EUROPEAN ASSESSMENT DOCUMENT

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CALCIUM SULPHOALUMINATE BASED CEMENT

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Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

The calcium sulphoaluminate (CSA) based Cement [1] referred to in this document is a special cement that is not covered by the harmonised European standard EN 197-1.

It is a hydraulic binder with rapid hardening features that contains a calcium sulphoaluminate (Yeelimite) content in the cement of at least 10% by mass.

The range of compositions is listed below (as descripted of EN 197-1 §9.3):

Calcium sulphoaluminate clinker	20 – 90 %
Cement CEM I and II acc. EN 197-1	0 – 80 %
Calcium sulfate (as defined in EN 197-1, clause 5.4)	0 – 30 %
Limestone (as defined in EN 197-1, clause 5.2.6)	0 – 30 %
Minor additional constituents (as defined in EN 197-1, clause 5.3)	< 5 %[2]
Additives as defined in EN 197-1, clause 5.5)	< 2 %[3]
Of which organic additives as defined in EN 197-1, clause 5.5)	< 0,2 %

The calcium sulphoaluminate 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 calcium sulphoaluminate clinker is a hydraulic material which is composed mainly by $C_4A_3\$$ or $C_4(A,F)_3\$$ (Yeelimite). The content of Yeelimite is usually greater than 45% by mass. The remaining consisting of calcium silicates (2CaO SiO_2) and other compounds.
The yeelimite must remain a majority compound in the CSAK-clinker, its content must be ≥ 45%.

Hydraulic hardening of “Calcium sulphoaluminate based cement” is primarily due to Yeelimite, but, when present in the composition, Portland cement also participates in the hardening process.

This cement complies with the specifications of the standard EN 197-1 except the following points presented below.

Table 1: Comparison between cement characteristics and specifications of EN 197-1

Cement properties	Specifications of EN 197-1 standard
This cement contains as constituent a calcium sulphoaluminate (CSA) clinker (20 – 90 %)	EN 197-1 does not authorize the sulphoaluminate clinker
Initial setting time can be < 45 min	Initial setting time ≥ 45 min (§ 7.1.2)
Sulfate (as SO_3) content > 4%	Sulfate (as SO_3) content ≤ 4,0 % (table 4)
Chloride content can be > 0,10% If the chloride content is above 0,10% by mass, the upper limit value shall be declared by the manufacturer.	Chloride content ≤ 0,10 % (§ 7.3)

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.

[1] The "Calcium sulphoaluminate based Cement" will be referred to as "Product".

[2] The residues of CSA-clinker process can be integrated as minor additional constituents

[3] EN 197-1 §5.5 specified: 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 %, is declared on the packaging and/or the delivery note

Relevant manufacturer's stipulations 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.

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

1.2.1 Intended use(s)

The "Product" is a cement for production of concrete, mortar, grouts and other mixes including in particular cast-in-situ and prefabricated structural concrete conforming to EN 206 and the national complements and screed material conforming to EN 13813.

The "Product" is 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 the "Product" for the intended use of 50 years when installed in the works (provided that de "Product" is 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[4].

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

CEM	Portland or Portland composite cements, CEM I or CEM II according to EN 197-1
C$\bar{S}$	Calcium sulphate according to EN 197-1 §5.4
CSA	calcium sulfoaluminate
CSAK	calcium sulfoaluminate clinker
L or **LL**	Limestone according to EN 197-1 §5.2.6

Abbreviations:

CDF	=	Capillary suction of De-icing solution and Freeze thaw test
D	=	days
Dcr	=	direct carbonation resistance
Dnss	=	Non-steady state chloride diffusion coefficient
FT	=	Freeze thaw test without de-icing agent
ftc	=	freeze thaw cycles
FPM	=	flat prism method
FTS	=	Freeze thaw test with de-icing salt
mig	=	chloride penetration by the non-steady-state migration
rcr	=	relative carbonation resistance
RDM	=	relative dynamic modulus of elasticity
SPM	=	square prism method

4 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.

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2 shows how the performance of the “Product” is established in relation to the essential characteristics.

Table 2: Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

Nr	Essential characteristic	Assessment method	Type of expression of product performance *(level, class, description)*
Basic Work Requirement 1: Mechanical resistance and stability			
1	Early strength (1 ≤ t ≤ 24 h)	See 2.2.1	Level [MPa]
2	Standard strength (28 days)	See 2.2.2	class (class ≥ 32,5 MPa acc. to EN 197-1 table 3)
3	Calcium sulphoaluminate (Yeelimite) content in the cement	See 2.2.3	Level [% by mass]
4	Cement composition	See 2.2.4	CSAK Level [% by mass] $C\overline{S}$ Level [% by mass] CEM Level [% by mass] L or LL Level [% by mass] acc. to EN 197-1
5	Initial setting time	See 2.2.5	Level [min]
6	Soundness	See 2.2.6	≤ 10 mm (acc. to EN 197-1 table 3)
7	Sulfate content	See 2.2.7	level [% by mass]
8	Chloride content	See 2.2.8	≤ 0,10 % by mass[5] acc. to EN 197-1 table 4
9	Density	See 2.2.9	level [g/cm³]
10	Fineness (Blaine)	See 2.2.10	level [cm²/g]
11	Effect of high temperature on mortar hardened under standard conditions	See 2.2.11	description (graph)
12	Shrinkage	See 2.2.12	**Method Shr_M:** level **Method Shr_c:** level
13	Effect of high temperature on mortar at early age	See 2.2.13	description (graph)
14	Sulfate Resistance	See 2.2.14	**Method S_{FPM}:** level **Method S_{SPM} :** level
15	Carbonation of concrete	See 2.2.15	**Method C_{dcr}:** level **Method C_{rcr}:** level
16	Resistance to chloride penetration	See 2.2.16	**Method D_{mig}:** level **Method D_{nss}:** level
17	Freeze-thaw resistance (without de-icing agent)	See 2.2.17	**Method FT_{cube}:** level **Method FT_{CF}:** level **Method FT_{beam}:** level
18	Freeze-thaw and de-icing salt resistance	See 2.2.18	**Method FTS_{CDF}:** level **Method FTS_{slab}:** level
Basic Work Requirement 3: Hygiene, health and environment			
19	Content, emission and/or release of dangerous substances	See 2.2.20	Level or “No performance assessed”

5 *If the chloride content is above 0,10 % by mass, the upper limit value shall be declared by the manufacturer.*

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

2.2.1 Early strength

The early strength of the "Product" shall be determined in accordance with EN 196-1 at t hours ($1 \leq t \leq 24$).

Tests are made on mortars as described in EN 196-1 §6. Due to the very early setting time of some formula, the addition of a retarding admixture makes the preparation of the samples easier. When used, the nature and the dosage of retarding admixture shall be given in the ETA. The limits for carrying out strength tests at early age is to be given in the ETA (x hour ± y min, with y=15 min when x=24 h).

The early strength of the "Product" at t hours ($1 \leq t \leq 24$) is to be stated in the ETA.

2.2.2 Standard strength at 28 days

The standard strength of the "Product" shall be determined in accordance with EN 196-1 at 28 days.

Tests are made on mortars as described in EN 196-1 §6. Due to the very early setting time of some formula, the addition of a retarding admixture makes the preparation of the samples easier. When used, the nature and the dosage of retarding admixture is to be stated in the ETA.

The standard strength of the "Product" at 28 days is to be stated in the ETA. The class is to be at least 32,5 MPa.

2.2.3 Calcium sulphoaluminate content

The calcium sulphoaluminate content in the cement, expressed as Yeelimite, shall be determined from calcium sulphoaluminate content in the Calcium sulphoaluminate clinker with XRD-analysis with Rietveld refinement.

The calcium sulphoaluminate content in the cement, expressed as Yeelimite, is to be stated in the ETA.

2.2.4 Cement composition

The composition of the "Product" shall be determined by an appropriate verification method, see EN 197-1, clause 9, table 6 footnote i.

The composition of the main constituents of the "Product" is to be in the following range:

CSA clinker	20 - 90% by mass
$CaSO_4$ ($C\overline{S}$)	0 - 30% by mass
CEM	0 - 80% by mass
L or LL	0 - 30% by mass

2.2.5 Initial setting time

The initial setting time of the "Product" shall be determined in accordance with EN 196-3.

In some cases, the water cement ratio can be fixed: in this case, the value must be given in the ETA.

