

Minutes Meeting Delft August 30th 2018

WG1&2 “Correlation between atmospheric carbonation and carbonation induced by accelerated testing at high CO₂ concentrations” and “Effect of SCMs on natural and accelerated carbonation of blended Portland cements”

Members present:

Leon Black, Stefanie Van Greve-Dierfeld, Nele De Belie, Kosmas Sideris, Charlotte Thiel, Natalia Alderete, Philip Van Den Heede, Elke Gruyaert, Hanne Vanoutrive, Özlem Cizer, Jan Elsen, S. Kamali-Bernard, Ivan Ignjatović, Siham Kamali-Bernard, Karl-Christian Thienel, Carmen Andrade, Karen Skrivener, Barbara Lothenbach, Olonade Kolawole Adisa, Zengfeng Zhao U Liege

Discussion point 1 „Literature review“:

Presentation on Literature review WP 1&2 (Appendix A). Chapters were reorganized and some parts were added.

Survey for additional participants from other WP's in addition to the former E-Mail request within WG1&2. Additional participants were added. Chairs (names in bolt Appendix A) for a specific chapter were designated.

L. Black prepare skeleton outline with guidelines for words and figs. per section, reference style and abbreviations by September 2018 (Appendix B).

Chapters will be prepared before Christmas, compiled and mailed without much editing to all authors by half January 2019. Numbering will be performed during paper finalizing / editing process. Literature references will be given by Name & Year [Morandea2013].

Comments from authors (missing information ...) will be given by half February 2019.

Edited clean version will be finished by half March 2019 (before 3rd Meeting Rovinj, Croatia, 18-22 March 2019). The final editing will be performed by WG Chairs.

Discussion point 2 „round robin test“:

Round robin tests will be performed taking different standards. A compilation of standardized test conditions will be distributed by Susan Bernal (Appendix C). Each lab will perform carbonation tests following the standardized procedure in its country. For round robin testing mortar samples are favored. One goal is the ranking to different types of SCM (OPC, BFS, GGBS, MK...). Production of concrete/mortar is traditionally in one lab, but if the standards are very restrictive in preconditioning, than production should be performed in each specific lab.

Stefanie v. Greve-Dierfeld 13.09.2018

Appendix A

WP 1 & 2

Literature review

S.v. Greve-Dierfeld, Leon Black

| Parameter affecting carbonation and carbonation progress | Name |
|---|--|
| Mix design/SCM and effect on carbonation resistance (carbonation of portlandite /C-S-H (Ca/Si), CaCO₃ precipitation, pH, porosity evolution (sound, partly carbonated, carbonated)) | |
| Mechanisms of carbonation reactions | Barbara Lothenbach , Maciej Zajac, Özlem Cizer, Jan Elsen (Ku Leuven) |
| Carbonation of portlandite and Kinetics of CO₂ sequestration | Carmen Andrade , Özlem Cizer, Jan Elsen (Ku Leuven), Barbara Lothenbach |
| W/CaO_{reactive} resp. CaO content and age (degree of hydration) W/C | Kosmas Sideris, S. KAMALI-BERNARD Greve-Dierfeld |
| SCM | Kosmas Sideris, S. KAMALI-BERNARD Greve-Dierfeld , Olonade Kolawole Adisa |
| Aggregate: paste / mortar / concrete | Karen Scrivener , R. Douglas Hooton, Carmen Andrade |
| Other aggregates (type of aggregate, recycled aggregate, lightweight aggregate or additions SAP, PP, SF) | Cesar Medina , Isabel F. Saez del Bosque, Ivan Ignjatovic – recycled aggregate Karl-Christian Thienel (lightweight) Zengfeng Zhao U Liege (recycled aggregates) |

Parameter affecting carbonation and carbonation progress

Name

Curing and its effect on carbonation of concretes with different SCM / mix designs see above

Effect on carbonation resistance

Hanne Vanoutrive + **Elke Gruyaert**

S. KAMALI-BERNARD

Kosmas Sideris

Greve-Dierfeld

on porosity and pore size distribution

Natalia Alderete, Andrade

Interaction with CO₂ concentration (portlandite/C-S-H (Ca/Si, calcite precipitation))

