BAW
Bundesanstalt für Wasserbau

Kompetenz für die Wasserstraßen

BAWCode of practice

Frost Resistance Tests for Concrete (MFB)

2025 Edition

EU Notification No XXX

Note:

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BAW Codes of Practice, Recommendations and Guidelines

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Amendments

Compared to the BAW code of practice Frost Resistance Tests for Concrete (MFB), 2012 edition, the standard references have been updated. In addition, the designations of subsections for acceptance criteria have been adapted and standardised in Sections 8 and 9. The terms ‘decisive’ and ‘additional’ previously contained in the designation have been deleted, as both acceptance criteria must always be complied with and are deemed equivalent.

In addition, an Annex 1 has been added to the code of practice in order to ensure uniform calculation of statistical characteristics in the context of test evaluation.

Previous editions

BAW code of practice Frost Resistance Tests for Concrete (MFB), 2012 edition.

Preliminary remarks

The BAW code of practice Frost Resistance Tests for Concrete (MFB) describes how to test the frost resistance and freeze-thaw and de-icing agent resistance of concrete and sprayed mortar/sprayed concrete. There is currently no test standard for implementing these tests that fully incorporates the evaluation criteria relevant for hydraulic structures. The test as per DIN CEN/TS 12390-9 only allows scaling to be determined on the concrete surface.

According to this code of practice, the CIF test /1/ is to be used to test frost resistance, and CDF test /2/ is to be used to test freeze-thaw and de-icing agent resistance. Both test methods have been published as RILEM recommendations. The following test description corresponds in principle to the RILEM recommendation for the CIF test /1/ and has been adapted in some respects to the requirements of waterways engineering. These modifications concern sample production, sample geometry, sample storage, test and acceptance criteria. Advances in the CIF test methodology and the above-mentioned modifications also apply to the CDF test, meaning that in addition to surface scaling, internal damage, determined by measuring ultrasonic transit time, is also used as an assessment criterion for the CDF test. Except for the different test solution, this results in a uniform procedure for testing frost resistance and freeze-thaw and de-icing agent resistance.

The acceptance criteria laid down for the assessment of frost resistance and freeze-thaw and de-icing agent resistance are based on the types of concrete and sprayed concrete commonly used in waterways engineering[1] and apply to the assessment of test specimens prepared specifically for suitability and quality testing. The acceptance criteria do not apply to the assessment of existing structures undergoing structural inspection.

1 Introduction

The CIF test investigates resistance to freeze-thaw attack using pure water as a test solution. CIF means ‘Capillary Suction, Internal damage and Freeze-thaw test’. During the test, the degree of water saturation is increased, initially by isothermal capillary suction and then by defined freeze-thaw cycles (frost suction)

[1] Concretes and sprayed concretes commonly used in waterways engineering are typically those that meet the requirements of the Additional Technical Terms of Contract - Waterways Engineering (ZTV-W), categories 215 and 219. It may be necessary to specify separate acceptance criteria for concretes with a high cement paste content and for concretes without air-entraining admixtures and with an atypically low air content which are not usually used in waterways engineering.

corresponding to the uniaxial loading occurring in practice. The CIF test enables the combined measurement of moisture uptake, internal damage and surface scaling caused by a number of freeze-thaw cycles with uniaxial heat and moisture flux in the presence of water. The internal structural damage caused by water saturation has a decisive influence on frost resistance.

The CDF test is used to test resistance to freeze-thaw attack in the presence of de-icing agent. CDF means 'Capillary suction of De-icing chemicals and Freeze-thaw test'. The CDF test enables the combined measurement of moisture uptake, internal damage and surface scaling caused by a number of freeze-thaw cycles with uniaxial heat and moisture flux in the presence of a defined test liquid. A defined solution of de-icing salt (3% sodium chloride solution) is generally used. Surface scaling is the dominant feature of the freeze-thaw and de-icing agent resistance test.

2 Literature and normative references

/1/ CIF test - Test method for determining the frost resistance of concrete (CIF). Final Recommendation of RILEM TC 176-IDC 'Internal damage of concrete due to frost action: Test methods of frost resistance of concrete. Materials and Structures, Vol. 37 - No 274 (12.2004) p. 742-75.

