BS 1881-210:2013

BSI Standards Publication

Testing hardened concrete

Part 210: Determination of the potential carbonation resistance of concrete – Accelerated carbonation method

bsi.

...making excellence a habit.™

Publishing and copyright information

The BSI copyright notice displayed in this document indicates when the document was last issued.

Published by BSI Standards Limited 2013

ISBN 978 0 580 78352 4

ICS 91.100.30

The following BSI references relate to the work on this standard:
Committee reference B/517
Draft for comment 12/30260361 DC

Publication history

First (present) edition June 2013

Amendments issued since publication

Date	Text affected

Contents

Annexes

List of figures

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 14, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 1881 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 June 2013. It was prepared by Technical Committee B/517, *Concrete and related products*. A list of organizations represented on this committee can be obtained on request to its secretary.

Information about this document

This part of BS 1881 is based on prTS12390-12, which received a negative vote. Consequently the CEN work item has been deleted. As this standard reflected UK experience with accelerated carbonation testing, it has been published as a British Standard with modifications to eliminate the various options.

Relationship with other publications

BS 1881 is published in the following parts:

- BS 1881-113, *Method for making and curing no-fines cubes*;
- BS 1881-119, *Method for determination of compressive strength using portions of beams broken in flexure (equivalent cube method*);
- BS 1881-122, *Method for determination of water absorption*;
- BS 1881-124, *Methods for analysis of hardened concrete*;
- BS 1881-125, *Method for mixing and sampling fresh concrete in the laboratory*;
- BS 1881-128, *Method for analysis of fresh concrete*;
- BS 1881-129, *Method for the determination of density of partially compacted semi-dry fresh concrete*;
- BS 1881-130, *Method for temperature matched curing of concrete specimens*;
- BS 1881-131, *Methods for testing cement in a reference concrete*;
- BS 1881-201, *Guide to the use of non-destructive methods of test for hardened concrete*;
- BS 1881-204, *Recommendations on the use of electromagnetic covermeters*;
- BS 1881-206, *Recommendations for determination of strain in concrete*;
- BS 1881-207, *Recommendations for the assessment of concrete strength by near-to-surface tests*;
- BS 1881-208, *Recommendations for the initial surface absorption of concrete*;
- BS 1881-209, *Recommendations for the measurement of dynamic modulus of elasticity of concrete*;
- DD 216, *Determination of chloride content of fresh concrete*.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This page deliberately left blank

Introduction

Ferrous steel reinforced concrete structures need to be durable to ensure that the intended working life is achieved. The corrosion of reinforcement induced by carbonation can play a significant role in a structure's serviceability and consequently, carbonation resistance of concrete is an important property to measure.

1 Scope

This part of BS 1881 describes a method for ranking the potential carbonation resistance of concrete using an accelerated carbonation test.

NOTE 1 This test is an accelerated test because there is exposure to much higher than atmospheric levels of CO_2 *and is at a relative humidity conducive to a maximum rate of carbonation.*

NOTE 2 The test under reference conditions takes a minimum of 112 days comprising a minimum age of the specimen prior to conditioning of 28 days, a minimum conditioning period of 14 days and a minimum exposure to increased CO_2 *levels of 70 days.*

NOTE 3 The use of such test data in service-life modelling is still a matter of much academic debate and at present there is no consensus on an appropriate model.

It is not a method for the determination of carbonation depths in existing concrete structures.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensible for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 12350-2, *Testing fresh concrete – Part 2: Slump test*

BS EN 12350-3, *Testing fresh concrete – Part 3: Vebe test*

BS EN 12350-4, *Testing fresh concrete – Part 4: Degree of compactability*

BS EN 12350-5, *Testing fresh concrete – Part 5: Flow table test*

BS EN 12390-1, *Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds*

BS EN 12390-2:2009, *Testing hardened concrete – Part 2: Making and curing specimens for strength tests*

BS EN 12390-3, *Testing hardened concrete – Part 3: Compressive strength of test specimens*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 depth of carbonation

depth measured using a phenolphthalein solution sprayed on the freshly-split concrete surface

3.2 single point carbonation depth
depth of carbonation measured at a single point on a specimen, $d_{k,\ point}$

3.3 specimen face carbonation depth
mean depth of carbonation of a single exposed face of a single specimen, $d_{k,\ face}$

3.4 specimen carbonation depth
mean depth of carbonation of a single specimen, $d_{k,\ spec}$

3.5 mean carbonation depth
mean depth of carbonation of two specimens, d_k

4 Principle

Two concrete cubes are cast and cured for 28 days in accordance with BS EN 12390-2. The two concrete cubes are then 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 with CO_2 level of (4.0 ±0.5)%, temperature (20 ±2) °C and relative humidity (55 ±5)% for a period of at least 70 days. 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 [1], giving a single determination of the depth of accelerated carbonation.