Leon Black

| Parameter affecting carbonation and carbonation progress | Name |
|---|---|
| Constant conditions: acceleration / slowing / in dependency of SCM / changes with time in porosity | |
| Relative humidity/ degree of saturation effect on aging (Curing) | S. KAMALI-BERNARD Philip Van den Heede Greve-Dierfeld, Carmen Andrade, Charlotte Thiel |
| CO₂ concentration and partial pressure | Charlotte Thiel, Philip van den Heede, Nele De Belie |
| Concrete / mortar / paste properties/characteristics affecting carbonation resistance of different SCM (see SCM types above) | |
| Porosity and pore size distribution (uncarbonated/ partly carbonated/ carbonated) | Hanne Vanoutrive + Elke Gruyaert (on pastes) Natalia Alderete |
| Permeability/CO₂ diffusivity/sorptivity (uncarbonated/ partly carbonated/ carbonated) | S. KAMALI-BERNARD Greve-Dierfeld |

| Test conditions currently applied | Name |
|--|---|
| Temperature | Susan Bernal, Leon Black |
| Relative humidity | Susan Bernal, Leon Black |
| CO₂ concentration | Susan Bernal, Leon Black |
| pH indicator, pH at colour change, effect of e.g. temperature, moisture, pore solution on colour change | Hanne Vanoutrive + Elke Gruyaert Susan Bernal John Provis |
| measurement points in time, amount of measurements | Susan Bernal, Leon Black |
| Sample geometry, amount of samples (1D transport, radial transport, 2D...) | Susan Bernal, Leon Black |
| data evaluation/ determination of carbonation resistance, | Susan Bernal, Leon Black |
| standards | Susan Bernal, Leon Black |
| preconditioning and curing time (majority) | Susan Bernal, Leon Black |

Susan shares a table (with standard procedures) that is already compiled and others are requested to add missing information

No volunteers

- Grain size
- Paste/mortar/concrete
- (curing) Interaction with CO₂ concentration
portlandite/C-S-H (Ca/Si, calcite precipitation)
- Temperature

Guideline for ordinary papers Materials and Structures:

- ***8000 words***
- ***max. 15 tables and figures***

Appendix B

Factors affecting carbonation of blended Portland cements under natural and accelerated carbonation - Literature Review

Abstract

1 Introduction

1.1 Mechanisms of carbonation reactions

1.2 Carbonation of portlandite and Kinetics of CO₂ sequestration

2 Mix design and its effect on carbonation resistance

2.1 Buffering capacity, porosity (w/c, type of blend, amount of binder)

Note: W/CaO reactive resp. CaO content and age (degree of hydration) W/C; SCM

2.2 Interfacial transition zone

Note: Aggregate: paste / mortar / concrete

2.3 Type of aggregate

Note: recycled aggregate, lightweight aggregate

3 Curing time and type

3.1 Effect on porosity and pore size distribution

3.2 Effect on carbonation resistance

3.3 Effect on accelerated conditions

Note: Interaction with CO₂ concentration (portlandite/C-S-H (Ca/Si, calcite precipitation))

4 Effect of Environmental conditions on carbonation

4.1 Relative humidity

Note: degree of saturation effect on aging (Curing) and temperature

4.2 CO₂ Concentration and partial pressure

5 Effect of carbonation concrete performance

5.1 Concrete porosity and pore size distribution

Note: Porosity and pore size distribution (uncarbonated/ partly carbonated/ carbonated)

5.2 Its effect on transport properties

Note: Porosity and pore size distribution (uncarbonated/ partly carbonated/ carbonated) and its effect on Permeability/CO₂ diffusivity/sorptivity (uncarbonated/ partly carbonated/ carbonated)

