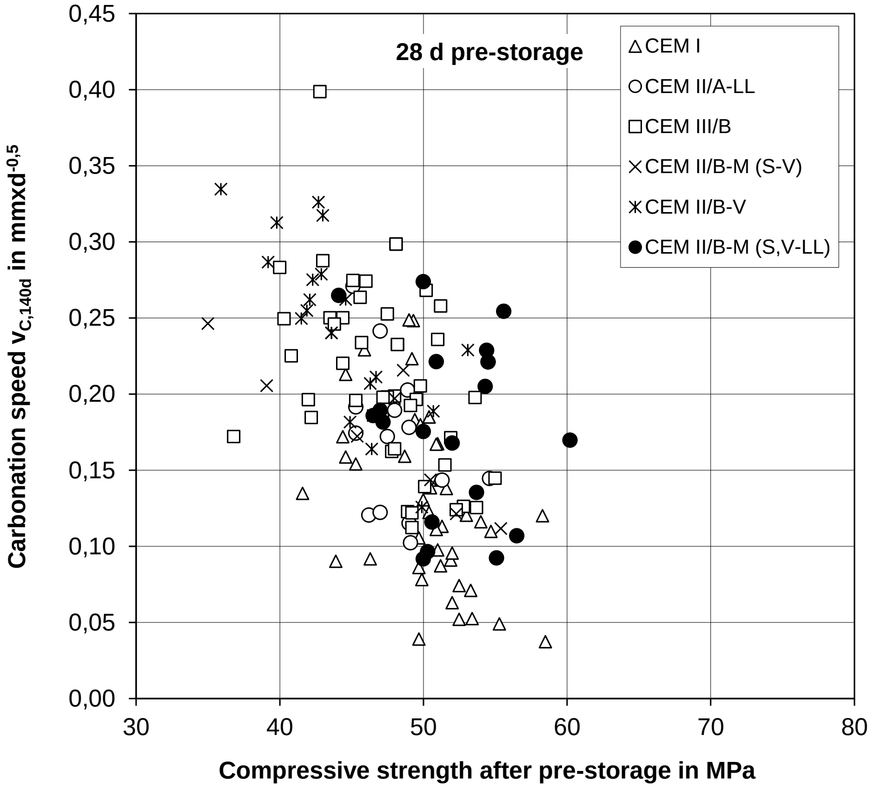
		f_C in MPa			Carbonation depth in mm								$F_{C,P}^{-0,5}$ in $N^{-0,5}$ x mm	Carbo. speed in mm / $d^{0,5}$	
		Pre-st. 7 d	35 d	140 d main-st.	14 d	28 d	56 d	98 d	140 d	1 a	2 a	5 a		$v_{C,140d}$	$v_{C,5a}$
CEM II/B-M (S, V-LL)															
	min	28,5	51,2	50,8	0,2	0,4	1,0	1,5	1,8	3,1	3,7	6,8	0,146	0,169	0,147
	max	46,7	66,2	71,0	1,6	1,8	2,7	3,2	3,6	4,7	6,0	10,1	0,187	0,337	0,243
	AVG	38,1	56,6	60,2	0,7	1,0	1,6	2,1	2,7	4,0	5,2	8,6	0,163	0,246	0,203
	s	4,3	4,0	6,0	0,5	0,5	0,5	0,5	0,6	0,6	1,3	1,1	0,010	0,039	0,032
CEM II/A-LL (C 80 %; LL 20 %)															
	min	30,3	36,1	31,6	0,0	0,2	0,6	1,0	1,3	2,3	4,2	7,0	0,150	0,106	0,173
	max	44,3	64,3	63,7	1,0	1,7	2,6	3,5	4,1	6,0	7,8	12,9	0,182	0,409	0,290
	AVG	38,3	54,0	55,0	0,5	0,9	1,5	2,0	2,3	3,8	5,8	9,0	0,162	0,218	0,217
	s	3,3	6,2	7,4	0,3	0,4	0,5	0,6	0,6	1,0	1,0	1,5	0,007	0,079	0,031
CEM II/B-M (S-V) (C 65 %; S 15 %; V 20 %)															
	min	27,1	45,6	45,8	0,0	0,2	1,0	1,4	2,1	3,7	4,9	7,2	0,162	0,166	0,178
	max	38,0	58,8	64,7	1,3	1,8	2,7	3,2	4,0	6,5	8,3	14,3	0,192	0,335	0,327
	AVG	31,8	50,9	55,3	0,6	1,1	1,8	2,3	2,9	4,7	6,3	9,5	0,178	0,277	0,226
	s	3,7	4,7	6,0	0,4	0,5	0,6	0,6	0,7	1,1	1,4	2,3	0,010	0,062	0,049
CEM II/B-V (C 70 %; V 30 %)															
	min	24,9	40,7	43,3	0,0	0,1	0,5	1,0	1,5	3,5	5,3	8,0	0,166	0,177	0,179
	max	36,1	60,9	64,5	1,7	2,4	3,2	4,5	4,8	8,6	9,6	14,3	0,200	0,481	0,318
	AVG	30,1	48,4	51,9	1,1	1,7	2,5	3,1	3,7	5,4	7,2	10,6	0,183	0,316	0,240
	s	3,2	5,0	5,5	0,5	0,6	0,7	0,8	0,9	1,3	1,3	1,7	0,010	0,075	0,036
CEM III/B															
	min	19,2	35,3	36,6	0,1	0,9	1,5	1,5	2,0	3,1	5,5	7,5	0,154	0,167	0,178
	max	41,9	62,0	67,6	1,8	2,6	3,5	4,2	5,0	8,0	10,5	17,1	0,228	0,504	0,394
	AVG	28,3	49,1	52,4	0,9	1,5	2,3	3,0	3,6	5,5	7,6	11,5	0,190	0,330	0,269
		4,3	5,3	5,8	0,4	0,4	0,5	0,7	0,7	1,1	1,4	2,4	0,015	0,079	0,055
CEM I															
	min	27,8	45,5	46,6	0,0	0,1	0,1	0,3	0,8	2,0	3,2	5,0	0,152	0,087	0,121
	max	43,3	63,0	64,0	1,4	1,8	2,2	3,2	3,6	6,2	7,8	9,9	0,190	0,391	0,247
	AVG	37,2	56,1	58,1	0,5	0,8	1,3	1,7	2,2	3,4	4,7	6,9	0,165	0,202	0,164
	s	4,2	3,7	3,9	0,3	0,4	0,5	0,7	0,7	0,9	1,0	1,4	0,010	0,072	0,030