NOTE Experience has shown that reliance on a single determination of accelerated carbonation depth might (rarely) give a non-representative value [2]. This risk is eliminated by testing at five weeks, seven weeks and ten weeks and inspecting the resulting curve for any unusual value.

When testing at more than one age, concrete prisms are used. Two prisms are cast and cured for 28 days in accordance with BS EN 12390-2. 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 with CO_2 level of (4.0 ±0.5)%, temperature (20 ±2) °C and relative humidity (55 ±5)% for the overall test period of at least 70 days. 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.

Ten single point carbonation depths, $d_{k,\ point,}$ are measured after each exposure period on each prism or cube and the depth of carbonation, d_k, is expressed as the mean of the 20 readings.

5 Reagents and apparatus

5.1 *Paraffin wax or equivalent,* to seal the non-exposed faces of test specimens.

5.2 *Solution of 1g of phenolphthalein powder dissolved in a 100 ml solution of 70 ml ethanol and 30 ml of deionized water.*

WARNING. The European Chemical Agency is proposing that phenolphthalein is classified as a substance of very high concern on the basis of its classification as carcinogen category 1B. Handle phenolphthalein powder using safety gloves in a fume cupboard fitted with an extractor.

5.3 *Magnifier and gauge,* capable of measuring the depth of carbonation perpendicular to the exposed concrete surface with a precision of 0.2 mm.

5.4 *Storage chamber,* with a CO_2 concentration (4.0 ±0.5)% by volume, temperature (20 ±2) °C and relative humidity (55 ±5)%.

NOTE 1 See Annex A for information on a suitable chamber.

NOTE 2 Experience [3] has shown that if saturated surface-dry specimens are placed in the storage chamber shortly after removal from water curing, the relative humidity might exceed that permitted. Also, in storage chambers without active control of the levels can drop below the permitted tolerance as the carbonation process continues. The storage chamber should therefore have active control on relative humidity and temperature.

NOTE 3 Relative humidity levels may be maintained using methods at the discretion of the laboratory, for example by active humidification and/or dehumidification or saturated salt solutions.

5.5 *Apparatus for recording the relative humidity,* with a precision of ±2.0% and the temperature with a precision of ±0.5 °C.

5.6 *Apparatus for recording CO_2 concentration*, with a precision of ±0.1% by volume.

NOTE Recording apparatus should be fitted with an audio or visual alarm to alert breaches of CO_2 concentration within the storage chamber due to possible apparatus malfunction.

5.7 *Fans,* capable of facilitating steady circulation of air within the storage chamber.

6 Production of specimens

6.1 General

Make cubes and/or prisms for the determination of the carbonation resistance in accordance with this British Standard. If the specimens are to be made by a test laboratory, supply them with a full specification including the mix quantities and the mixing procedure, and where appropriate, the constituent materials. Where the specimens are prepared by the client or their representative, inform the test laboratory of the day of casting and record that the specimens were stored in accordance with this British Standard.

Ensure prisms are not less than 280 mm long with a cross-section of not less than 70 mm × 70 mm from which slices approximately 50 mm thick can be split off at each date of carbonation testing. 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.

NOTE The use of mould release agents on the prism/cube moulds should be avoided as they can influence the carbonation depth.

6.2 Making prism/cubes and making and testing prism and cubes

6.2.1 For each mix, cast two prisms/cubes from a single batch of concrete. Cast prisms horizontally in accordance with BS EN 12390-2:2009, **5.1** to **5.4**.

6.2.2 After finishing the prisms/cubes, cover the exposed surface with polythene or similar impermeable sheeting to prevent drying.

6.2.3 After (20 ±4) h, strip the moulds and transfer the prisms/cubes without delay into a water filled bath with temperature control (20 ±2) °C in accordance with BS EN 12390-2.

NOTE 1 At least two compressive strength specimens should be made and tested in accordance with BS EN 12390-2 at 28 days. Where a number of mixes are made, additional testing, e.g. the 28 day strength, should be undertaken to confirm consistent manufacture, or identify anomalous batches where mixes might need to be repeated.

6.2.4 Upon removal of the specimens from the curing tank, immediately wrap and seal them in polythene or a similar material that can prevent drying during transportation or transport them whilst remaining fully immersed in water, e.g. in a mobile curing tank.

