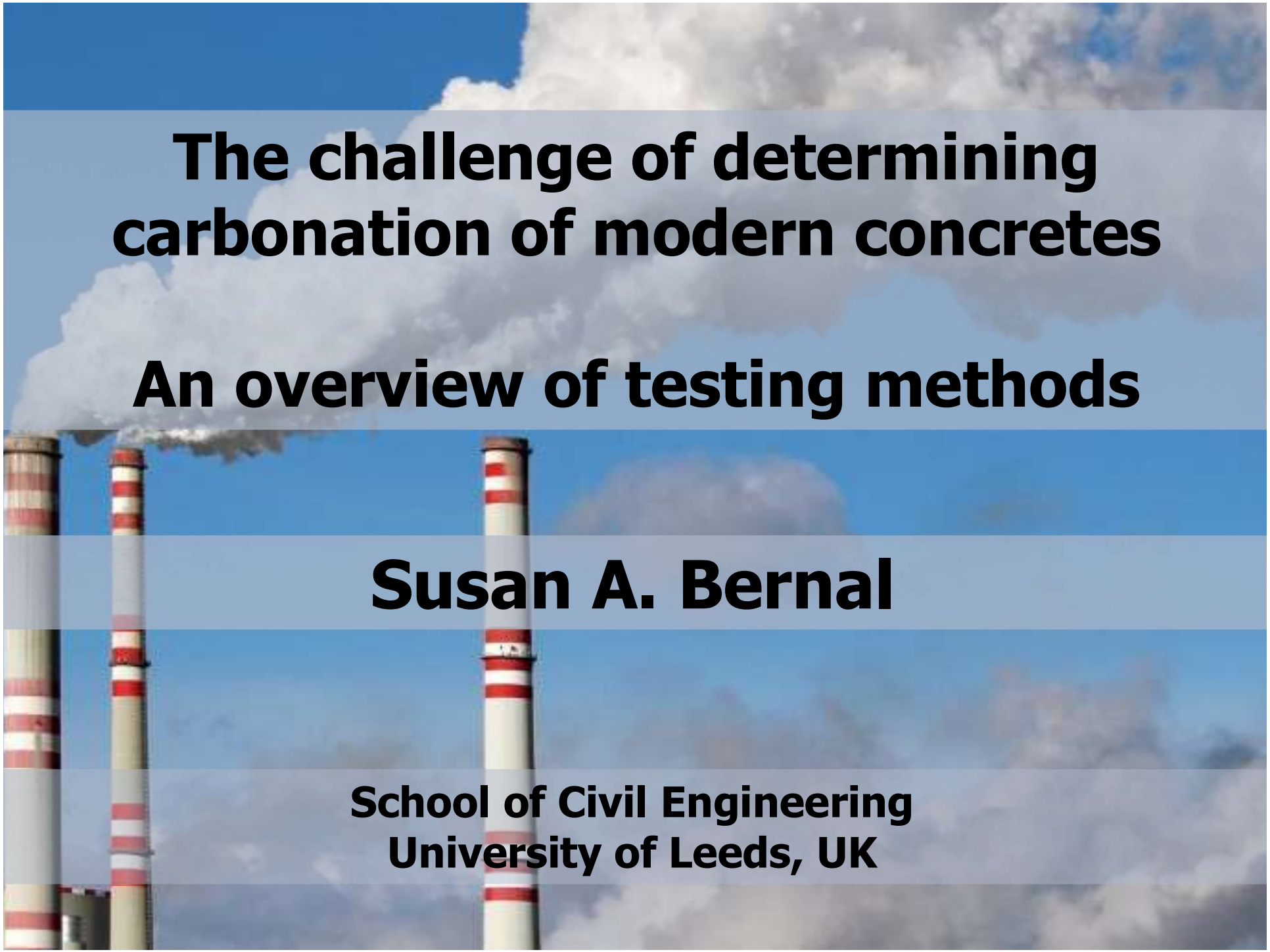


The challenge of determining carbonation of modern concretes

An overview of testing methods

Susan A. Bernal

School of Civil Engineering