The initial setting time of the "Product" is to be stated in the ETA.

2.2.6 Soundness

The soundness of the "Product" shall be determined in accordance with EN 196-3.

In some cases, the water cement ratio can be fixed: in this case, the value must be stated. Due to the very early setting time of some formula, the addition of a retarding admixture makes the preparation of the samples easier. When used, the nature and the dosage of retarding admixture shall be stated in the ETA.

The preparation and disposition are carried on according to EN 196-3.

The soundness of the "Product" is to be not greater than 10 mm acc. to EN 197-1 table 3.

2.2.7 Sulfate content

The sulfate content, expressed as SO_3, of the "Product" shall be determined in accordance with EN 196-2.

The sulfate content, expressed as SO_3, of the "Product" is to be stated in the ETA.

2.2.8 Chloride content

The chloride content by mass acc. to EN 197-1 table 4 shall be determined in accordance with EN 196-2 and the level of the chloride content is to be stated in the ETA.

2.2.9 Density

The density of the "Product" shall be determined according to EN 196-6.

The density of the "Product" is to be stated in the ETA.

2.2.10 Fineness (Blaine)

The fineness of the "Product" shall be determined according to EN 196-6.

The fineness of the "Product" is to be stated in the ETA.

2.2.11 Effect of high temperature on mortar hardened under standard conditions

The effect of high temperature on mortar with "Product" and with Portland cement CEM I according to EN 197-1 as reference preliminary hardened in climate with (20 ± 2)°C and more than 95% relative humidity (climate 20/95) and then subjected to temperatures (40 °C and 60 °C) shall be compared to the effect on the samples stored at ((20 ± 2)°C when tested at the same age.

Preparation of standard mortar bars shall be carried out in accordance with EN 196-1.

The specimens are demoulded after 1 day. After demoulding the specimens are stored in water (+ 20 ± 2 °C) for 27 days.

After 28 days the specimens are stored immersed in water at a temperature of

- (20 ± 2) °C
- (40 ± 2) °C
- (60 ± 2) °C

The compressive strength of each series shall be determined according to EN 196-1 at a specimen age of 28, 35, 56 and 90 days. The results are shown in a diagram.

It is recommended to continue the test after 180 days and 1 years in order to verify the obtained results after 90 days and to improve the knowledge.

The diagram is documented in the ETA.

2.2.12 Shrinkage

Method 1: Shrinkage (mortar method) - Shr_M

The shrinkage of mortar with the "Product" shall be determined according to NF P 15-433, given in Annex A, on specimens with the dimension 40 mm x 40 mm x 160 mm, at a specimen age of 28 days.

Method 2: Shrinkage (concrete method) - Shr_C

The shrinkage of concrete with the "Product" shall be determined according to ISO 1920-8 on specimens with the dimension 75 mm x 75 mm x 280 mm.

The shrinkage shall be tested on concrete I, see table 3.

Table 3: Composition of concrete for the determination of shrinkage

	Composition per m³ fresh concrete
concrete I	c = 320 kg "Product" 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 are stored for (24 ± 2) hours in the mould, protected from drying at (20 ± 2)°C and > 95 % relative humidity.

After demoulding, the concrete prisms are cured in water with (20 ± 2) °C for 7 days. At an age of 7 days starting from moulding, the specimens are removed from water and the surface is wiped dry with a damp cloth. The specimens are to be stored in climate (20 ± 2) °C and (65 ± 5) % relative humidity (climate 20/65).

The weight measurement and the length measurement according to ISO 1920-8 are determined immediately after demoulding and curing moist after 24 hour, 3 and 7 days. After moist curing the weight measurement and the length measurement are determined during dry curing at the age after fabrication of 14, 21, 28, 35, 60, 90, 120 and 180 days.

The shrinkage of mortar Shr_M or Shr_C with "Product" is to be stated in the ETA.

2.2.13 Effect of high temperature on mortar at early age

The effect of high temperature on mortar with "Product" and with Portland cement CEM I preliminary cured for 3 ≤ x ≤ 24 hours in climate 20/95 and then subjected to high temperatures (40 °C and 80 °C) shall be compared to the effect on the samples stored at (20 ± 2)°C when tested at the same age.

Preparation of standard mortar bars shall be carried out in accordance with EN 196-1.

The specimens are demoulded after 3 ≤ x ≤ 24 hours. After demoulding the specimens are stored in water at a temperature of

- (20 ± 2)°C
- (40 ± 2)°C
- (80 ± 2)°C

The compressive strength of each series shall be determined according to EN 196-1 at storage time of x hours (with 3 ≤ x ≤ 24 hours), 24 hours, 2 days and 3 days.

The tolerances of molding out and breaking of test specimens for the early age will be specified in the ETA.

The diagram is documented in the ETA.

2.2.14 Sulfate resistance

Method 1: Sulfate resistance (Flat prism method) - S_{FPM}

The sulfate resistance of the "Product" shall be determined by the test method given in Annex B.

For test method given in Annex B the dynamic modulus of elasticity, the expansion of prisms immersed in test solution, compared with prism immersed under reference conditions and the photos is to be given in the ETA.

Method 2: Sulfate resistance (Square prism method) - S_{SPM}

The sulfate resistance of the "Product" shall be determined by the test method given in Annex C.

The sulfate resistance of the mortar with "Product" is compared to the sulfate resistance of the mortar with a reference cement (standard CEM I – SR 3 and CEM III/B - SR and/or CEM IV/B-SR according to EN 197-1).

For test method given in Annex C the average value of the expansion on mortar with the "Product" after 182 day shall be lower than or equal to the average expansion value on the reference mortar of the same age.

If at that time the first requirement is not fulfilled, the test shall be repeated after 364 days. The average value of expansion on mortar with the "Product" after 364 days shall be lower than or equal to the average expansion value on the reference mortar of the same age.

The difference between the average of the three specimens stored in distilled water and the three specimens stored in the sulphate solution is recorded for each storage period.

2.2.15 Carbonation of concrete

Method 1: Carbonation resistance – C_{dcr}

The carbonation depth of concrete made with "Product" is measured according to RILEM CPC 18.

The resistance of carbonation depth has to be tested on prisms (40 mm x 40 mm x 160 mm) with aggregates according to EN 12620.

The carbonation resistance shall be tested on concrete II, see table 4.

Table 4: Composition of concrete for the determination of carbonation depth

	Concrete mixtures for 3 specimens
concrete II	c = 450 g "Product" 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 are prepared according to EN 196-1, except the respect for the gap of (3±1mm) between the bowl and the blade that cannot be respected by the size grading of the sand.

After demoulding half of the specimens are stored immersed in water (20 ± 2) °C until the age of 7 days and the other half until the age of 28 days.

Afterwards the specimens are stored in climate 20/65 and ambient CO_2 content (commonly 350 to 450 p.p.m.).

Measurements of carbonation depth shall be performed after 14, 28, 56, 98 and 140 days for the delivery of the ETA. It is recommended to continue the tests on the same samples after 1, 2 and 5 years in order to verify the obtained results after 140 days and improve the knowledge.

Furthermore the compressive strength is determined according to EN 196-1:

- on the set of specimens n°1, at the age of 35 days (after 7 days pre-storing in water and 28 days in climate 20/65) and at the age of 147 days (after 7 days pre-storing in water and 140 days in climate 20/65),
- on the set of specimens n°2, at the age of 35 days (after 28 days pre-storing in water and 7 days in climate 20/65) and at the age of 168 days (after 28 days pre-storing in water and 140 days in climate 20/65).

The carbonation speed v_c is calculated by linear regression with:

$$d_C = d_0 + v_C \cdot \sqrt{t_C} \text{ expressed in mm / } \sqrt{d}$$

with:

d_c = carbonation depth (mm)

t_c = duration of carbonation (days)

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

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

The carbonation depth resp. the carbonation speed shall be plotted in the diagramms according to Annex D. The diagramms are given in the ETA.

Method 2: Relative carbonation resistance – C_{rcr}

The carbonation resistance of concrete made with "Product" is measured according to CEN/TS 12390-10, Annex A (environment A).

