EOTA®

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PORTLAND-POZZOLANA CEMENT FOR USE IN TROPICAL CONDITIONS

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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) No 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

The cements defined in the standard hEN 197-1 are usable in the intertropical zone. However, the realization of works in this zone can justify, because of the climate, the use of cements with lower standard strength or its slower development, in the test conditions of the standard EN 196-1. The manufacturing of such cements from a reactive clinker Portland can require the use of another constituent intended to optimize the development of the resistances and the heat of hydration, for example the pozzolanic filler.

The Portland-pozzolana cement for use in tropical conditions[1] referred to in this document is a special cement that is not fully covered by a European standard hEN 197-1.

This cement complies with the specifications of the standard hEN 197-1 except the following points presented in Table 1:

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

Cement properties	Specifications of hEN 197-1 standard
The pozzolanic material reactive silicon dioxide content can be less than 25,0% by mass	The pozzolanic material reactive silicon dioxide content shall be not less than 25,0% by mass (§5.2.3.1)

The pozzolanic fillers, utilized as main constituent or minor additional constituent, are natural materials, consisting essentially of silicon dioxide (SiO_2) and aluminium dioxide (Al_2O_3). Finely ground, these materials display pozzolanic properties close to those ones of the natural pozzolanas described in the 5.2.3 of the standard hEN 197-1. The notation of the "pozzolanic filler" is Z.

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

　　　　　Pozzolanic material (Z)　　　　　　　　　　level (6 to 35% by mass))

　　　　　Portland cement clinker (K)　　　　　　　　level (65 to 94% by mass))

　　　　　Minor additional constituents　　　　　　　level (0 to 5% by mass))

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 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.

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[1] The " Portland-pozzolanic cement for use in tropical conditions " will be named as "Product".

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

1.2.1 Intended use(s)

The "Product" is intended to be used for preparation of concrete, mortar, grout and other mixes for construction and for the manufacturing of construction products.

The "Product" is intended to be used for production of concrete, including in particular cast in situ and prefabricated structural concrete conforming to European standard EN 206 and all the European standards and Eurocodes related to concrete applications.

It is particularly adapted for a use in tropical climatic area (intertropical zone).

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[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

Z   Pozzolanic material
K   Clinker according to hEN 197-1 §5.2.1

Abbreviations:
D   =   days
dcr =   direct carbonation resistance
diff   =   chloride diffusivity by the unidirectional non-steady state penetration
mig   =   chloride penetration by the non-steady-state migration
rcr   =   relative carbonation resistance
SPM =   square prism method

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[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.

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

No	Essential characteristic	Assessment method	Type of expression of product performance *(level, class, description)*
Basic Work Requirement 1: Mechanical resistance and stability		
1	Reactive silicon dioxide content in pozzolanic material (Z)	See Clause 2.2.1	Level [% by mass]
2	Cement composition	See Clause 2.2.2	Z Level [% by mass] K Level [% by mass] Minor additional Level [% by mass] constituents (acc. to hEN 197-1)
3	Early strength - 7 days	See Clause 2.2.3	Level [MPa]
4	Standard strength - 28 days	See Clause 2.2.4	Class [MPa] (acc. to hEN 197-1 table 3)
5	Initial setting time	See Clause 2.2.5	Threshold level [min] ($\geq$75 min acc. to hEN 197-1 table 3)
6	Soundness (expansion)	See Clause 2.2.6	Threshold level [mm] ($\leq$ 10 mm acc. to hEN 197-1 table 3)
7	Sulfate content (as SO_3)	See Clause 2.2.7	Threshold level [% by mass] ($\leq$ 3,5 % by mass acc. to hEN 197-1 table 4)
8	Chloride content	See Clause 2.2.8	Threshold level [% by mass] ($\leq$ 0,10 % by mass acc. to hEN 197-1 table 4)
9	Carbonation of concrete	See Clause 2.2.9	Method C_{dcr}: Description [graph] Method C_{rcr}: Level [mm]
10	Resistance to chloride penetration	See Clause 2.2.10	Method D_{mig}: Level [m²/s] Method D_{diff}: Level [m²s^{-1}]
11	Sulfate Resistance	See Clause 2.2.11	Method S_{FPM}: Level [mm/m] Method S_{SPM}: Level [%]

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

2.2.1 Reactive silicon dioxide content in pozzolanic material (Z)

The reactive silicon dioxide content of the pozzolanic material shall be determined in accordance with EN 196-2.