University of Leeds, UK

Proposed paper outline

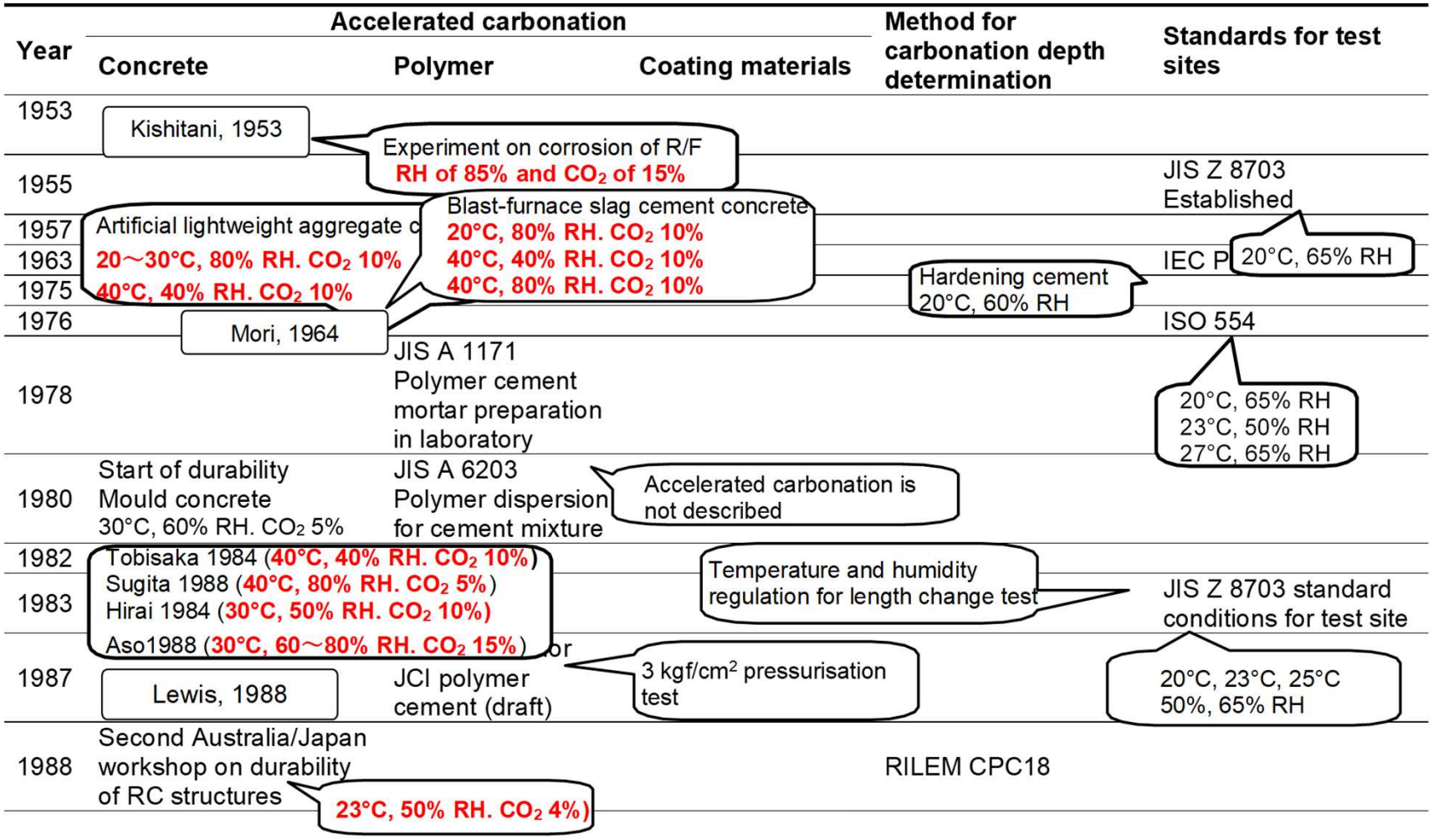
- Example of standardised testing methods development
- (Japan experience – Hokkaido U)