/2/ CDF test - Test method for determining the freeze-thaw and de-icing agent resistance of concrete - Test with a sodium chloride solution (CDF). RILEM Recommendation TC117-FDC: Freeze-thaw and de-icing resistance of concrete. Materials and Structures Vol. 29 (1996) 523-528.

CEN/TR 15177 DIN Technical Report CEN/TR 15177:2006-06. Testing the freeze-thaw resistance of concrete - Internal structural damage; German version CEN/TR 15177:2006.

DIN CEN/TS 12390-9 Testing hardened concrete – Part 9: Frost and freeze-thaw and de-icing agent resistance - scaling; German version CEN/TS 12390-9:2016

DIN 1045-2 Concrete, reinforced concrete and prestressed concrete structures - Part 2: Concrete – Specification, performance, production and conformity – Application rules for DIN EN 206-1

DIN EN 12350-5 Testing fresh concrete – Part 5: Extent of expansion

DIN EN 12350-6 Testing fresh concrete – Part 6: Bulk density of the fresh concrete

DIN EN 12350-7 Testing fresh concrete – Part 7: Air content - Pressure methods

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

DIN EN 12390-2 Testing hardened concrete – Part 2: Preparing and curing test specimens for strength test

DIN EN 12504-4 Testing concrete in structures – Part 4: Determination of ultrasonic pulse velocity

DIN EN 14488-1 Testing of spray concrete – Part 1: Sampling fresh and hardened concrete

DIN ISO 5725 Accuracy (correctness and precision) of measurement methods and results

VDI/VDE 3522 Time performance of contact thermometers, June 1987.

3 Definitions

a) Frost resistance is the resistance to freeze-thaw cycles using demineralised water as the test liquid.

b) Freeze-thaw and de-icing agent resistance is the resistance to freeze-thaw cycles with a de-icing salt solution as the test liquid.

c) The test liquid is the liquid absorbed by the specimen during the test (section 4 c).

d) Scaling or surface scaling is the loss of material from the surface of concrete caused by freeze-thaw or freeze-thaw de-icing agent attack.

e) Internal damage is the damage to the internal structure of concrete (even without any visible external damage) which leads to a change in the properties of the concrete (e.g. a reduction in the dynamic modulus of elasticity, bending tensile strength and resistance of the boundary zone of the concrete to the penetration of harmful substances).

f) The reference point is the physical measuring point at which the temperature cycle is regulated.

g) The reference temperature is the temperature measured at the reference point.

h) The test surface is the surface of the test specimen over which the temperature change and the test liquid act on the specimen during the test procedure.

i) The ultrasonic transit axis is the hypothetical shortest distance between the centres of the ultrasonic coupling surfaces on the transmitter and receiver.

j) The ultrasonic transit path is the path over which the ultrasonic transit time is measured; it is the shortest path on the ultrasonic transit axis between the ultrasonic transmitter and receiver.

k) The ultrasonic transit time is the time required by an ultrasonic pulse wave to cover the ultrasonic transit path between the transmitter and receiver.

l) The test liquid is used as the coupling medium. It enables a reproducible signal transfer to take place between the ultrasonic transducer couplings and the test specimen.

4 Testing device

a) *Climate chamber:* temperature of (20 ± 2) °C and relative humidity of 65 ± 5%.
In the climate chamber, the rate of evaporation from a free water surface shall be 45 ± 15 g/(m² h). This is usually achieved with a wind speed of ≤ 0.1 m/s. A bowl with a depth of approximately 40 mm and a cross-sectional area of 225 ± 25 cm² shall be used to measure evaporation. The bowl shall be filled up to 10 ± 1 mm below the brim.
The CO_2 content in the climate chamber must be maintained at a daily average value in the range from 300 ppmv to 1,000 ppmv as per CEN/TS 12390-9.

b) *Lateral sealing*: Aluminium foil with butyl adhesive (reference method) or epoxy resin (alternative method). The sealing must be durable at temperatures of -20 °C. It must not become brittle or detach from the specimen when the minimum temperature is reached. A suitable primer shall be used.

c) *Test liquid:*
Frost resistance test (CIF test): demineralised water
Freeze-thaw and de-icing agent resistance test (CDF test): standard de-icing solution (97 % by mass demineralised water and 3% by mass NaCl).