The reactive silicon dioxide of the pozzolanic material shall be stated in the ETA.

2.2.2 Cement composition

The composition 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" shall be in the following range:

Pozzolanic material (Z)	level (6 to 35% by mass))
Clinker (K)	level (65 to 94% by mass))
Minor additional constituents	level (0 to 5% by mass))

The composition of the "Product" shall be stated in the ETA.

2.2.3 Early strength

The early strength of the cement is the compressive strength determined at 7 days, in accordance with EN 196-1.
The early strength (7 days) shall be stated in the ETA.

2.2.4 Standard strength at 28 days

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

2.2.5 Initial setting time

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

The initial setting time of the "Product" shall be at least 75 minutes acc. to hEN 197-1, table 3. The initial setting time shall be stated in the ETA.

2.2.6 Soundness

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

The soundness shall be less than 10 mm acc. to hEN 197-1, table 3 (limit value for single results: 10 mm). The soundness shall be stated in the ETA.

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 (as SO_3) shall be stated in the ETA.

The sulfate content (as SO_3) shall be less than 3,5 % by mass acc. to hEN 197-1, table 4 (limit value for single results: 4,0 % by mass).

2.2.8 Chloride content

The chloride content of the product shall be determined in accordance with EN 196-2.

The chloride content of the "Product" shall be not greater than 0,10 % by mass acc. to hEN 197-1.

Note: For pre-stressing applications cements may be produced according to a lower requirement. If so, the value of 0,10 % by mass shall be replaced by this lower value which shall be stated in the delivery note.

2.2.9 Carbonation of concrete

Method 1: Carbonation resistance – C_{dcr}

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

The carbonation resistance 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 I, see table 3.

Table 3: Composition of concrete for the determination of carbonation resistance

	Concrete mixtures for 3 specimens
concrete I	c = 450 g "Product" g = 1350 g aggregates [1] w = 225 g water $\left(\dfrac{w}{c} = 0,50\right)$ 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 A. 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, with an environment of the test perform by a storage chamber descripted in CEN/TS 12390-10 Annex A.

The carbonation resistance shall be tested on concrete IIa (concrete made with the "Product") and concrete IIb (reference concrete).

The composition of concrete IIa and concrete IIb are chosen in accordance with limit values described in the exposure class XC1 in table F1 of EN 206.

Values are the following:

- w/c = 0.65 (w = effective water)
- Strength class = C20/25
- Cement content   = 260 kg/m3

The composition of the 2 concretes is identical except the origin of the cement. The cement used to make the reference concrete is a normalised cement according to hEN 197-1. It is a blend cement containing pozzolana: CEM II/A or B – P. The cement is chosen in order that the pozzolana content range corresponds to the one of the "Product".

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 delivery 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. The carbonation depths of the concretes after 182 days storage shall be stated in the ETA.

Note: 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".

2.2.10 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 hEN 197-1 as reference shall be determined in accordance with the test method given in Annex B.

The resistance to chloride penetration shall be tested on concrete IIIa and IIIb, see table 4.

Table 4: Composition of concrete for the determination of the resistance to chloride penetration test – method D_{mig}

	Composition per m³ fresh concrete
concrete IIIa	c = 320 kg "Product" g = ….. kg aggregates [1] $\dfrac{w}{c}=0{,}50$ with w = effective water
concrete IIIb	c = 320 kg CEM I acc. to hEN 197-1 g = ….. kg aggregates [1] $\dfrac{w}{c}=0{,}50$ 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 B 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} shall be given in the ETA.