6 Summary and outlook

Appendix C

Summary of standardised carbonation testing methods

| Test | Specimen specifications/ curing | Specimens preconditioning required | pH indicator | Exposure conditions | Carbonation reading |
|--|--|---|---|--|---|
| AFPC-AFREM, 1997 | | Specimens after 28 days of curing (immersed in water) are storage in controlled climatic conditions of 50% RH and 20°C until constant weight | 0.1% of phenolphthalein in an alcoholic solution | [CO ₂] -50% T- 20°C RH – 65 % | |
| BSI 1881-210:2013 (Testing hardened concrete. Determination of the potential carbonation resistance of concrete. Accelerated carbonation method) | For a single determination of carbonation depth, 100 mm or greater cubes may be used. Ensure that the shortest dimension of the prism/cube is not less than 4 times the maximum nominal upper aggregate size. Prisms not less than 280 mm long with a cross-section of not less than 70 mm x 70 mm from which slices approximately 50 mm thick can be split off at each date of carbonation testing. | Two concrete cubes are conditioned in a laboratory air environment for 14 days prior to sealing the top, bottom and two opposite side faces. After sealing of all but two faces, the cubes are placed in a storage chamber for a period of at least 70 days. When testing at more than one age, the prisms are conditioned in a laboratory air environment for 14 days prior to sealing the top, bottom and two end faces. After sealing all but two longitudinal faces, the prisms are placed in a storage chamber for the overall test period of at least 70 days. | 1g of phenolphthalein powder dissolved in a 100 ml solution of 70 ml ethanol and 30 ml of deionized water | [CO ₂] - 4.0 ±0.5% T -20 ±2°C RH - 55 ±5% | After 70 days exposure, the cubes are split in half perpendicular to the exposed faces, and the depth of carbonation is measured in accordance with this British Standard, which is taken from RILEM CPC-18, giving a single determination of the depth of accelerated carbonation. After each exposure period, a 50 mm slice is broken from each prism and tested for carbonation depth. After splitting off a slice, the split end faces of the prisms are sealed and the remainder of the prisms returned to the storage chamber. |
| CUR-Aanbeveling 48:2010 (Procedures, criteria and test methods for testing the suitability of novel cements for application in concrete and for the equivalent performance of concrete with fillers) | Natural carbonation. A minimum of 1 specimen should be tested of no less than 100 x 100 x 400 mm ³ . Desiccant should not be used or as little as possible applied, because its use can influence the carbonation depth After one day the specimens need to be stripped and stored at 20 °C and relative humidity (RH) of ≥ 95%. Accelerated carbonation. At least two sample should be tested of less than 100 x 100 x 400 mm ³ . Desiccant should not be used or as little as possible applied, because its use can influence the carbonation depth. After one day the specimens should be stripped and stored in a water bath of saturated lime at 20 ± 2°C. | Natural carbonation. In three day old samples paraffin wax should be applied in three layers on the two end faces, the finish side and the opposite side. Immediately after the application of the paraffin wax, the specimens need to be exposed to laboratory atmosphere at a temperature of 20 ± 2 °C and a relative air humidity of 65 ± 5% up to the moment of testing. Accelerated carbonation. At 28 days of age the samples are removed from the water bath and immediately stored for 14 days at (20 ± 2) °C and relative humidity of (65 ± 5)%. Afterwards paraffin wax should be applied in three layer in each specimen, in the two end faces (finishing side and the opposite side) | 1g of phenolphthalein dissolved in 70 mL of ethanol, diluted to 100 mL with distilled or deionised water | Natural carbonation [CO ₂] – 0,04% Accelerated carbonation - [CO ₂] – 4 ± 0,5% T – 20 ± 2 °C RH – 55 ± 5% | Natural carbonation. The carbonation depth must be determined on each specimen at a 91-day age on the fresh fracture surface of a split slab according to RILEM CPC-18. Additional measurements at 182 and 364 days of exposure are recommended for concretes with blast furnace slag or pulverized coal fly ash. Accelerated carbonation. After 56 days of exposure the carbonation depth of the specimens must be determined on the fresh fracture surface of a split slab according to RILEM CPC-18. On each side, the carbonation depth must be determined at five positions evenly distributed along the length of the side. The depth should be measured with an accuracy of 0.5 mm per position. The result for each specimen is the average of the ten measurement values. The end face of the specimens must be re-coated with three layers of paraffin wax after the slab has been split. |
| EN 12390 -10:2007 (Testing hardened concrete. Part 10. Determination of the relative carbonation resistance of concrete) | This is a method for evaluating the carbonation resistance of concrete mixes by comparison with a concrete mix with known carbonation resistance. For each mix, cast two prisms and at least 6 cubes or cylinders from a single batch of concrete. Cast the prisms horizontally. After finishing the prisms, cover the exposed surface with polythene or similar impermeable sheeting to prevent drying. After 24 h, the moulds shall be stripped and the prisms transferred without delay into a close-fitting, sealed polythene bag or similar storage material and stored at (20 ± 2) °C | After 50% of the 28d strength has been achieved by the cubes/cylinders, the prisms shall be removed from their polythene bags and placed in the storage chamber or under local environmental conditions. If outside conditions are chosen, the relative humidity shall be periodically measured. The prisms shall be positioned in a way that permits air to circulate freely around all faces. | A solution of 1 % phenolphthalein in 70 % ethanol. | [CO ₂] – 0,035 ± 0,005 % T - 20 ± 2°C RH - 65 ± 5 % | The carbonation front shall be measured at five points on each face. To locate these points the edge length shall be divided into eight equal distances. The five central points shall be used. With the help of a ruler or a sliding gauge and a magnifier, the carbonation depth shall be determined perpendicular to the surface of the prism with a precision of 0,2 mm per measured point. If the edges of the uncarbonated square are rounded off within the outer measuring points, then only the three central points are recorded. The depth of the carbonation front shall be measured on all four faces of both prisms giving a total of forty measurement points. The mean depth |