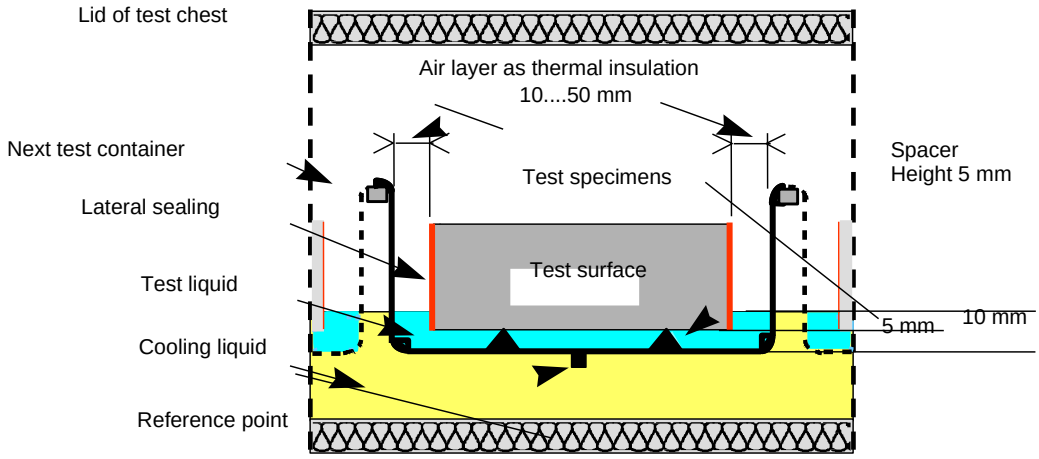
d) *Test containers (Lufttemperatur, Deckel, Prüfbehälter, seitliche Abdichtung, Prüfflüssigkeit, Prüffläche, Probekörper, Abstandhalter, Höhe and Deckel der Prüftruhe, Nebenliegender Prüfbehälter, seitliche Abdichtung, Prüfflüssigkeit, Kühlflüssigkeit, Referenzpunkt, Luftspalt als thermische Isolierung, Abstandhalter, Höhe):* The test containers are made of stainless steel. The size of a test container shall be such that the thickness of the air layer between the vertical sides of the test specimen and the test container is limited to 30 ± 20 mm[2,3]. A spacer of 5 ± 0.1 mm and a lid are also required.

Lufttemperatur, Deckel, Prüfbehälter, seitliche Abdichtung, Prüfflüssigkeit, Prüffläche, Probekörper, Abstandhalter, Höhe	*Air temperature, lid, test container, lateral sealing, test liquid, test surface, test specimens, spacer, height*

Figure 1: Capillary suction

[2] The air layer between the vertical surfaces of the test specimens and the test container acts as thermal insulation.

[3] The stainless steel containers are adapted in various modular sizes so that the same boundary conditions are encountered for each specimen size.



Deckel der Prüftruhe, Nebenliegender Prüfbehälter, seitliche Abdichtung, Prüfflüssigkeit, Kühlflüssigkeit, Referenzpunkt, Luftspalt als thermische Isolierung, Abstandhalter, Höhe

Lid of test chest, next test container, lateral sealing, test liquid, cooling liquid, reference point, air layer as thermal insulation, spacer, height

Figure 2: Test container with test specimen in thermostatic bath

e) Temperature-controlled test chest (Figure 3): A chest with a thermostatic bath is used. The temperature of the bath is controlled by a suitable device. The heating and cooling capacity and the control unit must be able to regulate the temperature system at the reference point as per the temperature cycle (Temperatur, Zeit).