Method 2: Chloride diffusion coefficient - D_{diff}

The chloride diffusion coefficient shall be determined in accordance with the test method given in EN 12390-11:2015

The resistance against chloride penetration shall be tested on concrete IV_a (concrete made with the "Product") and concrete IV_b (reference concrete), see table 5.

The composition of concrete IV_a and concrete IV_b are chosen in accordance with limit values described in chosen exposure class XS1 in table F1 of EN 206.

Table 5: Composition of concrete for the determination of the resistance to chloride penetration test – method D_{diff}

	Composition per m³ fresh concrete
concrete IVa	c = 300 kg "Product" g = ….. kg aggregates [1] $\dfrac{w}{c}=0{,}50$ with w = effective water Strength class = C30/37
concrete IVb	c = 300 kg CEM II/A or B – P acc. to hEN 197-1 g = ….. kg aggregates [1] $\dfrac{w}{c}=0{,}50$ with w = effective water Strength class = C30/37

[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 composition of the 2 concretes is identical except the origin of the cement. The cement used to make the reference concrete is a normalised cement according to hEN 197-1. It is a blend cement containing pozzolana: CEM II/A or B – P. The cement is chosen in order that the its reactive silica content range corresponds to the one of the "Product".

The chloride diffusion coefficient of the concrete with "Product" is compared to the chloride diffusion coefficient of the reference concrete.

The chloride diffusion coefficient D_{diff} shall be given in the ETA.

2.2.11 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 C.

For test method given in Annex C, the dynamic modulus of elasticity, the expansion of prisms immersed in test solution compared with prism immersed under reference conditions for 20 °C storage after 90 days and after 180 days and for 5 °C storage after 90 days and a detailed description of the specimens immersed in test solution after 90 days and 180 days shall 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 D.

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 according to hEN 197-1).

For test method given in Annex D 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.

All values and notes shall be given in the ETA.

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[3].

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 process of assessment and verification of constancy of performance are laid down in Table 6.

Table 6   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	Reactive silicon dioxide content in pozzolanic material (Z)	See clause 2.2.1*	Declared level	6/year [2) 4)] 1/month [3) 4)]	
2	Cement composition	See clause 2.2.2*	Declared level	1/month[2] 1/week[3]	
3	Early strength (7 days)	See clause 2.2.3	Declared level	acc. to hEN 197-1 table 6	
4	Standard strength (28 days)	See clause 2.2.4	Declared class		
5	Initial setting time	See clause 2.2.5*	≥75 min acc. to hEN 197-1 table 3		
6	Soundness	See clause 2.2.6	≤ 10 min acc. to hEN 197-1 table 3		
7	Sulfate content	See clause 2.2.7*	≤ 3,5 % by mass acc. to hEN 197-1 table 4		
8	Chloride content	See clause 2.2.8*	≤ 0,10 % by mass[3] acc. to hEN 197-1 table 4		

*   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 be reduced to one per month

2)   Routine situation

3)   Initial period (3 month)

4)   The minimum frequency of auto control testing during routine testing and initial period testing and the conformity criteria shall be in accordance with the basic requirements given in the clause entitled "Conformity criteria" in the EN 197-1 clause 9.2.2. For cements not being dispatched continuously, the frequency of testing and the point of sampling shall be as specified in the Works' quality manual (according to EN 197-2 clause 4.3.1).

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

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3   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 7.