The carbonation resistance shall be tested on concrete IIIa (concrete made with the “Product”) and concrete IIIb (reference concrete), see table 5

Table 5: Composition of concrete for the determination of carbonation depth

	Composition per m³ fresh concrete
concrete IIIa	c = 350 kg "Product g = … kg aggregates [1] w = 175 l water $\left(\frac{w}{c} = 0{,}50\right)$ W=effective water
concrete IIIb	c = 350 kg CEM I 52.5R g = … kg aggregates [1] w = 175 l water $\left(\frac{w}{c} = 0{,}50\right)$ 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

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

Concrete prisms are stored outdoor without curing under a ventilated shelter or in a carbonation chamber containing a CO_2 content close to the local normal climate.

Measurements of carbonation depth shall be performed after 182 days for the granting of the ETA. It is recommended to continue the tests on the same samples after 273, 365, 547 and 730 days in order to verify the obtained results after 182 days and improve the knowledge.

The carbonation resistance of the concrete with "Product" is compared to the carbonation resistance of the reference concrete.

Note 2: For the assessment of the carbonation resistance for the "Product" the carbonation depth shall be determined to a test age of 182 days. The test shall be repeated after 2 years to get data of the concrete with the "Product".

2.2.16 Resistance to chloride penetration

Method 1: Chloride migration coefficient - D_{mig}

The resistance to chloride penetration of concrete with the "Product" and with Portland cement CEM I according to EN 197-1 as reference shall be determined in accordance with the test method given in Annex E.

The resistance to chloride penetration shall be tested on concrete IVa and IVb, see table 6.

Table 6: Composition of concrete for the determination of the resistance to chloride penetration

	Composition per m³ fresh concrete
concrete IVa	c = 320 kg "Product" g = ….. kg aggregates [1] $\frac{w}{c} = 0{,}50$ with w = effective water
concrete IVb	c = 320 kg CEM I acc. to EN 197-1 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

For the test method given in Annex E the chloride migration coefficient of concrete (D_{mig}) with the "Product" is compared to the chloride migration coefficient of the reference concrete at an age 35 and 97 days.

The chloride migration coefficient D_{mig} is to be given in the ETA.

Method 2: Chloride diffusion coefficient - D_{nss}

The resistance to chloride penetration of concrete with the "Product" and with Portland cement as reference shall be determined in accordance EN 12390-11:2015 by the chloride diffusion coefficient.

The resistance to chloride penetration shall be tested on concrete IIIa (concrete made with the "Product") and concrete IIIb (reference concrete), see table 5.

For the chloride resistance of concrete according to EN 12390-11:2015 the chloride diffusion coefficient (D_{nss}) of concrete with the "Product" is compared to the chloride diffusion coefficient of concrete with Portland cement. The chloride diffusion coefficient D_{nss} is to be given in the ETA.

2.2.17 Freeze-thaw resistance without de-icing agent

Method 1: Freeze-thaw resistance (Cube-Procedure) - FT_{cube}

The freeze-thaw resistance of concrete with the "Product" shall be determined according to CEN/TS 12390-9 ("cube procedure").

The freeze-thaw resistance ("cube procedure") shall be tested on concrete V, see table 7.

Table 7: Composition of concrete for the determination of the freeze-thaw resistance without de-icing agent

	Composition per m³ fresh concrete
concrete V	c = 300 kg "Product" 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 scaling shall be measured after 10, 25, 50, 75 and 100 freeze-thaw cycles.

Furthermore the compressive strength of concrete V shall be determined according to EN 12390-3 after 28 days. The specimens are immersed in water after demoulding until the age of 7 days. Afterwards the specimens are stored in climate 20/65.

The scaling after 100 freeze-thaw-cycles (Cube-procedure) is to be given in the ETA.

Method 2: Freeze-thaw resistance (CF-Procedure) - FT_{CF}

The freeze-thaw resistance of concrete with the "Product" shall be determined according to CEN/TS 12390-9 ("CF-Procedure"). The internal structural damage shall be determined according to CEN/TR 15177.

The freeze-thaw resistance ("CF-Procedure") shall be tested on concrete composition IIIa, see table 5.

Furthermore the compressive strength of concrete IVa shall be determined according to EN 12390-3 after 28 days. The specimens are immersed in water after demoulding until the age of 7 days. Afterwards the specimens are stored in climate 20/65.

The relative dynamic modulus of elasticity (RDM) and scaling shall be measured after 0, 4, 10, 16, 22 and 28 freeze-thaw cycles.

The scaling after 28 freeze-thaw cycles (CF-procedure) and the relative dynamic modulus of elasticity (RDM) is to be given in the ETA.

Method 3: Freeze-thaw resistance (Beam-Procedure) - FT_{beam}

The freeze-thaw resistance of concrete with the "Product" shall be determined according to the reference method in CEN/TR15177 – Internal structural damage ("Beam test").

The freeze-thaw resistance ("Beam test") shall be tested on concrete IIIa, see table 5.

For the freeze-thaw resistance–internal damage according to CEN/TR15177 the relative dynamic modulus of elasticity (RDM) shall be measured after 7, 14, 28 and 56 freeze-thaw cycles.

The scaling after 56 freeze-thaw cycles (Beam-procedure) and the relative dynamic modulus of elasticity (RDM) is to be given in the ETA.

2.2.18 Freeze-thaw and de-icing salt resistance

Method 1: Freeze-thaw and de-icing resistance (CDF-Procedure) - FTS_{CDF}

The freeze-thaw and de-icing salt resistance of concrete with the "Product" shall be determined according to CEN/TS 12390-9 ("CDF- Procedure"). Furthermore the internal structural damage shall be determined according to CEN/TR 15177.

The freeze-thaw resistance with de-icing salt ("CDF-Procedure") shall be tested on concrete composition VI, see table 8.

Table 8: 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 "Product" 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

Furthermore the compressive strength of concrete V shall be determined according to EN 12390-3 after 28 days. The specimens are immersed in water after demoulding until the age of 7 days. Afterwards the specimens are stored in normal climate 20/65.

The air void parameter shall be determined according to EN 480-11 on concrete VI.

The relative dynamic modulus of elasticity (RDM) and scaling shall be measured after 0, 4, 6, 14, and 28 freeze-thaw cycles.

The scaling after 28 freeze-thaw cycles (CDF-procedure) is to be given in the ETA.

Method 2: Freeze-thaw resistance (Slab-Procedure) - FT_{slab}

The freeze-thaw and de-icing salt resistance of concrete with "Product" shall be determined according to CEN/TS 12390 9 ("Slab test"). Furthermore the internal structural damage shall be determined according to CEN/TR 15177.

The freeze-thaw and de-icing salt resistance ("slab test") shall be tested on concrete IIIa, see table 5.

For the freeze-thaw and de-icing salt resistance according to CEN/TS 12390-9 and CEN/TR15177 the relative dynamic modulus of elasticity (RDM) and scaling shall be measured after 7, 14 and 28 freeze-thaw cycles.

The scaling after 28 freeze-thaw cycles (Slab-procedure) is to be given in the ETA.

2.2.19 Reaction to fire

The "Product" is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire, in accordance with the provisions of Decision 1996/603/EC (as amended) 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.

2.2.20 Content and/or release of dangerous substances

The performance of the product related to the emissions and/or release and, where appropriate, the content of dangerous substances will be assessed on the basis of any information provided by the manufacturer using the following methods and criteria: (e.g. ENs, EOTA TR 034).

The assessment of the product will be made by resorting to already existing European assessment methods developed by CEN (or by EOTA, if CEN has not yet developed such methods) as described below:

If the concrete containing **CSA** is intended to be used in unsaturated or saturated soil, the following testing is necessary:

Leachable constituents of the concrete containing CSA have to be determined on the basis of a reference test specimen using Portland cement and a test specimen using CSA cement.

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

Cement: Portland cement CEM I 32,5 R according to EN 197-1; c = 280 kg/m^3

respectively CSA-Cement, c = 280 kg/m^3

Water / cement ratio: 0.6

Aggregate: Gravel sand according to EN 12620 with 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 with dimensions of 100 mm x 100 mm x 100 mm shall be created in accordance with EN 12390-2:2002-04 from both concrete mixtures (form oil must not be used). Usually, the cubes are removed from the forms after one day.