until they have reached 50 % of the reference strength.

Three cubes or cylinders shall be tested 28 d after casting. The other three cubes or cylinders shall be tested at different earlier ages to ascertain when 50 % of the reference strength has been achieved. Where the primary mix is designed to give the reference carbonation resistance, the cubes or cylinders shall be tested to ascertain when 50 % of the 28 d strength of the primary mix is achieved.

of carbonation shall be calculated and recorded for each face and the arithmetical average of the forty points shall be calculated and recorded.

The carbonation depth shall be measured at the following ages: 182 d, 273 d, 365 d, 547 d, 730 d ($\pm 2\%$) after placing in the storage chamber. Where the specimens are stored. The ages for measuring the carbonation depth shall be 365 d and 730 d ($\pm 2\%$) after placing on the exposure site and as specified thereafter. A slice approximately 50 mm thick shall be broken off the beam at each test age. The depths of carbonation on the freshly broken surface shall be measured.

Clear the broken surface immediately of dust and loose particles after breaking, and then spray with a fine mist of indicator solution. Avoid the formation of flow channels on the test surface. If only a weak colouration or none at all appears on the treated surface, spray again after 30 min.

The measurements shall begin at 1 h \pm 15 min after spraying and completed without a pause.

Accelerated testing: After finishing the test specimens, cover the exposed concrete surface with polythene or similar impermeable sheeting to prevent drying. After (24 \pm 2) h, the moulds shall be stripped and the test specimens transferred without delay into the EN 12390-2 standard curing condition. After 27 days of standard curing, the test specimens shall be exposed to laboratory air, T = (20 \pm 2) °C, RH = (65 \pm 5) % for (16 \pm 2) h and then they are placed in the climate controlled chamber.

Natural carbonation: For each concrete mix, cast at least two beams or at least six cubes for carbonation testing and at least 2 or if the strength development is not known, at least 5 compressive strength specimens from a single batch of concrete. After finishing the test specimens, cover the exposed surface with polythene or similar impermeable sheeting to prevent drying. After (24 \pm 2) h, the moulds shall be stripped and the carbonation test specimens transferred without delay into close-fitting, sealed polythene bags or similar storage material and stored at (20 \pm 2) °C until they have reached 50 % of the reference strength. If the temperature range is from 15 °C to 25 °C, 50 % of the reference strength may be assumed to have been achieved after 2 days for rapid, 4 days for medium and 7 days for slow concrete strength development.

A solution of 1g of phenolphthalein powder dissolved in a solution of 70 ml ethanol and 30 ml of deionized water

[CO₂] - 0,040 \pm 0,001%
T- 20 \pm 2°C
RH - 65 \pm 2%

After defined periods of exposure, an approximately 50 mm thick slice of the beam is broken off at each test age and tested for its carbonation depth. If cubes are being used, they are broken in half and one half of each cube is used to measure the carbonation depth, the other half being discarded.

The carbonation depth is measured at three locations on each face of each beam/cube giving a potential total of 12 measurements per specimen and potentially 24 measurements for the two specimens. The mean carbonation depth of all measurements is calculated. The remains of the beams are returned to the climate controlled chamber for testing at other pre-defined ages. Using at least three sets of measurements taken at 3 months, 6 months and 1 year, the rate of carbonation expressed as mm/ \sqrt{a} is determined. If the measured depth of carbonation is less than 5 mm at one year, the testing should be extended to two years.

FprEN 12390-10:2018
(Testing hardened concrete - Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide)

Pairs of beams of concrete (or two cubes per test age) from the same batch of concrete are stored in a climate controlled chamber or on a natural exposure site.

Note - The standardized climate controlled chamber procedure is the reference method.