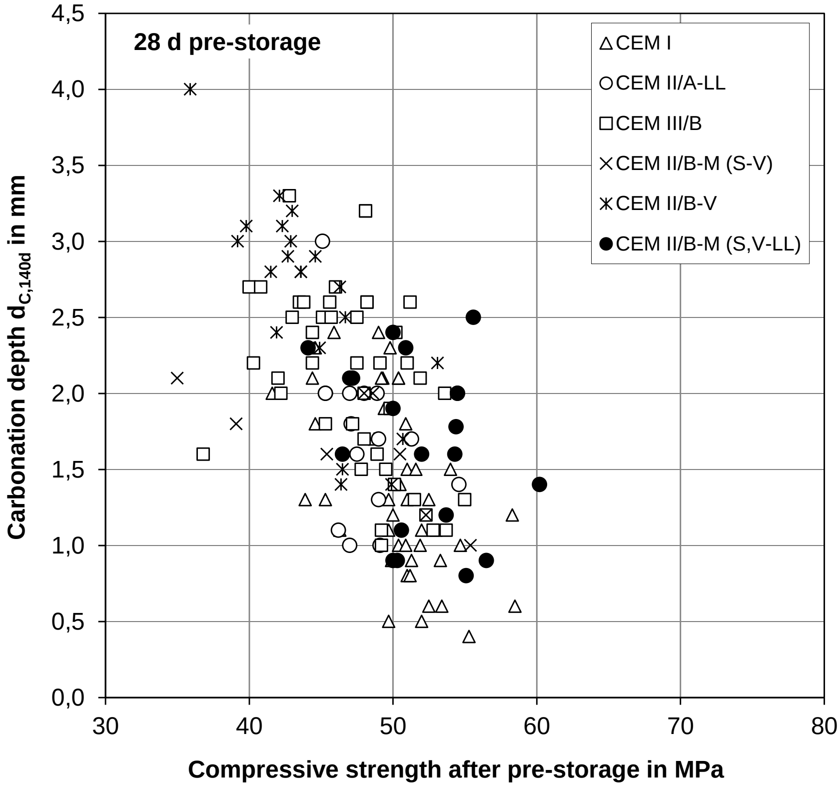
Carbonation test on concrete (w/c = 0,50) - **28** days pre-storage