After removal from the forms, the test specimens are tightly packaged and stored at a temperature of 20 ± 2 °C. The test specimens are generally 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 is produced by a tank test according to CEN/TS 16637-2. The eluates taken after 6 hours, 1 day, 2 days and 6 hours, 4 days, 9 days, 16 days, 36 days and 64 days shall be analysed for following environmentally relevant parameters:

- aluminium, antimony, arsenic, barium, lead, cadmium, chromium (total), chromate (Cr VI), cyanide (total), cobalt, copper, molybdenum, nickel, mercury, thallium, vanadium, zinc,
- chloride (Cl^-), sulfate (SO_4^{2-}), fluoride (F^-)
- TOC,
- pH-value, electrical conductivity, odour, colour, turbidity, and tendency to produce foam

The parameters shall be analysed with an appropriate standardised test method (this test method shall have a suitable method detection limit compared to the limit value).

Measured concentration of the leaching test according to CEN/TS 16637-2 of hardened concrete must be expressed per step for each parameter in µg/L and mg/m^2. Additionally the cumulatively released quantities must be expressed for each parameter in mg/m^2.

The used test methods for the analysis of the parameters shall be documented including method detection limits.

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: Decision 1997/555/EC[6].

The system is: 1+

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of product in the procedure of assessment and verification of constancy of performance are laid down in Table 9.

Table 9 Control plan for the manufacturer; corner stones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC)					
1	Early strength (1 ≤ t ≤ 24 h)	2.2.1	2.2.1	1	2/week 2) 4/week 3)
2	Standard strength (28 days)	2.2.2	2.2.2	1	
3	Calcium sulphoaluminate (Yeelimite) content	2.2.3*	2.2.3	1	1/month 2) 1/week 3)
4	Cement composition 4)	2.2.4*	2.2.4	1	
5	Initial setting time	2.2.5*	2.2.5	1	
6	Soundness	2.2.6	2.2.6	1	1/week 2) 4/week 3)
7	Sulfate content	2.2.7*	2.2.7	1	2/week 2) 4/week 3)
8	Chloride content	2.2.8*	2.2.8	1	2/month 1) 2) 1/week 3)
9	Density	2.2.9	2.2.9	1	1/month 2) 1/week 3)
10	Fineness (Blaine)	2.2.10	2.2.10	1	1/month 2) 1/week 3)
11	Shrinkage (method 1 : Shr_M 28 days)	2.2.12	2.2.12	1	1/month 2) 1/week 3)

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

1) When none of the test results within a period of 12 months exceeds 50 % of the characteristics value the frequency may reduce to one per month

2) Routine situation

3) Initial period (3 month)

4) Note concerning the cement composition:
The composition of the cement shall be checked by the manufacturer at least once per month using, as a rule, a spot sample taken at the point of release of the cement. The cement composition shall meet the requirements specified above. The limiting quantities of the main constituents specified above are reference values to be met by the average composition calculated from the spot samples taken in the control period. For single results, maximum deviations of -2 at the lower and +2 at the higher reference value are allowed. Suitable procedures during production and appropriate verification methods to ensure conformity to this requirement shall be applied and documented.

Statistical evaluation of FPC data shall be done in accordance with EN 197-1 Clause 9.2.2 and EN 197-2 Clause 5.3.

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6 Official Journal of the European Communities L 229/9 of 20/08/1997

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 the “Product” are laid down in Table 10.

Table 10 Control plan for the notified body; corner stones

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	acc. to EN 197-2				
Continuous surveillance, judgment and assessment of factory production control (FPC)					
2	acc. to EN 197-2				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	Early strength ($1 \leq t \leq 24$ h)	2.2.1	2.2.1	1	6/year
4	Standard strength (28 days)	2.2.2	2.2.2	1	6/year
5	Calcium sulphoaluminate (Yeelimite) content	2.2.3	2.2.3	1	6/year
6	Cement composition	2.2.4	2.2.4	1	6/year
7	Initial setting time	2.2.5	2.2.5	1	6/year
8	Soundness	2.2.6	2.2.6	1	6/year
9	Sulfate content	2.2.7	2.2.7	1	6/year
10	Chloride content	2.2.8	2.2.8	1	6/year
11	Density	2.2.9	2.2.9	1	6/year
12	Fineness (Blaine)	2.2.10	2.2.10	1	6/year
13	Shrinkage (method 1 : Shr_M 28 days*)	2.2.12	2.2.12	1	6/year

4 REFERENCE DOCUMENTS

As far as no edition date is given in the list of standards thereafter, the standard in its current version at the time of issuing the European Technical Assessment is of relevance.

EN 196-1	Methods of testing cement - Determination of strength	
EN 196-2	Methods of testing cement - Chemical analysis of cement	
EN 196-3	Methods of testing cement - Determination of setting time and soundness	
EN 196-6	Methods of testing cement - Determination of fineness	
EN 197-1	Cement - Part 1: Composition, specification and conformity criteria for common cements	
EN 197-2	Cement - Part 2: Conformity evaluation	
EN 206	Concrete - Specification, production, performance and conformity	
EN 480-11	Admixtures for concrete, mortar and grout - Test methods - Part 11: Determination of air void characteristics in hardened concrete; German version	2005
EN 12390-2	Testing hardened concrete - Part 2: Making and curing specimens for strength tests	
EN 12390-3	Testing hardened concrete - Part 3: Compressive strength of test specimens	
EN 12620	Aggregates for concrete	
CEN/TS 12390-9	Testing hardened concrete - Part 9: Freeze-thaw resistance, Scaling	
EN 12390-11	Testing hardened concrete - Determination of the chloride resistance of concrete, unidirectional diffusion	2015
CEN/TR 15177	Testing the freeze-thaw resistance of concrete - Internal structural damage	
ISO 1920-8	Testing of concrete - Part 8: Determination of drying shrinkage of concrete for samples prepared in the field or in the laboratory	
RILEM CPC 18	Measurement of hardened concrete carbonation depth, Materials and structures, Vol. 21	December 1988
CUR 48	Civiltechnisch Centrum Uitvoering Research en Regelgeving (Centre for Civil Engineering Research and Codes) - Recommendation 48 – suitability test for new cements for application in concrete	
NF P 15-433	Methods of testing cement – Determination of shrinkage and swelling	February 1994
EN 13813	Screed material and floor screeds - Screed material - Properties and requirements	June 2003
CEN/TS 16637-2	Construction Products - Assessment of release of dangerous substances	August 2014
EOTA TR 034	General Checklist for EADs/ETAs – Content and/or release of dangerous substances in products	

ANNEX A

Testing the Cements Shrinkage (mortar method) – Shr_M

A.1 References

NF P15-433 (February 1994): Methods of testing cement – determination of shrinkage and swelling

A.2 Preparation of test specimens and conservation before demoulding

The preparation of test specimens and their conservation before demoulding are executed according to the standard EN 196-1, by using moulds and measuring pin defined in the paragraphs A.4.2 of the present appendix.

A.3 Conservation of test specimens after demoulding

Test specimens, once turned out, are possibly weighed, then marked. They are arranged in a way that each of them is distant from neighbours of at least 1 cm, and in a way that they are surrounded with air on all the faces.

Test specimens are preserved in the room in which the air is permanently for a temperature of (20±2)°C and a humidity of (50±5)%.

NOTE: it is recommended that the air speed at the level of test tubes does not exceed 0.5 m/s.

A.4 Equipment

A.4.1 Moulds

Moulds are in accordance with the requirements of the standard EN 196-1, however the tolerances on the internal dimensions of every compartment are the following ones:

- length: ± 0.8 mm,
- width: ± 0.5 mm,
- height: ± 0.5 mm.

The walls of the mould corresponding to the bases of test specimens are drilled according to the longitudinal axis of these, so as to allow the fixation by screw of pins intended for the measures.

A.4.2 Pins for measurement

These pins, in not reactive hard material and non-reactive with binder, contain a conical recess, with dimensions defined in the figure A.1, ensuring the contact at each extremity of the test specimens, with the ball carried by the touches of the measuring device.

Dimensions in millimetres

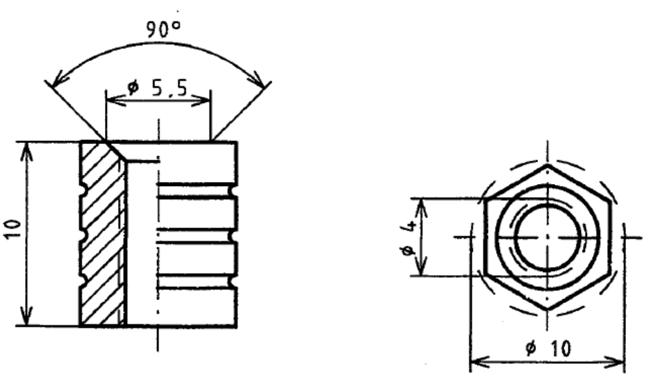


Figure A.1

They are tapped in the axis and are 10 mm long, their side, of shape ensuring a good anchoring, are inscribed inside a cylinder of maximal diameter of 10 mm.