- Effect of pre-conditioning (B.Lothenbach & S. Bernal)
  - Emphasising on effect on hydration degree
  - Potential drying shrinkage
  - Degree of saturation of specimens

- Effect of exposure conditions (A. Vollpracht)
  - CO2 concentration (natural vs. accelerated)
  - Relevance of RH and T used in testing for different climates

- pH measurements (C. Thiel)
  - Different types of indicators, time when reading needs to be made
  - Relevance of pH changes in terms of durability of SCM containing concrete

Carbonation testing conditions - Japan



Courtesy of Elakneswaran Yogarajah, Hokkaido University

Carbonation testing conditions - Japan

UNIVERSITY OF LEEDS

Year	Accelerated carbonation			Method for carbonation depth determination	Standards for test sites
	Concrete	Polymer	Coating materials		
1991	AIJ high durability reinforced concrete design and construction guidelines (draft)		Metropolitan expressway public corporation, Coating of concrete and repairing criteria for FRP (draft)		
1992	20°C, 60% RH. CO_2 5%			JHS311 Japan highway Test method for carbonation of concrete	
1996		JIS A 6203 Polymer dispersion and dispersible polymer powder for cement mixture	30°C, 60% RH. CO_2 5%		
1999			JHS417 Japan Highway Public Corporation Quality standard test methods for concrete coating materials	30°C, 60% RH. CO_2 5% Acceleration period 1 month and carbonation depth less than 1 mm	
2000	Transfer test method from JIS A 6203	JIS A 1171	Tokaido Maintenance standard for Shinkansen concrete structure	20°C, 60% RH. CO_2 5% Acceleration period 70 days and carbonation depth less than 3 mm	

Courtesy of Elakneswaran Yogarajah, Hokkaido University

Carbonation testing conditions - Japan

Year	Accelerated carbonation			Method for carbonation depth determination	Standards for test sites
	Concrete	Polymer	Coating materials		
2001	JIS Planning Committee				
2002				JIS A 1152 Method for measuring carbonation depth of concrete	
2003	JIS A 1153 Method of accelerated carbonation test for concrete				
2004			Revison of JHS417 JSCE-K571 Test methods for surface impregnation materials		
2010	ISO/CD1920-12				