		f_C in MPa			Carbonation depth in mm								$F_{C,P}^{-0,5}$ in $N^{-0,5}$ x mm	Carbo. speed in mm / $d^{0,5}$	
		Pre-st. 28 d	35 d	140 d main-st.	14 d	28 d	56 d	98 d	140 d	1 a	2 a	5 a		$v_{C,140d}$	$v_{C,5a}$
CEM II/B-M (S, V-LL)															
	min	44,1	50,6	61,2	0,0	0,2	0,3	0,5	0,8	1,8	4,0	4,9	0,129	0,092	0,130
	max	60,2	67,6	76,4	0,7	1,0	1,5	2,2	2,5	3,6	5,1	9,9	0,151	0,274	0,247
	AVG	51,7	58,9	67,2	0,3	0,5	0,9	1,4	1,7	2,5	4,4	7,6	0,139	0,182	0,187
	s	4,0	27,0	30,6	0,2	0,3	0,4	0,5	0,6	0,6	0,6	1,4	0,005	0,062	0,031
CEM II/A-LL (C 80 %; LL 20 %)															
	min	45,1	52,5	60,0	0,0	0,0	0,0	0,4	1,0	2,0	3,0	6,0	0,135	0,102	0,157
	max	54,6	67,8	67,3	0,8	1,2	1,5	2,4	3,0	4,2	6,1	9,6	0,149	0,271	0,221
	AVG	48,0	58,2	62,9	0,3	0,6	0,9	1,3	1,7	3,2	4,7	7,7	0,144	0,170	0,192
	s	2,5	3,7	2,4	0,2	0,3	0,4	0,5	0,5	0,6	0,7	0,9	0,004	0,047	0,017
CEM II/B-M (S-V) (C 65 %; S 15 %; V 20 %)															
	min	35,0	48,3	59,8	0,0	0,0	0,1	0,3	1,0	2,0	2,5	4,4	0,134	0,112	0,109
	max	55,4	65,3	73,1	0,4	0,7	1,4	1,8	2,1	3,3	4,5	8,6	0,169	0,246	0,204
	AVG	46,8	58,7	65,8	0,2	0,5	0,9	1,3	1,7	2,7	3,6	6,4	0,147	0,177	0,154
	s	6,8	5,5	4,2	0,2	0,2	0,4	0,5	0,4	0,5	0,7	1,4	0,012	0,048	0,032
CEM II/B-V (C 70 %; V 30 %)															
	min	35,9	45,6	53,2	0,0	0,1	0,5	0,7	1,4	2,4	3,7	5,9	0,137	0,126	0,144
	max	53,1	62,5	69,9	1,1	1,9	2,4	3,1	4,0	5,2	6,9	11,3	0,167	0,335	0,253
	AVG	44,2	55,4	61,0	0,6	1,0	1,6	2,2	2,6	4,0	5,5	8,3	0,151	0,244	0,195
	s	4,0	4,4	4,6	0,3	0,5	0,5	0,6	0,7	0,8	0,9	1,4	0,007	0,056	0,028
CEM III/B															
	min	36,8	43,6	56,9	0,0	0,0	0,0	0,5	1,0	2,0	2,9	5,0	0,135	0,112	0,122
	max	55,0	63,6	73,0	0,8	1,3	1,9	3,0	3,3	5,4	7,8	11,5	0,165	0,399	0,279
	AVG	47,3	55,2	64,7	0,4	0,7	1,2	1,7	2,1	3,4	5,1	7,9	0,146	0,212	0,193
	s	4,1	4,6	4,2	0,2	0,3	0,4	0,5	0,6	0,9	1,1	1,6	0,007	0,061	0,038
CEM I															
	min	41,6	51,9	59,2	0,0	0,0	0,0	0,2	0,4	1,0	2,2	3,6	0,131	0,037	0,090
	max	58,5	71,3	72,6	1,0	1,1	1,6	2,2	2,4	3,5	4,7	7,8	0,155	0,249	0,177
	AVG	50,3	60,3	66,0	0,3	0,5	0,8	1,1	1,4	2,3	3,3	5,2	0,141	0,128	0,126
	s	3,5	4,1	3,3	0,2	0,3	0,4	0,5	0,6	0,7	0,8	1,0	0,005	0,056	0,022


7 d pre-storage
CEM I
CEM II/A-LL
CEM III/B
CEM II/B-M (S-V)
CEM II/B-V
CEM II/B-M (S,V-LL)
Carbonation speed $v_{C,140d}$ in $mmxd^{-0,5}$
0,55
0,50
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
15
20
25
30
35
40
45
50
55
60
Compressive strength after pre-storage in MPa


7 d pre-storage
CEM I
CEM II/A-LL
CEM III/B
CEM II/B-M (S-V)
CEM II/B-V
CEM II/B-M (S,V-LL)
Carbonation depth $d_{C,140d}$ in mm
5,5
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
15
20
25
30
35
40
45
50
55
60
Compressive strength after pre-storage in MPa


28 d pre-storage
CEM I
CEM II/A-LL
CEM III/B
CEM II/B-M (S-V)
CEM II/B-V
CEM II/B-M (S,V-LL)
Carbonation speed $v_{C,140d}$ in mmxd$^{-0,5}$
Compressive strength after pre-storage in MPa
0,00
0,05
0,10
0,15
0,20
0,25
0,30
0,35
0,40
0,45
30
40
50
60
70
80


28 d pre-storage
CEM I
CEM II/A-LL
CEM III/B
CEM II/B-M (S-V)
CEM II/B-V
CEM II/B-M (S,V-LL)
Carbonation depth $d_{C,140d}$ in mm
Compressive strength after pre-storage in MPa
0,0
0,5
1,0
1,5
2,0
2,5
3,0
3,5
4,0
4,5
30
40
50
60
70
80