The test chest must have supports above the bath to ensure an immersion depth of the test containers of 15 ± 3 mm. If the bath is not completely filled with test specimens, any gaps should be filled using empty test containers, for example.[4]

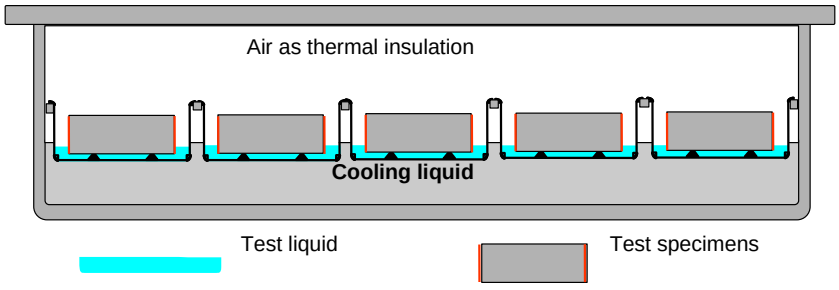


Figure 3: Temperature-controlled test chest

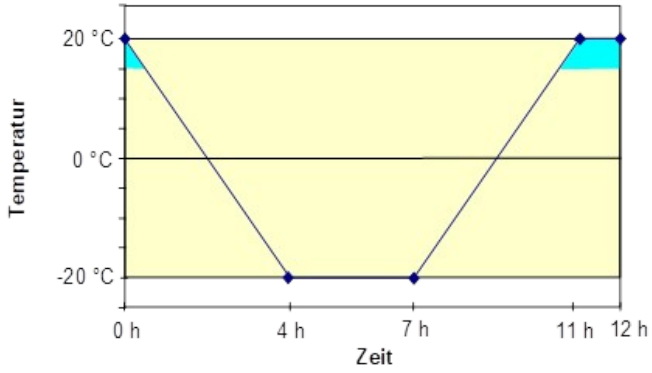
A test container placed at a representative point of the bath (usually the centre) is used for monitoring and controlling the reference temperature. This is measured in the liquid in the thermostatic bath underneath a test container. The reference point is positioned in close thermal contact in the centre of the base of the container.

A temperature gauge with accuracy of ± 0.05 K at 0 °C is used for the measurement. It must have a rectangular housing measuring 50 x 6 x 6 mm ± 0.2 mm. It is fixed so that the long side (50 x 6 mm) lies in the direction of flow. The time constant (t-90 %) of the probe (without securing device), deter-

[4] There is no need to cover the test containers if the test is conducted in a cryogenic bath as the lid of the chest provides sufficient protection against evaporation while the walls of the test container act as a cold trap.

mined as per VDI/VDE 3522 in a flowing water bath, shall be 6.3 s ± 0.8 s. A minimum temperature of -20 °C is used for calibration.

The equipment must ensure freeze-thaw cycles according to the temperature cycle shown in Temperatur, Zeit.



Temperatur, Zeit

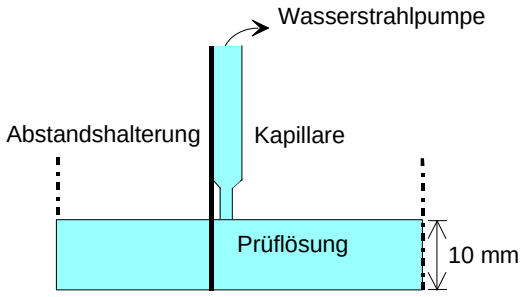
Temperature, time

Figure 4: Control temperature cycle. The measurements referred to in Section 7 may be performed at temperatures over 15 °C (shaded area in graph).

A freeze-thaw cycle takes 12 hours. Starting at +20 °C, the temperature is lowered at a constant cooling rate of 10 K/h over 4 hours. It is then maintained at a constant -20 °C for 3 hours before being raised back to +20 °C at a heating rate of 10 K/h over 4 hours. The temperature is kept constant at +20 °C for 1 hour. The temperature cycle is monitored at the reference point. The temperature measured at the reference point may not deviate from the minimum temperature by more than ± 0.5 K or more than ± 1 K from all other temperatures. A constant time shift between individual test containers is permitted.

The temperature tolerance may be exceeded for a maximum interval of 10 minutes immediately after the first ice formation.

f) *Device for adjusting the liquid level*: e.g. a suction device (Figure 5). The suction device may consist of a capillary tube with a spacer of 10 ± 1 mm connected to a water jet pump to suck up excess liquid from the test containers.