6.2.5 On arrival at the test laboratory, unwrap and ensure that the test specimens have not been damaged.

6.2.6 Store the test specimens in a water filled curing tank with temperature control (20 ±2) °C in accordance with BS EN 12390-2:2009 until they are 28 days old.

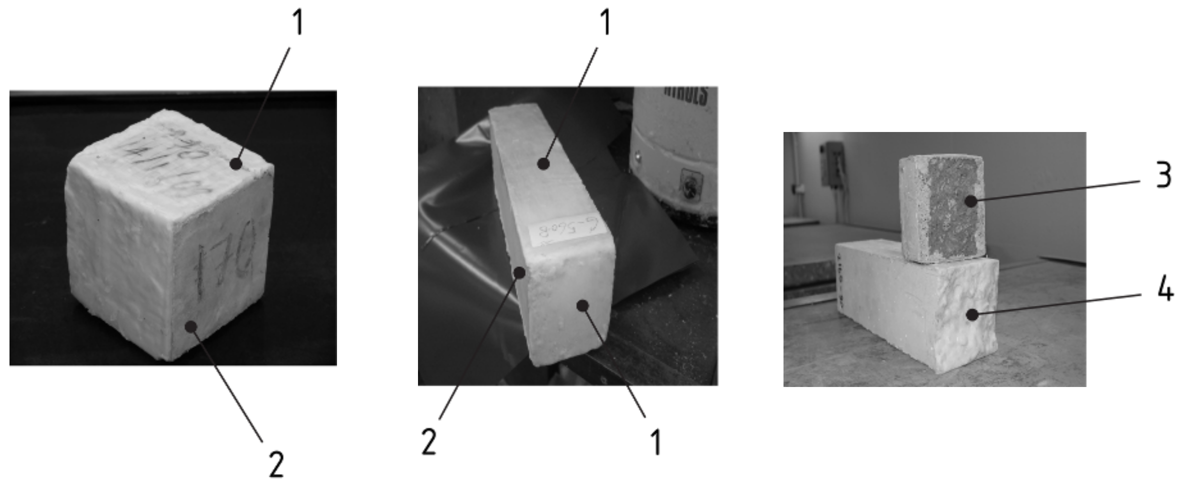
6.2.7 At an age of 28 days, remove the prisms/cubes from the water bath and transfer them to a laboratory air drying environment (between 18 °C and 25 °C, between 50% and 65% relative humidity) for 14 days.

6.2.8 After 14 days conditioning, seal the top and bottom longitudinal faces and the two end faces of prisms (or top, bottom and two side faces of cubes) using paraffin wax or a similar material that can prevent ingress of CO_2 and allow carbonation on two cast longitudinal surfaces, see Figure 1.

NOTE 1 The purpose of sealing the top, bottom and end faces is to minimize any corner effect from multi directional carbonation and also to prevent longitudinal carbonation taking place through the prism/cube.

NOTE 2 If paraffin wax is used to seal the surfaces, melt it in a temperature controlled crucible and apply to the concrete surface with a paint brush in three equal layers, leaving the wax to set on the concrete between each application.

Figure 1 **Sealing of prism specimen prior to and during testing**



Key

1	Waxed faces	3	Concrete slice split and sprayed with phenolphthalein
2	Exposed faces	4	Prism split and resealed

6.2.9 Place the prisms/cubes in the carbonation storage chamber (**5.4**) (see Annex A for an example of a suitable chamber), positioned in a way that permits air to circulate freely around the two faces that are to be carbonated (see Annex A).

7 Carbonation depth measurements

7.1 Exposure period and generation of colour change

7.1.1 Measure the carbonation depth of prisms after the following exposure periods: 56 days, 63 days and 70 days, or as specified after placing in the storage chamber. Measure the carbonation depth of cubes at 70 days unless otherwise specified.

7.1.2 Break a slice approximately 50 mm thick from the prism after each exposure period and reseal the split surface on the remaining prism to prevent longitudinal carbonation (Figure 1). Where a single determination of the carbonation depth is made on a cube after 70 days of storage, split the cube in half. Measure the depths of carbonation on the freshly broken surface of the split slice.

NOTE Slicing by saw is not suitable.

7.1.3 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 no colouration at all appears on the treated surface, spray again after 30 min.

> **WARNING.** The indicator solution is flammable. Avoid ingestion, contact with skin or eyes and inhalation of the vapour. Possible effects on the human body include kidney damage and cancer. Use nitrile gloves and safety goggles and use in a well ventilated space or when wearing a suitable mask.