20°C, 60% RH. CO_2 5%

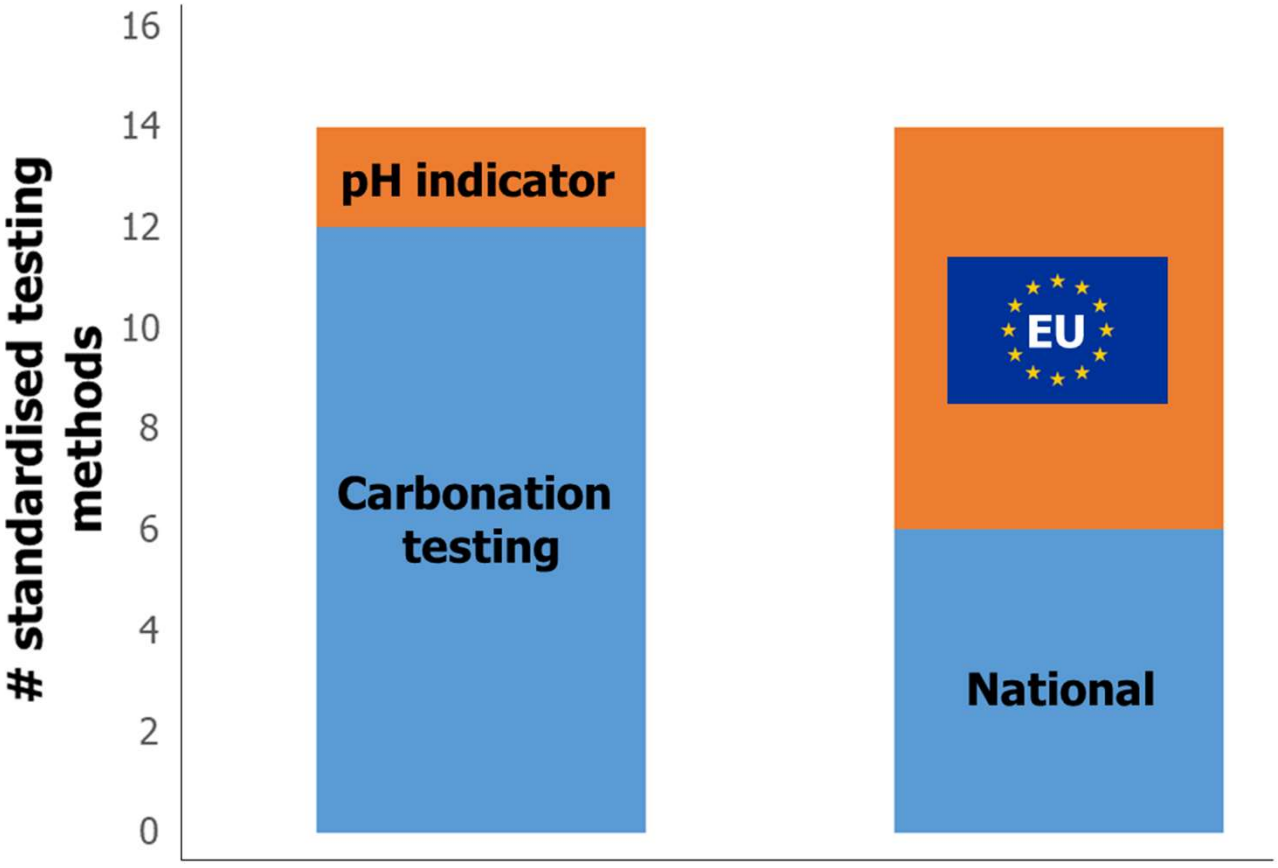
23°C, 50% RH. CO_2 4%

20°C, 60% RH. CO_2 5%

Courtesy of Elakneswaran Yogarajah, Hokkaido University

To the best of my knowledge

Carbonation tests



USA and Canada do not have standardised tests for carbonation

**Data from 2018-2019*

Sample pre-conditioning

Test	Specimens preconditioning required
BSI 1881-210:2013	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.
CUR-Aanbeveling 48:2010	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)
EN 12390 -10:2007	**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.
FprEN 12390-10:2018	Accelerated testing: After finishing the test specimens, cover the exposed concrete surface with polythene or similar impermeable sheeting to prevent drying. After (24 ± 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 ± 2) °C, RH = (65 ± 5) % for (16 ± 2) h** and then they are placed in the climate controlled chamber.

Sample pre-conditioning

Test	Specimens preconditioning required
GB T50082-2009 (previously GBJ 82-85)	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 60ºC for 48 hours prior carbonation exposure.**
ISO/DIS 1920-12	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) %.**
NT Build 357	Specimens are stripped 1 day after casting, and **cured in water at 20 ± 2ºC for 14 days**, then cured in air at **50 ± 5% RH, 20 ± 2ºC** until reaching a total of 28 days of curing
RILEM CPC-18	Not specified

Carbonation reading

Test	Carbonation reading
BSI 1881-210:2013	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.
CUR-Aanbeveling 48:2010	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.**

RILEM CPC-18

The measured **depth of carbonation is influenced by the time of measuring** after application of the indicator solution …. **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.