Wasserstrahlpumpe, Abstandshalterung, Kapillare, Prüflösung

Water jet pump, spacer, capillary tube, test solution

Figure 5: Suction device

g) *Ultrasonic bath (Prüfbehälter, Probekörper, Prüflösung, Wasser, Ultraschallbad)*: The dimensions of the ultrasonic bath must be large enough to ensure that there is no mechanical contact between the test container and the ultrasonic device in the coupling medium. In addition, a minimum distance of at least 15 mm between the test container and the bottom of the bath must be ensured. The ultrasonic bath must meet the following power requirements: ERS power 250 W; RF maximum power 450 W with double half-wave operation; frequency 35 kHz.

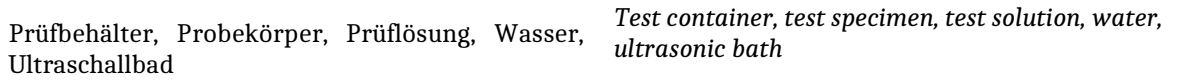


Figure 6: Ultrasonic bath

h) *Device for measuring the ultrasonic transit time*: The ultrasonic transit time can be measured using a commercially available ultrasonic measuring device that is suitable for determining the transit times of longitudinal waves in the case of direct transit through concrete in accordance with DIN EN 12504-4. The use of a device indicating the signal pattern (arrival amplitude) is recommended to check the plausibility of the measurements. The transducer couplings must operate in a frequency range between 50 and 150 kHz. The transducer couplings should have a diameter of 30 ± 10 mm.

i) *Test containers for ultrasonic transit time measurement*: A container made of electrically non-conductive material (e.g. polymethyl methacrylate) is used to measure the transit time. The ultrasonic couplings shall be placed in such a way that the transit axis is parallel to and at a distance of 35 mm from the test surface (e.g. in recesses on two opposite sides of the container, see Figure 9). The dimensions of the test container must ensure calibration in accordance with Section 7.4.2.

(j) *Calibration test specimen*: A calibration test specimen is used to calibrate the ultrasonic transit time measurement assembly. The calibration test specimen has dimensions of 150 x 110 x 70 mm (± 0.1 mm) and shall have a defined supplied ultrasonic transit time and gauge marks.

(k) *Specimen tray*: A tray (preferably of 1 mm V2A steel) with handles to facilitate handling of test specimens during measurement of liquid absorption and internal damage. The dimensions of the tray must be larger than those of the test surface to ensure all scaled material can be collected. The height of the folded-up edges of the tray must be 10 mm ± 2 mm.

l*)* *Drying cabinet*: A drying cabinet maintained at a temperature of 110 ± 5 °C must be used.

m) *Paper filters*: Paper filters are used to collect scaled material.

n) *Scales:* For weighing scaled material, accuracy of ± 0.01 g .

o) *Scales*: For weighing test specimens; accuracy of ± 0.1 g.

p) *Vernier callipers*: With accuracy of ± 0.1 mm.

q) PTFE plates: PTFE plate or other material with an equivalent water-repellent surface as shape for the test surface. The geometry of the plate is adapted to the shape for the 150 mm cube and the thickness is 2 mm < d ≤ 5 mm (see DIN CEN/TS 12390-9, 7.2.2).

5 Test specimens

5.1 Basic requirements

In principle, a test series consists of at least five specimens with a total test surface of at least 0.08 m^2. Five test specimens enable a statistical evaluation to be made and any outliers to be identified. The height of the specimens is 70 mm (± 2 mm).

5.2 Preparation of standard test specimens

5.2.1 Test specimens for testing concrete

5.2.1.1 Dimensions

The standard test specimen has the dimensions (length x width x height) 150 x 150 x 70 mm (± 2 mm). The width of the specimen may be reduced to a minimum of 110 mm.

5.2.1.2 Preparation of test specimens for suitability and quality testing

Concrete production

The test specimens for the suitability and quality testing of concrete mixes are made in 150 mm cube moulds as specified in DIN EN 12390-1. When mixing the concrete, the requirements of DIN 1045-2, Section 9.8 must be observed. The test specimens must be cast and compacted on a vibrating table in accordance with DIN EN 12390-2. The time taken to compact the concrete shall be long enough to achieve complete compaction and depends on the consistency of the concrete. The frost resistance of concrete depends to a large extent on pore structure, in particular capillary-inactive air content and density. As a result, concretes with varying degrees of compaction may also differ in their resistance to frost. For this reason, during suitability and quality testing, complete compaction of the concrete is particularly important for the assessment of frost resistance. Compaction must be carried out until no further air noticeably escapes from the fresh concrete. Segregation or bleeding of the concrete is not permitted.