7.1.4 Begin the measurements at 75 min after first spraying and complete them without a pause.

NOTE The measured depth of carbonation can be influenced by the time of measuring after application of the indicator solution.

8 Determination of the carbonation depth

8.1 General

Determine the carbonation depth of the colour change in accordance with **8.2**.

8.2 Measuring the depth of carbonation

8.2.1 Measure the carbonation depth at five points on each exposed face. To locate these points, divide the edge length into six equal distances and use the five central points, d.

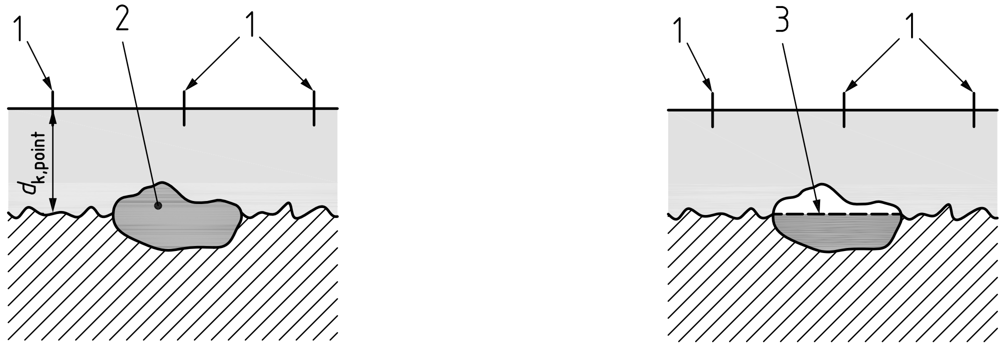
8.2.2 Using a ruler or sliding gauge and a magnifier, determine the point carbonation depth, $d_{k,\ point}$, perpendicular to the exposed surface of the prism with a precision of 0.5 mm per measured point.

8.2.3 Measured the depth of carbonation on the one broken face on both prisms giving (normally) a total of at least 20 measurement points.

8.3 Appreciation of dense aggregates

Dense aggregate particles that lie within the carbonation front are not coloured by the phenolphthalein and the carbonation front is interrupted by the particle, Figure 2a). For determining the carbonation depth, use the theoretical carbonation depth at the intersection of the location point and a line connecting the limits on each side of the particle, Figure 2b).

Figure 2 **Procedure for obtaining the carbonation depth where the point falls within a dense aggregate particle**



a) Dense aggregate interrupting carbonation front

b) Theoretical carbonation front drawn across dense aggregate

Key

1 Measuring points

2 Dense aggregate

3 Theoretical carbonation front

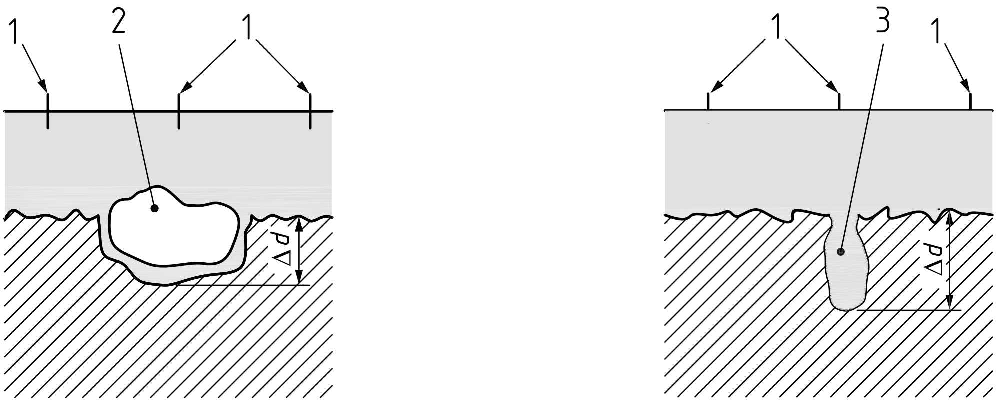
8.4 Appreciation of pores and porous aggregates and extreme values

*COMMENTARY ON **8.4***

When there are pores or particles of porous aggregates lying in the area of the carbonation front, extreme values of the carbonation depth can appear, see Figure 3.

When the measured values of $\Delta d_{k,\ point}$ are less than 4 mm, use them in the calculation of the mean carbonation depth. Do not include higher values of $\Delta d_{k,\ point}$ when calculating the mean carbonation depth, but record the existence of high values of $\Delta d_{k,\ point}$ in the test report.