Table 7   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 hEN 197-2				
Continuous surveillance, judgment and assessment of factory production control (FPC)					
2	acc. to hEN 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	Reactive silicon dioxide content in pozzolanic material (Z)	See clause 2.2.1	Declared Level	1	6/year[*]
4	Cement composition	See clause 2.2.2	Declared Level	1	6/year[*]
5	Early strength (7 days)	See clause 2.2.3	Declared Level	1	6/year[*]
6	Standard strength (28 days)	See clause 2.2.4	Declared Class	1	6/year[*]
7	Initial setting time	See clause 2.2.5	≥75 min acc. to hEN 197-1 table 3	1	6/year[**]
8	Soundness	See clause 2.2.6	≤ 10 min acc. to hEN 197-1 table 3	1	6/year[*]
9	Sulfate content	See clause 2.2.7	≤ 3,5 % by mass acc. to hEN 197-1 table 4	1	6/year[*]
10	Chloride content	See clause 2.2.8	≤ 0,10 % by mass[3] acc. to hEN 197-1 table 4	1	6/year[*]
[*]	The number of samples taken shall be at least 6 per year for each certified cement dispatched continuously from the factory. When certain certified cements are not dispatched continuously, this frequency and the point of sampling may be altered by mutual agreement between the certification body and the manufacturer.				

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
hEN 197-1	Cement - Part 1: Composition, specification and conformity criteria for common cements
hEN 197-2	Cement - Part 2: Conformity evaluation
EN 206	Concrete - Specification, performance, production and conformity
EN 12620	Aggregates for concrete
CEN/TS 12390-10	Testing hardened concrete - Part 10: Determination of the relative carbonation resistance of concrete
EN 12390-11	Testing hardened concrete - Determination of the chloride resistance of concrete, unidirectional diffusion
RILEM CPC 18	Measurement of hardened concrete carbonation depth, Materials and structures, Vol. 21. (www.rilem.org)
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. (http://cur-aanbevelingen.nl)
EOTA TR 034	General Checklist for EADs/ETAs – Content and/or release of dangerous substances in products