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| <p>prEN 12390-12:2018 (Testing hardened concrete. Part 10. Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide.)</p> | <p>For each mix, cast two prisms or eight cubes from a single batch of concrete. After finishing the prisms/cubes, cover the exposed surface with polythene or similar impermeable sheeting to prevent drying. After 20 ± 4 h, the moulds shall be stripped and the prisms/cubes transferred without delay into a water filled bath with temperature control (20 ± 2)°C.</p> <p>After removal from the curing tank the specimens shall be immediately wrapped and sealed in polythene or similar material that will prevent drying during transportation. Alternatively they should be transported whilst remaining fully immersed in water e.g. in a mobile curing tank. On arrival at the test laboratory, the test specimens shall be unwrapped, checked for damage and then stored in a water filled curing tank with temperature control (20 ± 2) °C in accordance with EN12390-2 until they are 28 days old.</p> | <p>At an age of 28 days, the prisms/cubes shall be removed from the water bath and transferred to a laboratory air drying environment (18°C to 25°C, 50-65 % relative humidity) for 14 days. After 14 days of exposure to laboratory air, the test specimens shall be placed in the carbonation storage chamber.</p> <p>The prisms/cubes shall be positioned in a way that permits air to circulate freely around the faces where carbonation measurements are to be taken.</p> | <p>A solution of 1g of phenolphthalein powder dissolved in a solution of 70ml ethanol and 30 ml of deionised water</p> <p>[CO₂] - 3.00 ± 0.10% T - 20 ± 2°C RH - 57 ± 3 %</p> | <p>The carbonation depth of slices from the prisms or two of the cubes shall be measured after 7, 28 and 70 days of exposure.</p> <p>A slice approximately 50 mm thick shall be broken off the prism after each exposure period and the rest of the prism returned to the storage chamber. The cubes shall be split in half parallel to the trowelled face. The depths of carbonation on the freshly broken surface of the split slice of the prism or one half of the cube shall be measured.</p> <p>Clear the broken surface immediately of dust and loose particles after breaking, and then spray with a fine mist of indicator solution⁶. Avoid the formation of flow channels on the test surface. If only a weak colouration or none at all appears on the treated surface, spray again after 30 minutes.</p> <p>The measurements shall begin at 1 h ± 15 min after first spraying and completed without a pause, or if the readings cannot be started within this period, use a fixing solution to retain the colour without change. Where a fixing solution has been used, the timing of the depth measurements is not critical.</p> |
| <p>EN 13295:2004 (Products and systems for the protection and repair of concrete structures. Test methods. Determination of resistance to carbonation)</p> | <p>The test shall be carried out on rectangular specimens of various sizes. For a grout, mortar or concrete, a prism-shaped specimen of 40 mm x 40 mm x 160 mm shall be the minimum size used. For a concrete, with a maximum aggregate size of > 10 mm the minimum size of specimen shall be 100 mm x 100 mm x 400 mm.</p> | <p>For PCC (grouts, mortars and concretes) - Specimens covered with a plastic film for 24h, then demoulded and sealed again with a plastic film for 48h. After this, the samples are unwrapped and cured for 25 days under the same temperature and humidity conditions specified for the carbonation testing.</p> <p>For CC (grouts, mortars and concretes) - Specimens covered with a plastic film for 24h, then demoulded and cured under water at 21±2 °C for 27days.</p> | <p>1g of phenolphthalein dissolved in 70 mL of ethanol, diluted to 100 mL with distilled or deionised water</p> <p>[CO₂] -1%, T- 21 ± 2°C RH- 60 ± 10%</p> | <p>Carbonation depth shall be measured for both the test specimens and concrete at the end of the drying conditioning and then after 56 days in the cabinet. Carbonation shall be measured on freshly broken faces from each prism.</p> <p>For each measurement, a slide of 15 mm minimum thickness shall be broken off the prism using the chisel or bolster and the piece sprayed with the phenolphthalein indicator solution. Measurements of the depth of carbonation shall then be made (60 ± 5) min after spraying.</p> <p>The carbonation depth for the specimen is the average depth on all four sides.</p> |
| <p>prEN 14630:2013 (Products and systems for the protection and repair of concrete structures - Test methods - Determination of carbonation depth in</p> | <p>In situ testing may be carried out by chiselling from the structure under investigation to reveal an adequate area of freshly broken concrete. The test is normally carried out in situ.</p> <p>Alternatively, large fragments or core samples may be removed from the structure. Where cores are obtained by wet cutting or where the maximum nominal aggregate size exceeds 16 mm, the minimum nominal diameter of cores shall be 50 mm. Any surface water shall be removed from cores and fragments as quickly as possible. They shall be marked to indicate their location and orientation with respect to the</p> | <p>Not specified</p> | <p>A solution of phenolphthalein indicator normally 1g phenolphthalein is dissolved in 70 ml ethyl alcohol and diluted to 100 ml with distilled or deionised water.</p> <p>Not specified</p> | <p>Cores shall be split along their longitudinal axis and as nearly as possible across the diameter of the core.</p> <p>Large fragments (normally those with a smallest dimension of approximately 50 mm) shall be split as nearly as possible perpendicularly to the original external concrete surface; smaller fragments should not be split further but tested immediately after they are removed from the structure.</p> <p>The freshly broken surfaces shall be cleared of any dust and loose particles without the use of water or abrasion and shall be sprayed with just enough phenolphthalein indicator solution to wet the surface without running down the surface. The test shall be</p> |