Figure 3 **Procedure for obtaining the carbonation depth where the point falls on a porous aggregate particle or on air void.**



Key

1 Measuring points

2 Pourous aggregates

3 Air voids

NOTE Values of $\Delta_{dk, point}$ *greater than 4 mm should not be used when calculating the average carbonation front.*

8.5 Expression of the results

Calculate and record the following:

a) the mean depth of carbonation for each exposed face of a specimen $d_{k, face}$; and

b) the mean depth of carbonation for each specimen $d_{k, spec}$.

The accelerated carbonation depth of the concrete mix is the arithmetical mean of the mean carbonation depth of two specimens, $d_{k,}$ at 70 days.

Where testing is undertaken on prisms at alternative exposure periods, express the results as the arithmetical mean of two specimens, $d_{k,}$ at the reported alternative exposure periods.

9 Test Report

Include the following in the test report:

a) reference of the concrete under test;

b) date of casting specimens;

c) date of start of test;

d) all measured minimum and maximum carbonation depths of at least 20 points at the reference exposure period of 70 days or the specified exposure periods;

e) mean carbonation depth of specimen faces, $d_{k, face}$, each specimen, $d_{k, spec}$, and the overall mean, d_k;

f) if any, the number of values of, $d_{k, point}$, and their magnitude that were not included in the calculation of the mean value; and

g) any non-conformity with the test conditions, e.g. any failure to maintain the required CO_2 for an identified short period.

NOTE The test report may also contain:

1) details of the concrete mixes;

2) *individual test results and relevant photographic records;*
3) *results of additional testing, e.g. compressive strength results as 28 days;*
4) *any additional comments or observations; and*
5) *any accreditation for undertaking the test procedure.*

10 Precision

The repeatability (r) of the test procedure (95% confidence level) is r = 1.4 mm with a repeatability standard deviation of 0.5 mm over a range of carbonation depths from 8 mm to 23 mm.

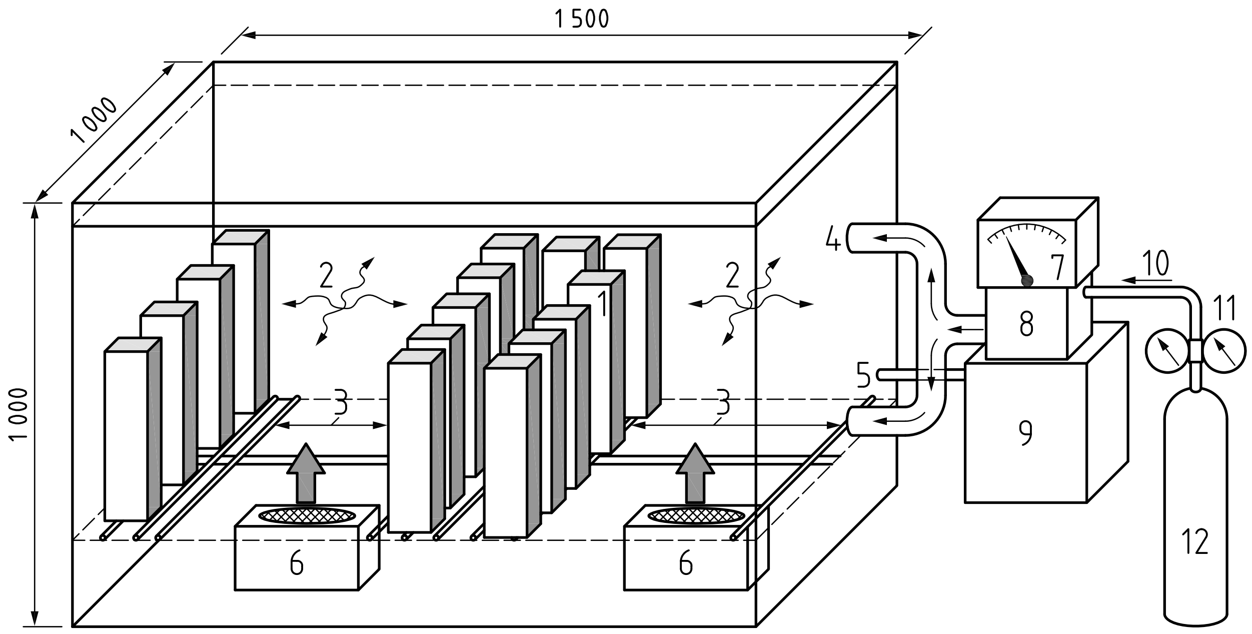
Annex A (informative)

Guidance on suitable storage chambers

The features of a typical storage chamber are given in Figure A.1. For the reference conditions, the CO_2 content of the air within the storage chamber should be (4.0 ±0.5)% by volume. When a large number of specimens are placed in a chamber, the CO_2 content can fall rapidly and remain below the required levels. For this reason, the CO_2 content should be controlled, and a suitable method is by means of a CO_2 injector connected to the chamber to replace CO_2 consumed by the carbonation reaction. Suitable apparatus are shown in Figure A.2 and Figure A.3. Monitoring of the readings from the CO_2 injection equipment should be carried out on a daily basis. Any deviations from this level should be reported.