ANNEX A - EVALUATION OF THE CARBONATION RESISTANCE

## Evaluation of the carbonation resistance - C$_{dcr}$

- February 2012 –

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		VC,140d	VC,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
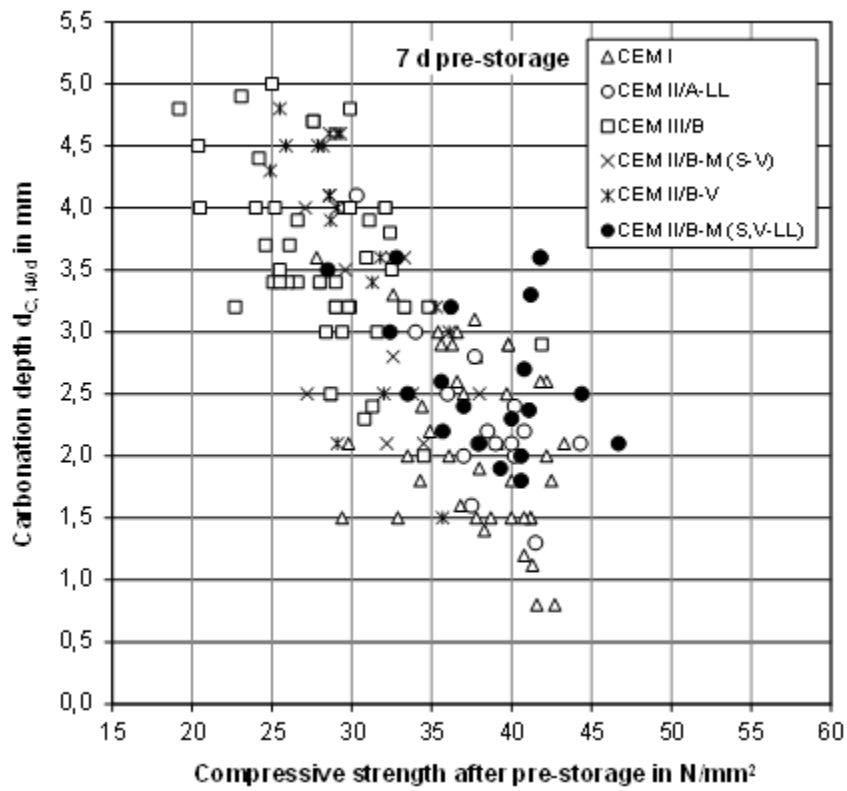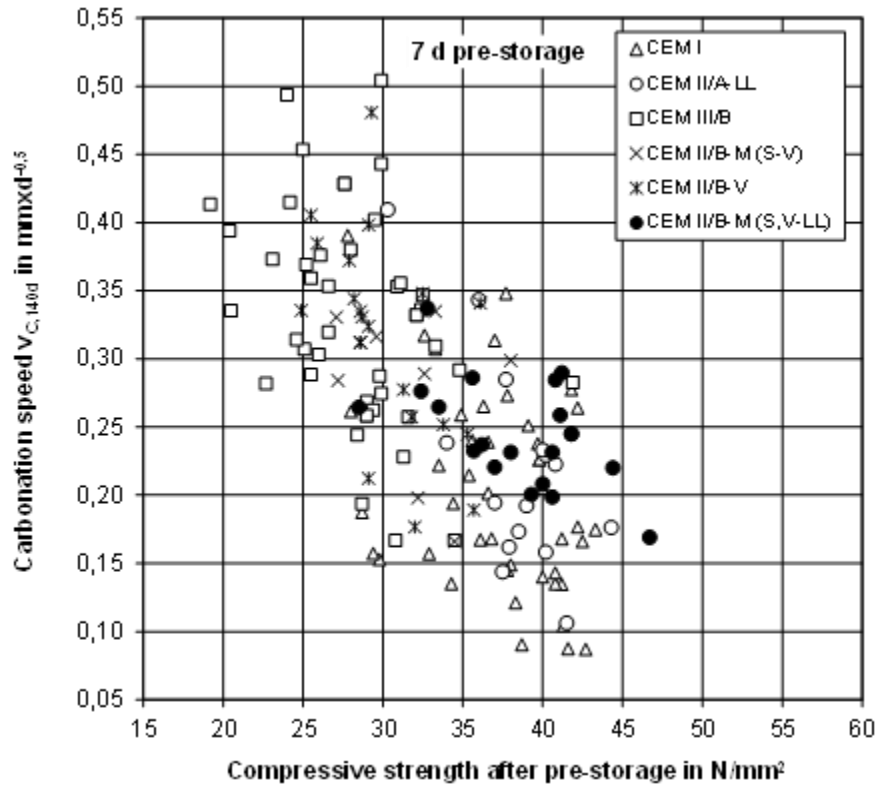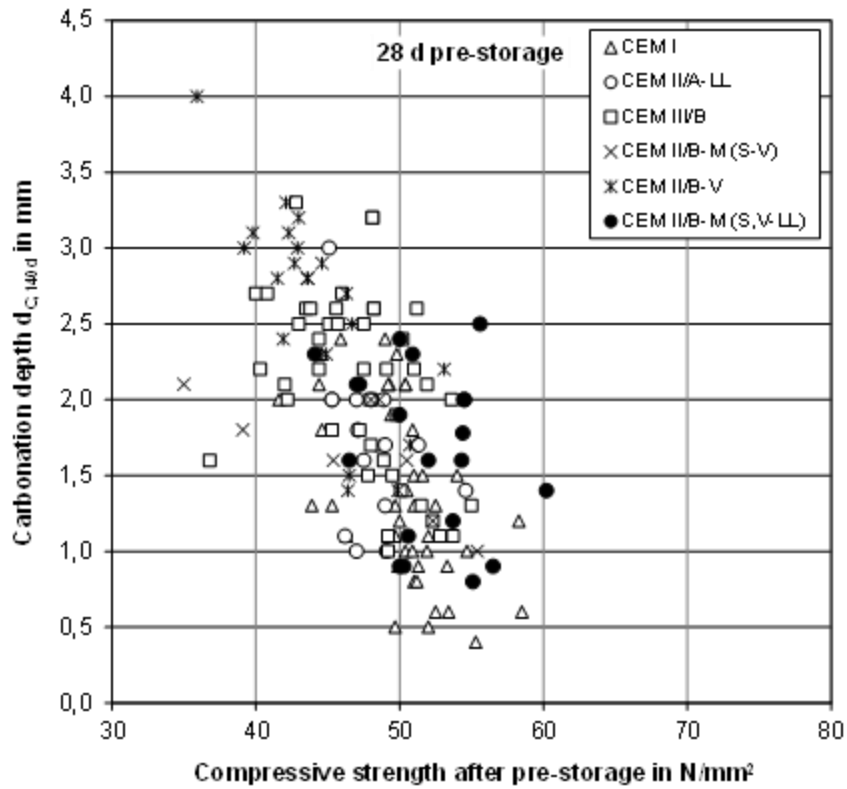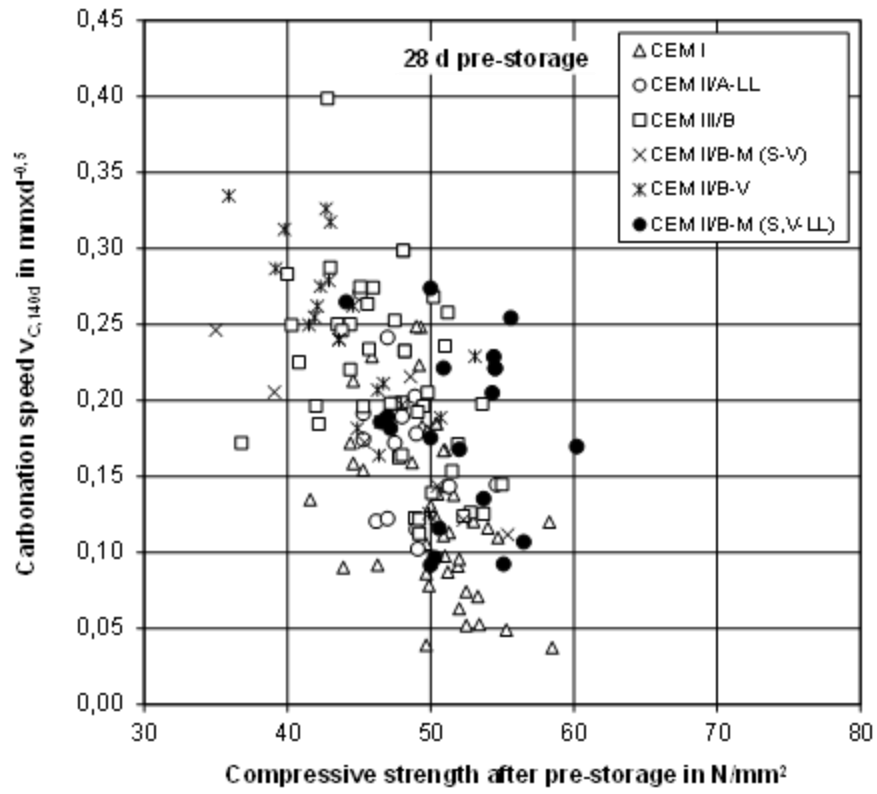
ANNEX B - TESTING THE RESISTANCE TO CHLORIDE PENETRATION BY THE NON-STEADY-STATE MIGRATION EXPERIMENTS