If admixtures are used, the quantities used shall be the same as those that are likely to be used in practice. The raw density of fresh concrete must be tested and documented in accordance with DIN EN 12350-6, the air content in fresh concrete in accordance with DIN EN 12350-7 and the consistency in accordance with DIN EN 12350-5.

Two vertical PTFE plates are placed firmly in the cube mould, with one each at two opposite sides of the mould. Water-repellent mould liners must not be treated with release agents. The test surface is the concrete surface cast against the PTFE plate. The maximum size of the aggregate in the concrete must not exceed one third of the shorter ultrasonic transit path (length and width as per 5.2.1.1).

Curing

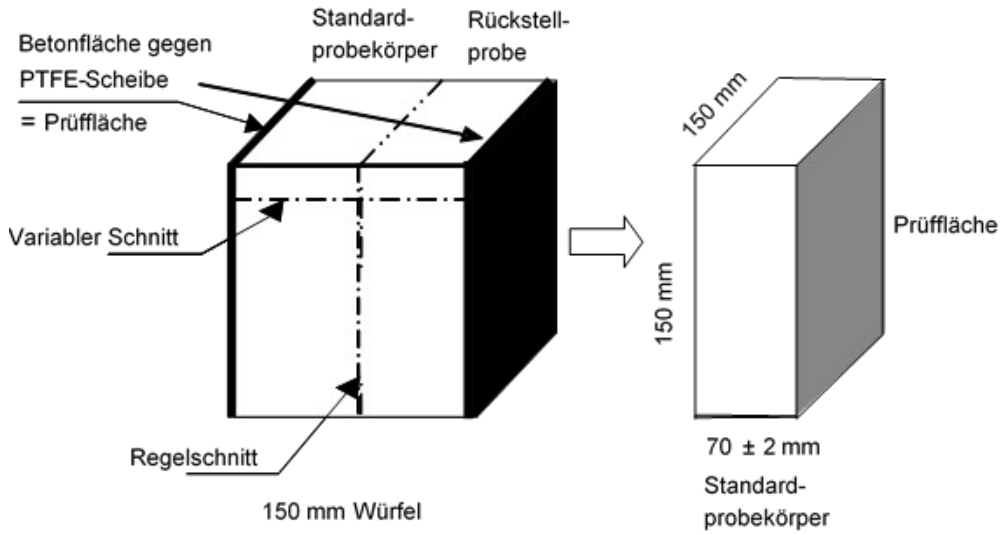
The test specimens are left in the moulds for 24 ± 2 hours, during which the free upper surfaces are protected against drying out and subsequently demoulded. The curing time in the moulds may be extended to 48 ± 2 hours if the strength development of the concrete is slow.

After removal from the moulds, the test specimens are stored in tap water at a temperature of (20 ± 2) °C. The length of storage in water after removal from the moulds depends on the time at which presaturation of the test specimens (capillary suction) begins (see Section 6). Unless otherwise agreed, presaturation begins when the compressive strength class is verified. The following periods therefore apply:

- Concretes conforming to DIN EN 206-1/DIN 1045-2 must be cured in water for 6 days (until day 7); presaturation begins on day 28.
- Concretes whose compressive strength class can be verified after 56 days can be cured in water for 13 days[5] (until day 14) if presaturation does not begin until day 56.

Cutting the test specimensCutting the test specimens

Immediately after water storage, the test specimens are sawn to the standard height. After cutting, a standard specimen body and a reference sample (Figure 7) are obtained. If a reduction in specimen width has been agreed, one side can be cut along the rough upper surface to a minimum width of 110 mm (variable cut). This treatment is followed by dry storage.