Exposure conditions

UNIVERSITY OF LEEDS

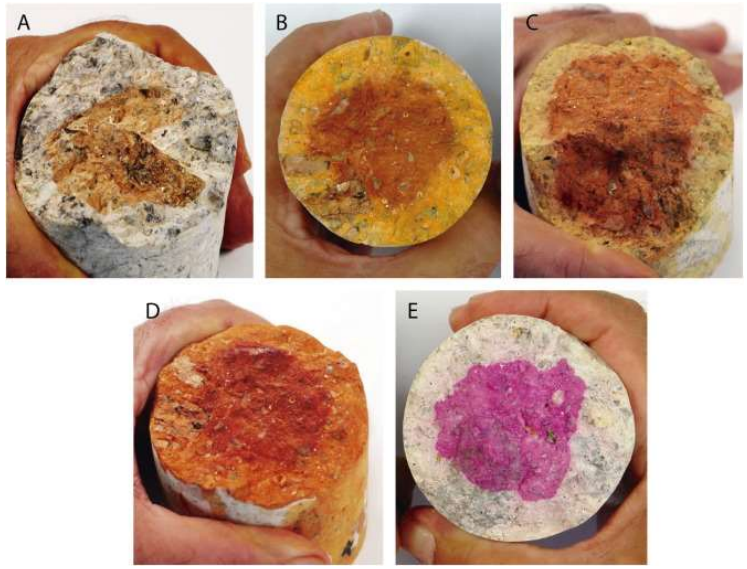
Test	Exposure conditions
prEN 12390-12:2018 Testing hardened concrete. Part 10. Determination of the carbonation resistance of concrete – accelerated carbonation method	**[CO_2] - 3.00 ± 0.10%** T - 20 ± 2°C RH - 57 ± 3 %
EN 13295:2004 Products and systems for the protection and repair of concrete structures. Test methods. Determination of resistance to carbonation	**[CO_2] - 1.0 %** T- 21 ± 2ºC RH- 60 ± 10%
EN 12390 -10:2007 Testing hardened concrete. Part 10. Determination of the relative carbonation resistance of concrete	**[CO_2] – 0,035 ± 0,005 %** T - 20 ± 2°C RH - 65 ± 5 %
FprEN 12390-10:2018 Testing hardened concrete - Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide	**[CO_2] - 0,040 ± 0,001%** T- 20 ± 2°C RH - 65 ± 2%

Exposure conditions

Test	Exposure conditions
NT Build 357 Concrete, repairing materials and protective coating – carbonation resistance	**[CO_2] -3%** T- no specified RH – 55-65 %
RILEM CPC-18 Measurement of hardened concrete carbonation depth	For indoor or outdoor storage, climate conditions must be precisely defined. For indoor storage **~ [CO_2] – 0.03%** T - 20ºC RH - 65% recommended.
prSIA 262/1: 2017 Concrete Structures: Supplementary Specifications	Natural carbonation **[CO_2] < 0,15 %** T – 20 ± 2 °C RH – 57 ± 3 Accelerated carbonation **[CO_2] – 4,0 ± 0,1 %** T – 20 ± 2 °C RH – 57 ± 3
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

pH indicator

According to Regulation (EC) No 1272/2008 (2008), phenolphthalein is suspected of causing genetic defects and can cause cancer



Concrete cores stained with curcumin solutions of 0.25% (A), 0.50% (B), 0.75% (C) and 1% (D) and with phenolphthalein solution 1% (E).

Chinchón-Payá et al. 2016. Cement and Concrete Research. 82:97-91

Acknowledgements

Member of the **RILEM Technical Committee 281-CCC** – Carbonation of Concrete with Supplementary Cementitious Materials, particularly member of WG1&2 and WG5

This study was sponsored by EPSRC through ECF EP/R001642/1.

Susan A. Bernal Lopez BEng DEng FIMMM
s.a.bernallopez@leeds.ac.uk