A.4.3 Measuring device

The device serving to measure the length of test specimens contains two sensors provided with a rectified ball with a diameter between 6 and 7 mm. It is capable of realizing the measures with a lower or more equal accuracy in 0.005 mm.

The mechanical zero of the device is made with a metal rod 160 mm in length the extremities of which reproduce the shape of the contacts of the test specimen. This rod is in invar metal or protected against the temperature variations that it can be able to undergo during the manipulations.

Note: It is good to have the second similar rod which will serve to control the possible wear of the first one, especially in laboratories making long-term measures.

A.5 Measures

Before every series of measures, the mechanical zero of the device is realized as indicated to the paragraph A.4.3.

The test specimen is vertically arranged and undergoes a rotation on its axis before the measure.

If from a measure to the other one, the variation of length of one of the three test specimens exceeds of more than 0.02 mm that of the test specimen having the most nearby variation, there is good reason to look for the cause (dust, bad contact, loosening of the pins, etc.) and if it cannot be eliminated, the test specimen must be put off.

A.6 Expression of the results

For each of three test specimens, the variation of relative length is calculated by difference between the initial measure when removed from the mould and the final measure in the specified terms at 28 days.

This variation of relative length, expressed in micrometres per meter, is defined by the following formula:

$$\frac{dL}{L} * 1000$$

With:
dL is the variation of length, expressed in micrometres,
L is the base length equal to 160 mm.

The shrinkage, at the determined age, is equal to the arithmetical average, rounded off in the closest about ten, values were measured on each of three test specimens.

ANNEX B

Testing the Sulfate Resistance of Special Cements – Flat prism method S_{FPM}

B.1 References

EN 196-1 Methods of testing cement - Part 1: Determination of strength.

B.2 Composite cement, cements

The sulfate resistance shall be tested on specimens made of mortar according to EN 196-1 for the "Product" to be examined and two or three reference cements (standard CEM I – SR 3 and CEM III/B – SR according to EN 197-1) according to the flat prism method.

B.3 Making of test specimens

24 flat prisms from each mortar with the dimensions 10 mm x 40 mm x 160 mm (12 with and 12 without measuring pin) shall be made in accordance with and/or following EN 196-1 and be compacted on the vibrating table.

B.4 Storage of test specimens

The 24 flat prisms shall first of all be stored for 2 days in the mould at (20 ± 2)°C and > 95 % RH (climate 20/95). After demoulding the 24 flat prisms shall be pre-stored until the age of 14 days, on edge, standing on gratings in saturated $Ca(OH)_2$ solution at (20 ± 2)°C.

At the age of 14 days, a series of 3 flat prisms with measuring pin and 3 flat prisms without measuring pin will be stored on edge, standing on gratings (sulfate storage) in a 4,4 % Na_2SO_4 solution at 5 °C and 20 °C. One series each of 3 flat prisms with measuring pin and 3 flat prisms without measuring pin will be stored on edge, standing on gratings (reference storage 5 °C) in a saturated $Ca(OH)_2$ solution at 5 °C. The other two series of 3 flat prisms each remain stored in saturated $Ca(OH)_2$ at 20 °C (reference storage 20 °C).

In all storages the ratio of volumes of solution/solid matter must be 3:1 to 5:1. The Na_2SO_4 solution is to be replaced every 14 days with a new Na_2SO_4 solution, temperature-controlled at 5 °C respectively 20 °C. The saturated $Ca(OH)_2$ solution is to be checked every 14 days for its saturation. If needed, it has to be concentrated.

B.5 Test

For the evaluation of the resistance to sulfate storage the length of the flat prisms and the dynamic modulus of elasticity of the flat prisms without measuring pin will be measured after a period of storage of 0, 14, 28, 56, 90, and 180 days. In addition the change in mass of the flat prisms is to be determined.

Photos of the specimens will be taken after every testing to illustrate the formations of the cracks.

B.6 Analysis

The elongation of the flat prisms is to be determined as mean value of the measured values from 3 specimens and the difference in elongation between the sulfate storage and the reference storage is to be assessed.

The dynamic modulus of elasticity is to be determined as mean value from the measured values from 3 specimens.

The elongations, the elongation difference, the dynamic modulus of elasticity and the photos are to be stated in the test report for all test dates.

ANNEX C

Testing the Sulfate Resistance –Square prism method S_{SPM}[7]

This test method is adapted from the CUR – Civiltechnisch Centrum Uitvoering Research en Regelgeving – Recommendation 48 testing procedure.

C.1 References

EN 196-1 Methods of testing cement - Part 1: Determination of strength.

C.2 Apparatus and solution

C.2.1 Containers

Containers for storage of distilled water and sulfate solution must have a capacity of 1.5 and 2.5 liters and measure at least 180 mm x 80 mm. Each container must be capable of containing 1.0 ± 0.1 liters of liquid, so that the depth of the liquid reaches at least 25 mm. All the containers must be fitted with light-proof lids and must 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 liters of liquid are used per three specimens.

C.2.2 Sulphate Solution

The sulphate solution must have a concentration of 16 ± 0.5 g SO_4 per liter, and is 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.

Note: The SO_4-content of the Na_2SO_4 must be measured before the solution is prepared, or the SO_4-content of the solution must be measured and corrected, if necessary.

C.3 Manufacturing of test specimens

The mortar must be prepared in accordance with paragraph 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.

C.4 Conditioning

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

The specimens must 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 clear from the bottom of the containers.

C.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 liter 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.

7 This test method is identical to CUR 48.

C.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

C.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 sulphate storage. The difference between the average of the three specimens stored in distilled water and the three specimens stored in the sulphate solution is recorded for each storage period.

ANNEX D

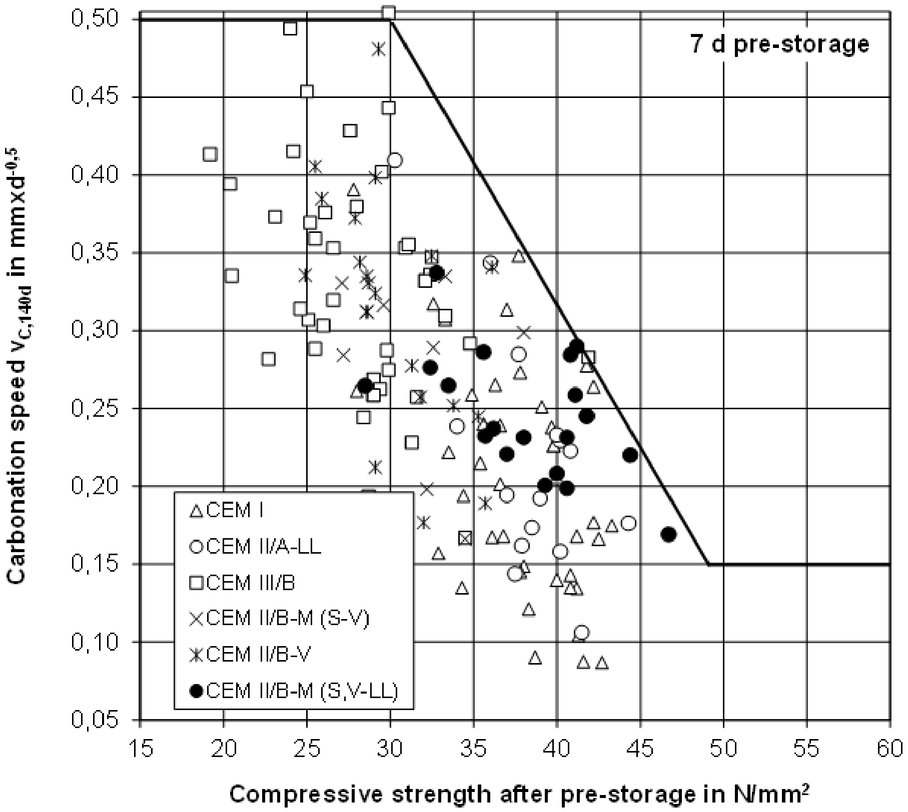
Evaluation of the carbonation resistance - C_{dcr}