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|--|--|---|---|---|--|
| hardened concrete by the phenolphthalein method) | original concrete surface, and shall then be stored in a dry place until tested, which should be as soon as possible after sampling. | completed as soon as possible after splitting the concrete face. | | | |
| GB T50082-2009 (previously GBJ 82-85) (Standard for test methods of long-term performance and durability of ordinary concrete) | <p>Rectangular prism (length to width ratio > 3) samples are preferred, with three duplicates included in each test group.</p> <p>Cubes can be used as alternatives. The number of duplicates included in each test group needs to be increased, given that each cube sample can only be tested once.</p> | <p>Samples after 28 days of curing under standard conditions should be used. For samples blended with supplementary cementitious materials (e.g. Fly ash), extended curing time may apply. Samples need to be preconditioned at 60°C for 48 hours prior carbonation exposure.</p> <p>After preconditioning, the prisms will be coated in melted paraffin wax, only leaving one (or two opposite) side to be exposed to carbonation. On the exposure surface, draw paralleled lines along the longitudinal axis every 10 mm, to provide indication points for measuring carbonation depth.</p> <p>The distance between samples in the carbonation chamber should be more than 50 mm.</p> | 1% phenolphthalein solution prepared in water diluted ethanol (ethanol to water ratio 4:1) | [CO ₂] -20%, T- 20 ± 2°C RH- 70 ± 5% | <p>Carbonation depths are measured at after 3d, 7d and 28 days of exposure, then split perpendicular to the exposed surface.</p> <p>The average of individual carbonation depth measured at each indication points is recorded as carbonation depth of one tested sample. The average 28 days carbonation depth of three duplicates in the same group is used as evaluation indicator.</p> <p>Evolution of carbonation depth plotted overtime is assessed, but not used as criterial for comparison between different samples.</p> |
| ISO/DIS 1920-12 (Testing of concrete. Determination of the carbonation resistance of concrete. Accelerated carbonation method) | <p>For the determination of the depth of carbonation at one exposure period, two cubic specimens having a cross-section of 100 mm or greater shall be prepared.</p> <p>For the determination of the depth of carbonation at more than one exposure period on the same test specimen, two prisms, 400 mm long and having a cross-section of 100 × 100 mm shall be prepared.</p> <p>The shortest dimension of the specimen, cube or prism, shall not be less than four times the maximum nominal upper aggregate size. Avoid or minimize the use of mould release agents, as they may influence the carbonation depth.</p> | <p>At an age of 28 days, the prisms/cubes shall be removed from the water bath and transferred for 14 days to a laboratory air drying environment having a temperature of (18 – 29) °C and relative humidity of (50-70) %.</p> <p>After 14 days conditioning, the top and bottom longitudinal faces and the two end faces of prisms (or top, bottom and two side faces of cubes) shall be sealed using paraffin wax or a similar material that will prevent ingress of carbon dioxide and allow carbonation on two cast longitudinal surfaces.</p> <p>Once the prisms/cubes have been sealed, they shall be placed in the storage chamber. The prisms/cubes shall be positioned in such a way that their exposed faces are vertical, and that permits air to circulate freely around the two faces that are to be carbonated.</p> | A solution of 1g of phenolphthalein powder dissolved in a 100 ml solution of 70 ml ethanol and 30 ml of deionised water | [CO ₂] – 4.0 ± 0.5 % T- 20 ± 2°C RH- 55 ± 5% <u>In hot climates</u> T - 27 ± 2°C RH - 65 ± 5%. | <p>The carbonation depth of prisms shall be measured after the following exposure periods: 56, 63 and 70 days or as specified after placing in the storage chamber. The carbonation depth of cubes shall be measured at 70 days unless specified otherwise. A slice approximately 50 mm thick shall be broken off the prism after each exposure period and the split surface on the remaining prism resealed to prevent longitudinal carbonation (Figure 1b). Where a single determination of the carbonation depth is made on a cube after 70 days of storage, the cube shall be split in half. The depths of carbonation on the freshly broken surface of the split slice shall be measured.</p> <p>Clear the broken surface immediately of dust and loose particles after breaking, and then spray with a fine mist of indicator solution. Avoid the formation of flow channels on the test surface. If only a weak colouration or none at all appears on the treated surface, spray again after 30 min. The measurements shall be conducted after the colour has stabilized.</p> |