Figure A.1 **Typical storage chamber with vertical storage**

Dimensions in *mm*



Key

1	Concrete specimens	7	CO_2 controller
2	Turbulent flow	8	Control box
3	Wooden platform	9	Dehumidifier
4	CO_2 inlet	10	Gas input
5	Steam inlet	11	Gas input
6	Fan	12	CO_2 gas cylinder

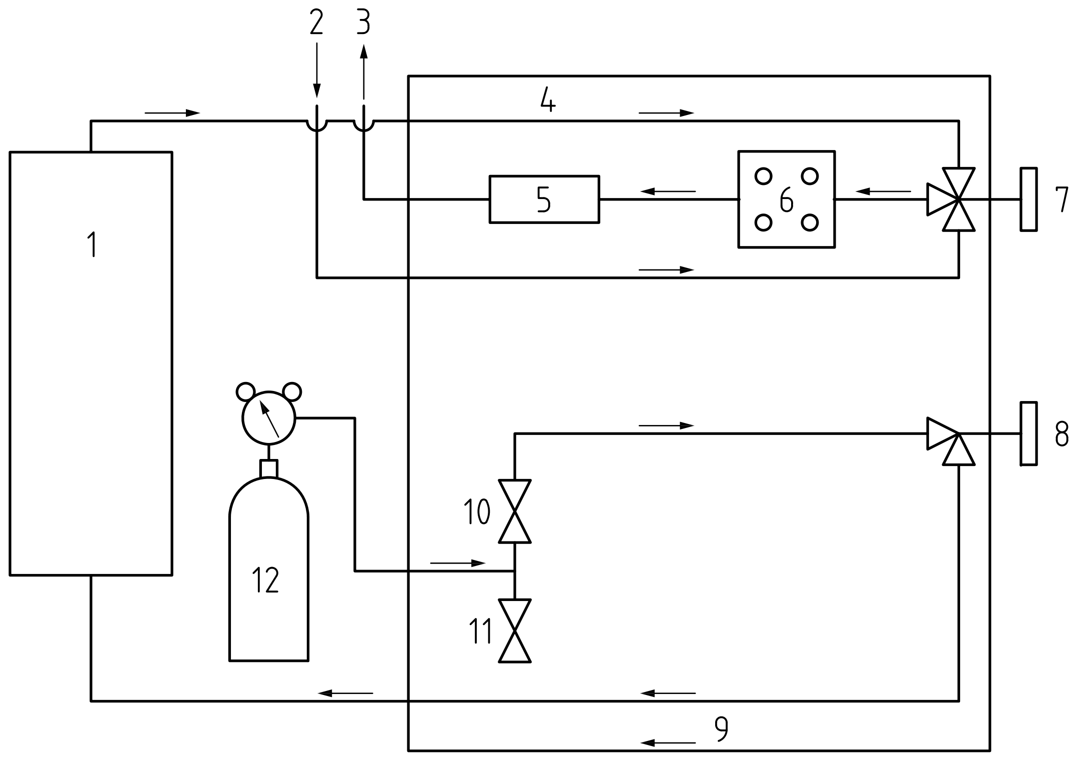
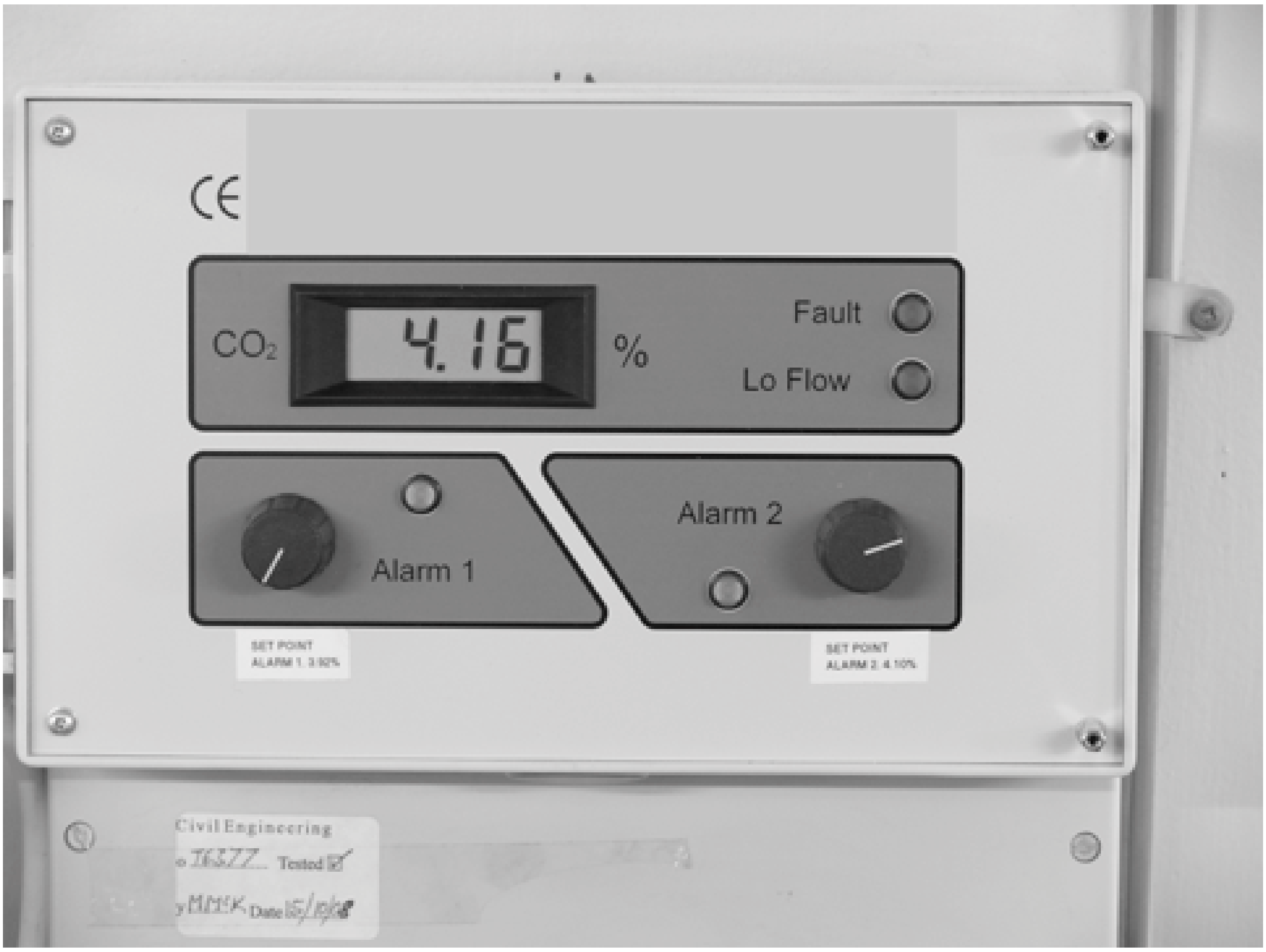