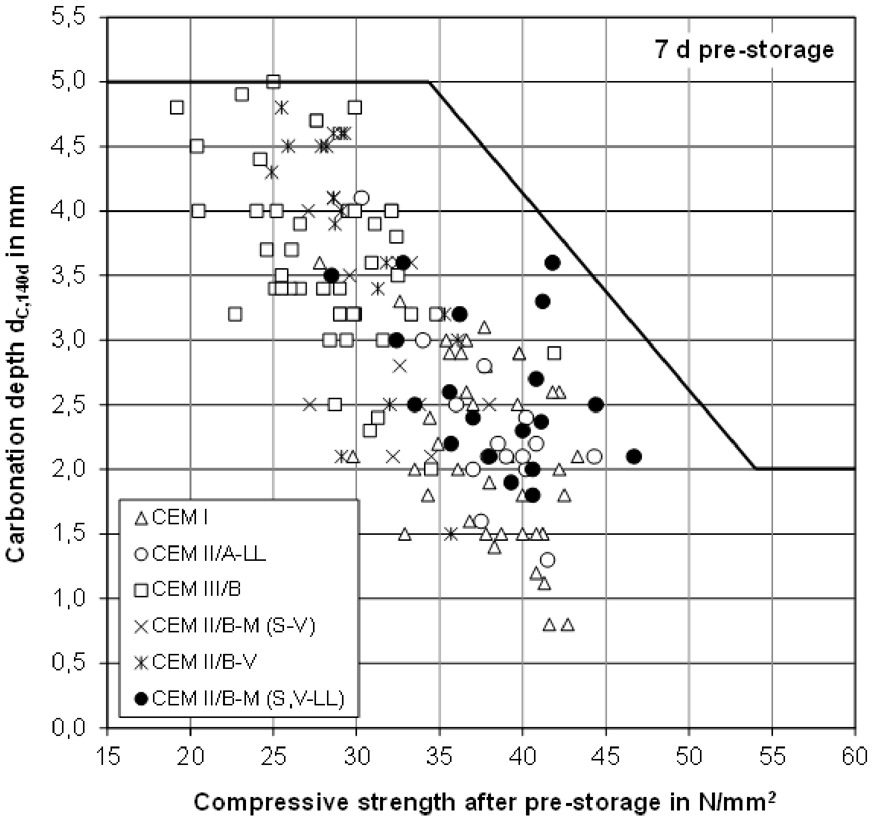
Carbonation test on concrete (w/c = 0,50) - **7** days pre-storage

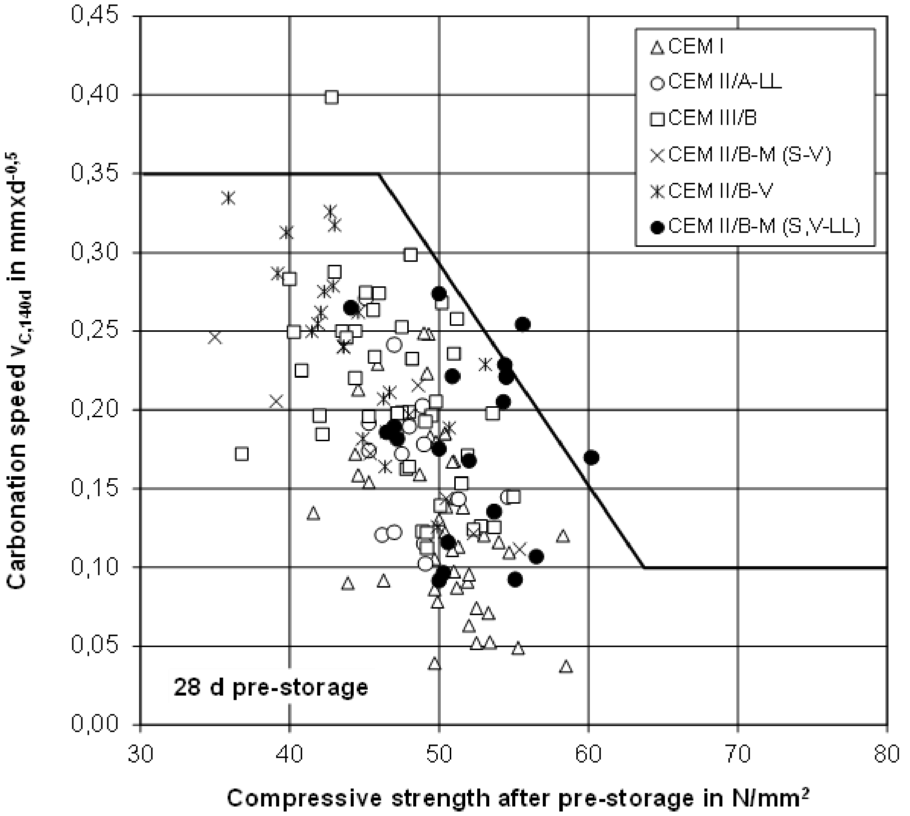
		f_C in N/mm²			Carbonation depth in mm								$F_{C,P}^{-0,5}$ in $N^{-0,5}$ x mm	Carbo. speed in mm / $d^{0,5}$	
		Pre-st. 7 d	35 d	140 d main-st.	14 d	28 d	56 d	98 d	140 d	1 a	2 a	5 a		$v_{C,140d}$	$v_{C,5a}$
CEM II/B-M (S, V-LL)															
	min	28,5	51,2	50,8	0,2	0,4	1,0	1,5	1,8	3,1	3,7	6,8	0,146	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

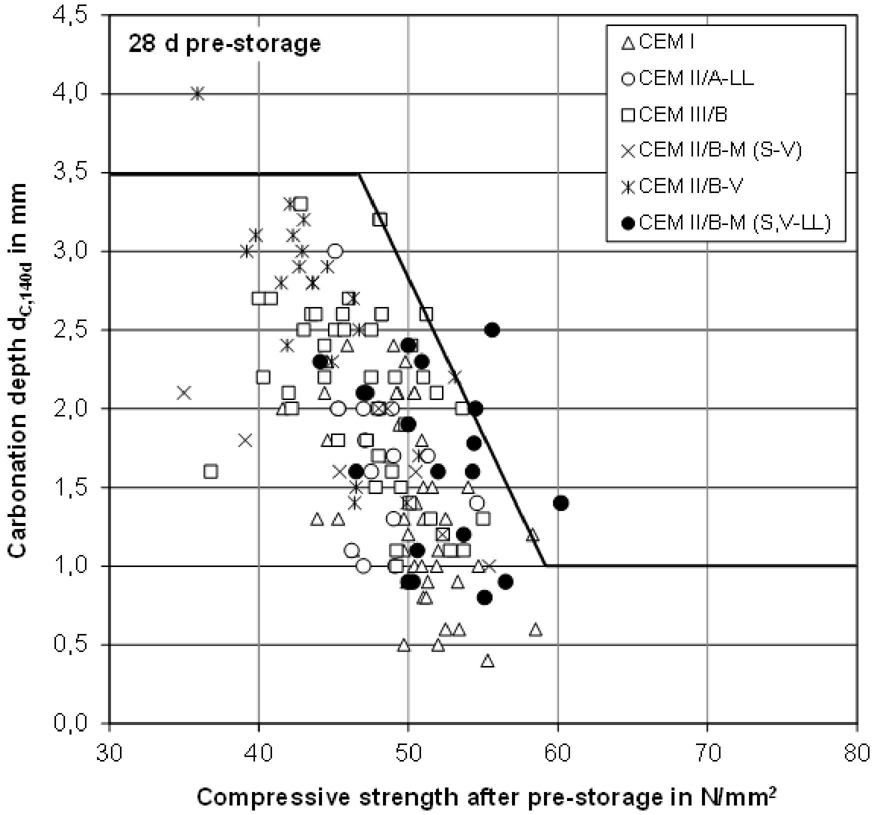
Carbonation test on concrete (w/c = 0,50) - **28** days pre-storage

		f_C in N/mm²			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
Carbonation speed $v_{C,140d}$ in mmxd$^{-0,5}$
Compressive strength after pre-storage in N/mm²
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
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)


7 d pre-storage
Carbonation depth $d_{C,140d}$ in mm
Compressive strength after pre-storage in N/mm²
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
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)


0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
30
40
50
60
70
80
Carbonation speed v_C,140d in mmxd^-0,5
Compressive strength after pre-storage in N/mm²
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)


4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
30
40
50
60
70
80
Carbonation depth d_C,140d in mm
Compressive strength after pre-storage in N/mm²
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)

ANNEX E

Testing the Resistance to Chloride Penetration by the Non-Steady-State Migration Experiments – Chloride migration coefficient D_{mig}

E.1 References

EN 12390-2 Testing hardened concrete – Part 2: Making and curing specimens for strength tests

E.2 Scope

This procedure is for determination of the chloride migration coefficient in concrete, mortar or cement-based repair materials from non-steady-state migration experiments.