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|--|--|---|---|---|---|
| LNEC E391:1993 (Concrete. Determination of accelerated carbonation) | The test may be carried out on laboratory cast concrete or mortar specimens of various shapes. Specimen may, in the case of concrete, be either of the cylinder type with diameter 100 mm and length 200 to 300 mm, or prisms with cross section 100 x 100 mm and length 300 - 500 mm. | Samples cured submerged in water for 14 days at 20 ± 2°C, and stored in an enclosed environment at 50 ± 5% RH and 20 ± 2°C until 28 days | 0.1% of phenolphthalein in an alcoholic solution | [CO ₂] - 5 ± 0.1% T- 23 ± 3°C RH – 55-65 % | After sampling, the specimens are placed inside the compartment, and exposed to the carbonation atmosphere. The carbonation depth is measured at least once a month. |
| NT Build 357 (Concrete, repairing materials and protective coating – carbonation resistance) | In the case of mortar, the RILEM prism type of 40 x 40 x 160 mm size may be used. The test is carried out with 2 or 3 parallel samples. | Specimens are stripped 1 day after casting, and cured in water at 20 ± 2°C for 14 days, then cured in air at 50 ± 5% RH, 20 ± 2°C until reaching a total of 28 days of curing | A solution of 1g phenolphthalein dissolved in 500 mL of distilled/ion exchanged water, and 500 mL ethanol | [CO ₂] -3%, T- no specified RH – 55-65 % | The specimens to be tested are compared with a reference concrete made of 300 - 350 kg Ordinary Portland Concrete (or equivalent), per m ³ concrete, water to cement ratio 0.60 ± 0.01, slump 120 ± 20 mm and a well graded aggregate with d _{max} 16 mm. |
| RILEM CPC-18 (Measurement of hardened concrete carbonation depth) | Concrete prisms with a cross-section of 100 mm x 100 mm that can be split into lengths of roughly 50mm, for each date of testing, are suitable. For mortar, prisms 40 mm x 40 mm x 160 mm are recommended from which a slice of roughly 20 mm is split off at each date of testing. In no case shall the shortest dimension of the prism be less than 3 times maximum aggregate size. For natural carbonation (e.g. indoor or outdoor storage) air must be able to reach the test surfaces unhindered at all times. For this reason, leave a free space of at least 20 mm around the specimens. | Not specified | A solution of 1% phenolphthalein in 70% ethanol | For indoor or outdoor storage, climate conditions must be precisely defined. For indoor storage ~ [CO ₂] – 0.03%, T - 20°C RH - 65% recommended. [CO ₂] – Not specified T- 20°C RH - 65% | The measured depth of carbonation is influenced by the time of measuring after application of the indicator solution. Therefore, measurements within a series of tests should always be made at the same time. Measuring about 24 hours after spraying is recommended, when the margin between carbonated and non-carbonated concrete is often more clearly demonstrated than at earlier measuring times. The precision of the measurement must be to the nearest 0.5 mm. Carbonation depths less than 0.5 mm are not differentiated. |
| UNI 9944:1992 (Corrosion and protection of reinforcing steel in concrete. Determination of the carbonation depth and of the chlorides penetration profile in concrete) | Not specified | Not specified | A solution of 1% phenolphthalein in ethanol | Not specified | Not specified |

NOTE – Some of the standards specify mixing, casting and curing conditions for specimens that are going to be tested

For alternative binders

- **BRE IP 11/98 (UK recommendation)** – Assessing carbonation depth in ageing high alumina cement concrete