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

B.1 References

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

B.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.

B.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.

B.4 Test Method

B.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.

B.4.2 Reagents and apparatus

B.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.

B.4.2.2 Apparatus

- Water-cooled diamond saw.
- Migration set-up: One design (see Figure B.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 B.2).
    - Catholyte reservoir: plastic box, 370 × 270 × 280 mm (length × width × height).
    - Plastic support: (see Figure B.3).
    - Cathode: stainless steel plate (see Figure B.3), about 0.5 mm thick.
    - Anode: stainless steel mesh or plate with holes (see Figure B.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.

B.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 $\pm$ 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.

B.4.4   Test procedure

B.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.

B.4.4.2   Temperature

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

B.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 B.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 B.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.

B.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 B.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 B.1).
- Record the final current and temperature before terminating the test.

B.4.4.5   Measurement of chloride penetration depth

- Disassemble the specimen by following the reverse of the procedure in B.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 B.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 B.5).

B.5   Expression of results

B.5.1   Test results

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

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

Where:

$$E = \frac{U-2}{L} \tag{2}$$

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

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 $\mathrm{erf}^{-1}\left(1-\dfrac{2\cdot0,07}{2}\right)=1,28$, the following simplified equation can be used:

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

Where:

D_{nssm}:   non-steady-state migration coefficient, $\times10^{-12}$ 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.

B.6 Appendix

Table B.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).

a. Rubber sleeve   e. Catholyte
b. Anolyte   f. Cathode
c. Anode   g. Plastic support
d. Specimen   h. Plastic box
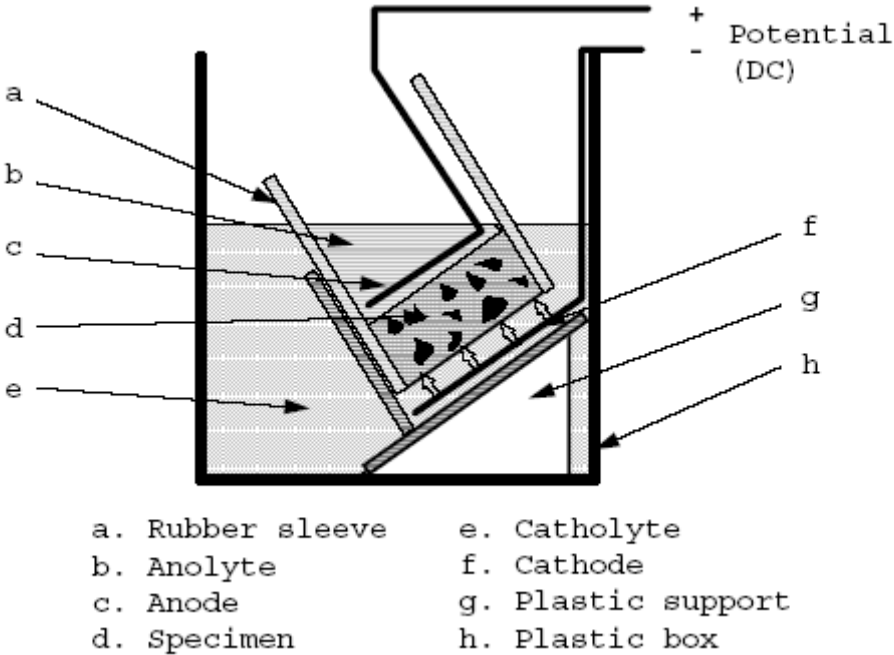
Figure B.1:   Arrangement of the migration set-up.
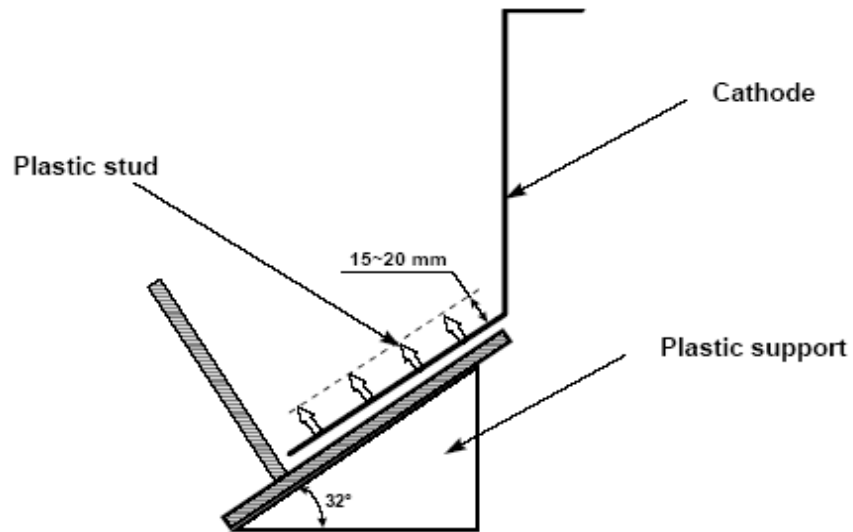