E.3 Field of Application

The method is applicable to hardened specimens cast in the laboratory or drilled from field structures. The chloride migration coefficient determined by the method is a measure of the resistance of the tested material to chloride penetration. This non-steady-state migration coefficient cannot be directly compared with chloride diffusion coefficients obtained from other test methods, such as the non-steady-state immersion test or the steady-state migration test.

E.4 Test Method

E.4.1 Principle

An external electrical potential is applied axially across the specimen and forces the chloride ions outside to migrate into the specimen. After a certain test duration, the specimen is axially split and a silver nitrate solution is sprayed on to one of the freshly split sections. The chloride penetration depth can then be measured from the visible white silver chloride precipitation, after which the chloride migration coefficient can be calculated from this penetration depth.

E.4.2 Reagents and apparatus

E.4.2.1 Reagents

- Distilled or deionised water.
- Calcium hydroxide: $Ca(OH)_2$, technical quality.
- Sodium chloride: NaCl, chemical quality.
- Sodium hydroxide: NaOH, chemical quality.
- Silver nitrate: $AgNO_3$, chemical quality.

E.4.2.2 Apparatus

- Water-cooled diamond saw.
- Migration set-up: One design (see E.1) includes the following parts:
  - Silicone rubber sleeve: inner/outer diameter 100/115 mm, about 150 mm long.
  - Clamp: diameter range 105 ~ 115, 20 mm wide, stainless steel (see Figure D.2).
  - Catholyte reservoir: plastic box, 370 × 270 × 280 mm (length × width × height).
  - Plastic support: (see Figure E.3).
  - Cathode: stainless steel plate (see Figure E.3), about 0.5 mm thick.
  - Anode: stainless steel mesh or plate with holes (see Figure E.4), about 0.5 mm thick.

  Other designs are acceptable, provided that temperatures of the specimen and solutions during the test can be maintained in the range of 20 to 25 °C.

- Power supply: capable of supplying 0 ~ 60 V DC regulated voltage with an accuracy of ±0,1 V.
- Ammeter: capable of displaying current to ±1 mA.
- Thermometer or thermocouple with readout device capable of reading to ±1 °C.
- Any suitable device for splitting the specimen.
- Spray bottle.
- Slide calliper with a precision of ±0,1 mm.
- Ruler with a minimum scale of 1 mm.

E.4.3 Preparation of the test specimen

6 cylinders from each concrete 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 climate (20/95). After demoulding the specimens shall be stored in water at 20 ± 5 °C until testing. At an age of 28 days respectively 90 days 3 specimens of each concrete are taken out of the water.

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

Note 1: The term 'cut' here means to saw perpendicularly to the axis of a core or cylinder, using a water-cooled diamond saw.

Until the test procedure the slices are stored immersed in water. The test procedure is started at an age of 35 days and 97 days.

E.4.4 Test procedure

E.4.4.1 Catholyte and anolyte

The catholyte solution is 10 % NaCl by mass in tap water (100 g NaCl in 900 g water, about 2 N) and the anolyte solution is 0,3 N NaOH in distilled or de-ionised water (approximately 12 g NaOH in 1 litre water). Store the solutions at a temperature of 20–25 °C.

E.4.4.2 Temperature

Maintain the temperatures of the specimen and solutions in the range of 20–25 °C during the test.

E.4.4.3 Preparation of the test

- Fill the catholyte reservoir with about 12 litres of 10 % NaCl solution.
- Fit the rubber sleeve on the specimen as shown in Figure D.4 and secure it with two clamps. If the curved surface of the specimen is not smooth, or there are defects on the curved surface which could result in significant leakage, apply a line of silicone sealant to improve the tightness.
- Place the specimen on the plastic support in the catholyte reservoir (see Figure E.1).
- Fill the sleeve above the specimen with 300 ml anolyte solution (0,3 N NaOH).
- Immerse the anode in the anolyte solution.
- Connect the cathode to the negative pole and the anode to the positive pole of the power supply.

E.4.4.4 Migration test

- Turn on the power, with the voltage preset at 30 V, and record the initial current through each specimen.
- Adjust the voltage if necessary (as shown in Table E.1). After adjustment, note the value of the initial current again.
- Record the initial temperature in each anolyte solution, as shown by the thermometer or thermocouple.
- Choose appropriate test duration according to the initial current (see Table E.1).
- Record the final current and temperature before terminating the test.

E.4.4.5 Measurement of chloride penetration depth

- Disassemble the specimen by following the reverse of the procedure in E.4.4.3. A wooden rod is often helpful in removing the rubber sleeve from the specimen.
- Rinse the specimen with tap water.
- Wipe off excess water from the surfaces of the specimen.
- Split the specimen axially into two pieces
- Spray 0,1 M silver nitrate solution on to the freshly split sections.
- When the white silver chloride precipitation on the split surface is clearly visible (after about 15 minutes), measure the penetration depth, with the help of the slide calliper and a suitable ruler, from the centre to both edges at intervals of 10 mm (see Figure E.5) to obtain seven depths (notes 2, 3 and 4). Measure the depth to an accuracy of 0,1 mm.

  Note 1: If no penetration front is clearly visible 30 minutes after silver nitrate spraying, a 5% aqueous solution of potassium dichromate ($K_2Cr_2O_7$) can be sprayed to reveal the penetration front.

  Note 2: If the penetration front to be measured is obviously blocked by the aggregate, move the measurement to the nearest front where there is no significant blocking by aggregate or, alternatively, ignore this depth if there are more than five valid depths.

  Note 3: If there is a significant defect in the specimen which results in a penetration front much larger than the average, ignore this front as indicative of the penetration depth, but note and report the condition.

  Note 4: To obviate the edge effect due to a non-homogeneous degree of saturation or possible leakage, do not make any depth measurements in the zone within about 10 mm from the edge (see Figure E.5).

E.5 Expression of results

E.5.1 Test results

Calculate the non-steady-state migration coefficient from Equation (1):

$$D_{nssm} = \frac{RT}{zFE} \cdot \frac{x_d - \alpha\sqrt{x_d}}{t} \qquad (1)$$

Where:

$$E = \frac{U-2}{L} \qquad (2)$$

$$\alpha = 2\sqrt{\frac{RT}{zFE}} \cdot \mathrm{erf}^{-1}\left(1 - \frac{2c_d}{c_0}\right) \qquad (3)$$

D_{nssm}: non-steady-state migration coefficient, m²/s;
z: absolute value of ion valence, for chloride, z = 1;
F: Faraday constant, F = 9,648 ×104 J/(V·mol);
U: absolute value of the applied voltage, V;
R: gas constant, R = 8,314 J/(K·mol);
T: average value of the initial and final temperatures in the anolyte solution, K;
L: thickness of the specimen, m;
x_d: average value of the penetration depths, m;
t: test duration, seconds;
erf^{-1}: inverse of error function;
c_d: chloride concentration at which the colour changes, $c_d \approx 0{,}07$ N for OPC concrete;
c_0: chloride concentration in the catholyte solution, $c_0 \approx 2$ N.

Since $\mathrm{erf}^{-1}\left(1-\frac{2\cdot 0{,}07}{2}\right)=1{,}28$, the following simplified equation can be used:

$$D_{nssm}=\frac{0{,}0239(273+T)L}{(U\text{-}2)t}\left(x_d-0{,}0238\sqrt{\frac{(273+T)L\,x_d}{U-2}}\right) \quad (4)$$

Where:

D_{nssm}: non-steady-state migration coefficient, $\times 10^{-12}$ m²/s;

U: absolute value of the applied voltage, V;

T: average value of the initial and final temperatures in the anolyte solution, °C;

L: thickness of the specimen, mm;

x_d: average value of the penetration depths, mm;

t: test duration, hour.