Figure A.2 **CO_2 monitoring/injection apparatus**

Key

1	Carbonation storage chamber	7	Selector valve
2	Zero air in	8	Fine metering valve
3	Sample out	9	CO_2 controller
4	Sample in	10	CO_2 controller valve hi
5	Pump	11	CO_2 controller valve lo
6	Thermal conductivity detector	12	CO_2 cylinder

Figure A.3 **CO_2 controller**

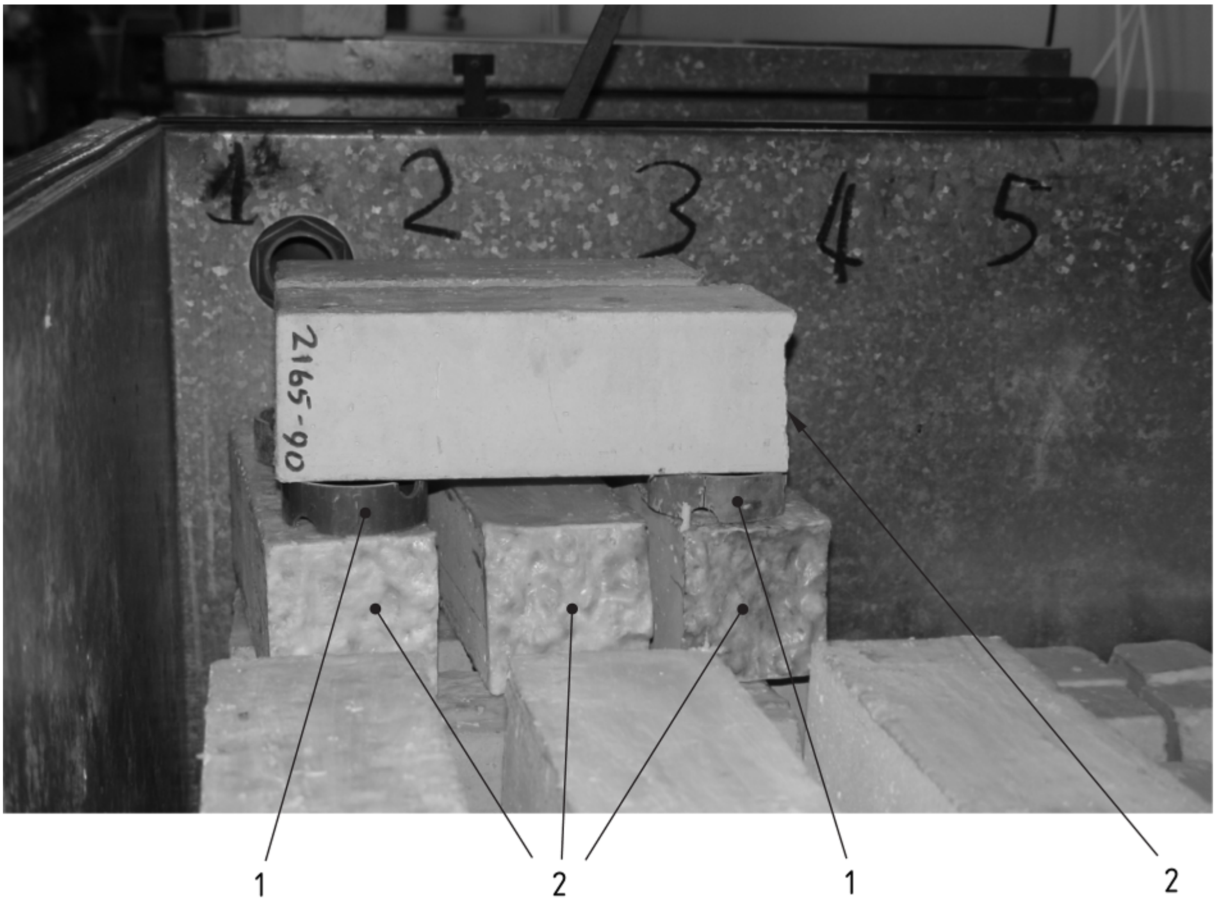


Prisms should be stored either horizontally or vertically. Where prisms are stored horizontally, they should be positioned in such a way to permit the free flow of air to the exposed, unsealed faces of the prism, e.g. using spacers cut from 50 mm diameter plastic piping. Spacers should be placed on the sealed faces of the specimens. Prisms should be placed in the storage chamber in a manner that ensures a gap of at least 50 mm between prisms, see Figure A.4. A similar gap should be provided between the prisms and the walls.

Mechanical fans (table fans are suitable) should be positioned within the storage chamber to ensure air circulation. The turbulence should be monitored during commissioning of the chamber by means of a smoke generator test or a similar method. The storage chamber should be tested with both the minimum and maximum number of prisms to be used to ensure adequate air circulation during use.

Experience [3] has shown that if non-standard saturated, surface-dry specimens are placed in the storage chamber, the relative humidity can exceed that permitted. The storage chamber should therefore have active control on relative humidity (55 ±5)% and temperature (20 ±2) °C.

Figure A.4 **Horizontal storage of specimens**



Key

1	50 mm plastic spacers	2	Exposed face of prism

Bibliography

[1] RILEM CPC-18. *Measurement of Carbonation Depth, Recommendations for the Testing and Use of Construction Materials*. 1988. pp 56-58.

[2] HARRISON T A, JONES M R, NEWLANDS M D, KANDASAMI S and KHANNA G. *Experience of using the prTS 12390-12 accelerated carbonation test to assess the relative performance of concrete*. Magazine of Concrete Research. Volume 64, Issue 8. 2012.

[3] NEWLANDS, M D. *Development of a Simulated Natural Carbonation Test and Durability of Selected CEM II Concretes.* PhD Thesis. University of Dundee. 2001. pp 258.

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

All the data, software and documentation set out in all British Standards and other BSI publications are the property of and copyrighted by BSI, or some person or entity that owns copyright in the information used (such as the international standardization bodies) and has formally licensed such information to BSI for commercial publication and use. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI. Details and advice can be obtained from the Copyright & Licensing Department.

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

...making excellence a habit.™