Figure B.2:   Stainless steel
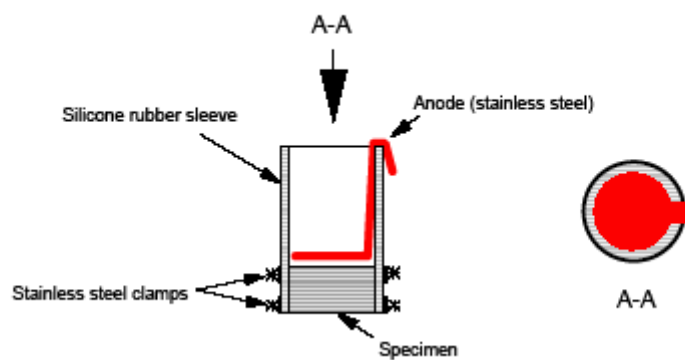
Figure B.3:　　Plastic support and cathode

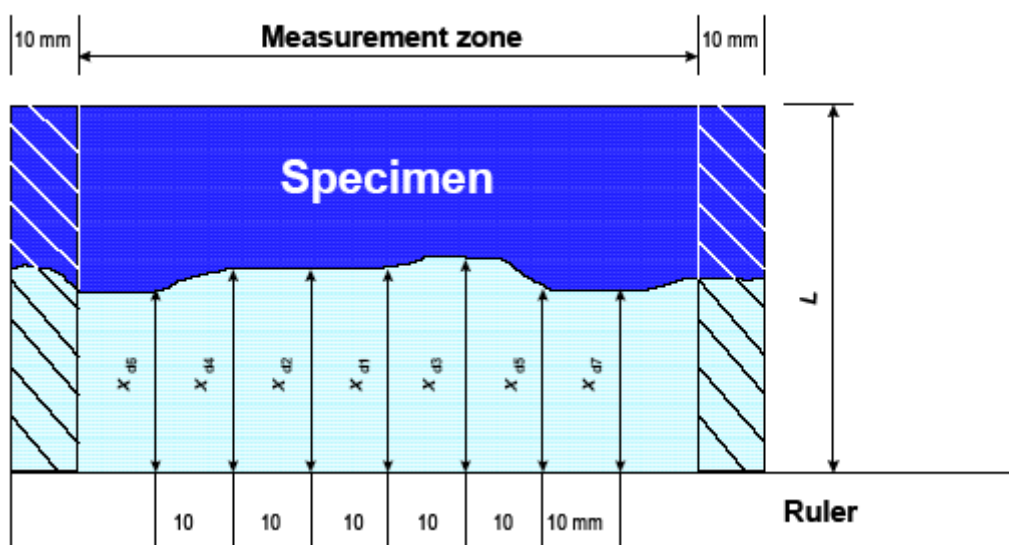Figure B.4:　　Rubber sleeve assembled with specimen, clamps and anode

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

ANNEX C - TESTING THE SULFATE RESISTANCE OF SPECIAL CEMENTS

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

- December 2011 -

C.1   References

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

C.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.

C.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.

C.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.

C.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.

C.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 D - TESTING THE SULFATE RESISTANCE

Testing the Sulfate Resistance –Square prism method S_{SPM}[4]

- February 2012 -

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

D.1   References

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

D.2   Apparatus and solution

D.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.

D.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.

D.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.

D.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.

D.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.

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[4]   This test method is identical to CUR 48.

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.

D.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

D.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.