E.6 Appendix

Table E.1: Test voltage and duration for concrete specimen with normal binder content

Initial current L30V (with 30 V)	Applied voltage U (After adjustment)	Possible new initial current I_0	Test duration t
mA	V	mA	hour
$I_0 < 5$	60	$I_0 < 10$	96
$5 \leq I_0 < 10$	60	$10 \leq I_0 < 20$	48
$10 \leq I_0 < 15$	60	$20 \leq I_0 < 30$	24
$15 \leq I_0 < 20$	50	$25 \leq I_0 < 35$	24
$20 \leq I_0 < 30$	40	$25 \leq I_0 < 40$	24
$30 \leq I_0 < 40$	35	$35 \leq I_0 < 50$	24
$40 \leq I_0 < 60$	30	$40 \leq I_0 < 60$	24
$60 \leq I_0 < 90$	25	$50 \leq I_0 < 75$	24
$90 \leq I_0 < 120$	20	$60 \leq I_0 < 80$	24
$120 \leq I_0 < 180$	15	$60 \leq I_0 < 90$	24
$180 \leq I_0 < 360$	10	$60 \leq I_0 < 120$	24
$I_0 \geq 360$	10	$I_0 \geq 120$	6

Note: For specimens with a special binder content, such as repair mortars or grouts, correct the measured current by multiplying by a factor (approximately equal to the ratio of normal binder content to actual binder content) in order to be able to use the above table.

In case of pure calcium sulphoaluminate cements, the above table cannot be used (a lower pH induces a lower conductivity). To avoid chlorides to get across the concrete specimen, an early penetration front measure should be done (e.g. after 6 hours at 20-30 V) to estimate a suitable testing time for the other specimens (corresponding to a front located around the middle of the section).

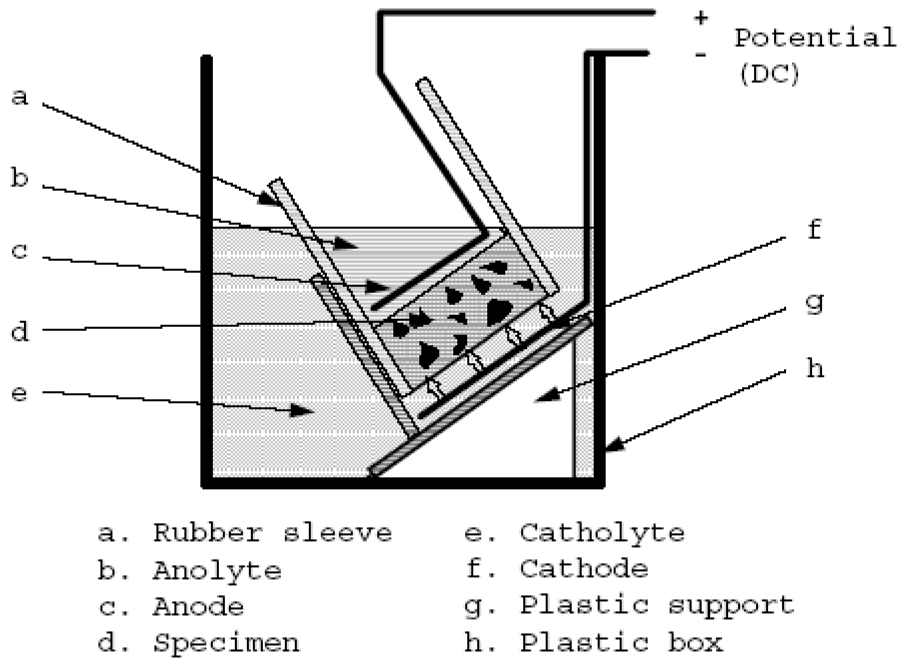


Figure E.1: Arrangement of the migration set-up.

Figure E.2: Stainless steel

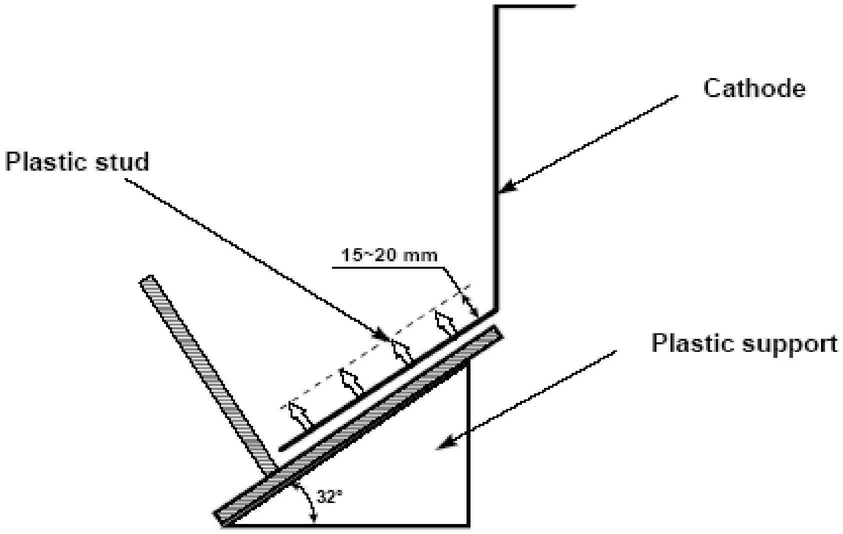


Figure E.3: Plastic support and cathode

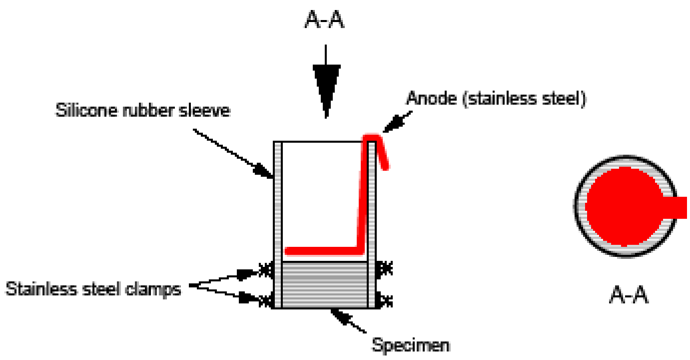


Figure E.4: Rubber sleeve assembled with specimen, clamps and anode

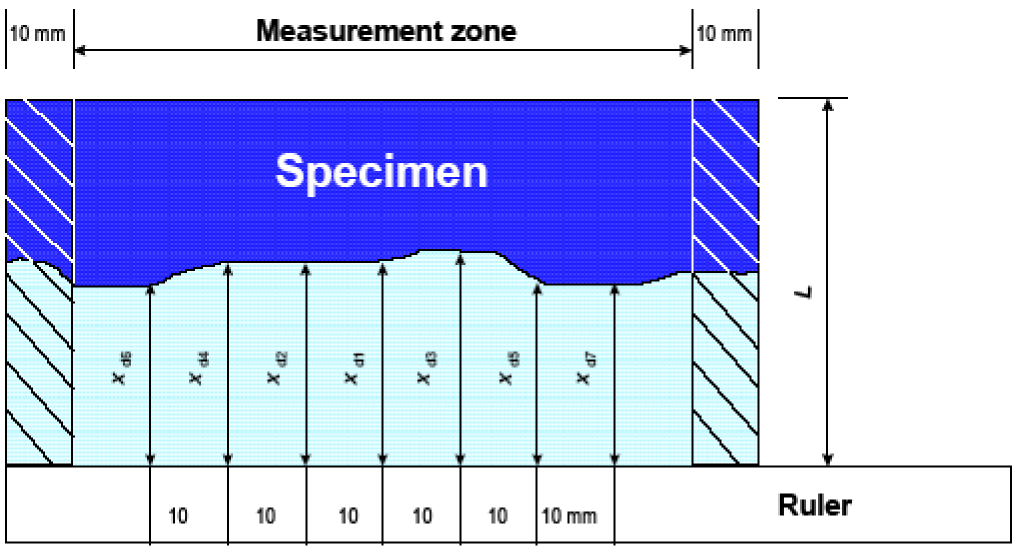


Figure E.5: Illustration of measurement for chloride penetration depths