Betonfläche gegen PTFE-Scheibe, Prüffläche, Variabler Schnitt, regelschnitt, Würfel, Standard-Probe Körper, Prüffläche	Concrete surface against PTFE plate, test surface, variable cut, standard cut, cube, standard test specimen, test surface

Figure 7: Cutting the specimen and reference sample with PTFE plates mounted at the sides of the mould

Alternatively, in accordance with DIN CEN/TS 12390-9, Section 7.3, a PTFE plate may be placed in the centre of the mould in order to divide it into two halves. In this case, saw cutting is not necessary. The vertically arranged PTFE plate serves as a mould wall, hence the plate must provide sufficient stiffness to en-

[5] One day less if the specimens are cured in the mould for 48 hours.

sure a flat surface as well as compliance with the height of the standard specimens. The centrally arranged plate can be fixed by two further plates, also arranged vertically. The test surface is the concrete surface in contact with the centrally arranged PTFE plate (test surface dimension about 140 x 150 mm). A standard sample and a reference sample are obtained per cube.

5.2.2 Test specimens for testing spray mortar/spray concrete

5.2.2.1 Dimensions

Samples may be cylindrical or rectangular in shape. Standard cylindrical test specimens must be 150 mm in diameter and 70 mm (± 2 mm) high and standard rectangular test specimens shall have 150 mm sides and a height of 70 mm (± 2 mm).

5.2.2.2 Preparation of test specimens for suitability and quality testing

Preparation and curing of test slabs

Five separate test slabs in accordance with DIN EN 14488-1 are required for the suitability and quality testing of sprayed mortar and sprayed concrete. The surfaces of the slabs must be left in the as-sprayed condition. After preparation, the test slabs are left in the moulds in a closed room at an air temperature between 15 and 22 °C for 24 ± 2 hours, during which the free upper surfaces are covered with damp cloths to protect them against moisture loss. The slabs are then demoulded. The curing time in the moulds may be extended to 48 ± 2 hours if the strength development of the slabs does not permit demoulding after 24 hours.

After demoulding, the plates are stored in tap water at (20 ± 2) °C. Unless otherwise agreed, the slabs must be stored in water for 6 days after demoulding[6] (until day 7).

Cutting the test specimens

Immediately after the slabs have been cured in water, one specimen and one reference sample are cut from each slab by sawing or drilling perpendicular to the as-sprayed surface using the wet-cutting method. The test specimens are sawn parallel to the as-sprayed surface, removing only as much material as necessary to produce a smooth, closed surface. The resulting surface is the test surface. The test specimens are then cut to a height of 70 ± 2 mm by a further saw cut parallel to the test surface. This treatment is followed by dry storage.

5.3 Non-standard test specimens

If non-standard concrete test specimens (e. g. specimens cut from components) are tested, this must be stated in the test report.

The minimum diameter of cores drilled from finished sprayed mortar or sprayed concrete components (e. g. for monitoring the quality of workmanship) depends on the maximum size of the aggregate. The minimum diameter of the specimens is 100 mm for maximum aggregate sizes up to 16 mm and 150 mm for larger maximum aggregate sizes.

The test surface of each specimen must be large enough to completely fit a circle with a diameter of 90 mm. The length-to-height ratio must not exceed 3. The height must be 70 mm (± 2 mm).

6 Test procedure

6.1 General

[6] One day less if the specimens are cured in the mould for 48 hours.

The test procedure consists of three steps: dry storage, presaturation by capillary suction, and freeze-thaw cycles. The test begins after the curing period immediately after collection of the test specimens. The start of presaturation by capillary suction determines the point at which freezing is started. For concretes according to DIN 1045-2, presaturation begins when the compressive strength class is verified at 28 days. If the compressive strength class is verified at 56 days, presaturation can also begin at 56 days.[7]

The storage periods for test specimens produced in accordance with Sections 5.2.1 or are specified in the following table:

Table 6.1: Storage periods prior to start of freezing

Storage after production	Curing[8] (in mould and in water) As per section 5.2	Dry storage in the climate chamber as per Section 6.2	Presaturation by capillary suction as per section 6.3
Start of presaturation by capillary suction	Storage period		
Day 28	7 days	21 ± 1 day	7 days
Day 56	14 days	42 ± 1 day	7 days

6.2 Dry storage

The test specimens are stored in a climate chamber as per Section 4(a) at (20 °C / 65 % r.F.) for surface drying. The storage period as per Table 6.1, is 21 ± 1 days if the concrete is tested at 28 days and 42 ± 1 days if the concrete is tested at 56 days. The specimens are placed on their sides at least 50 mm apart so that the test surfaces are free of obstruction. The change in mass must be measured.

During storage in the climate chamber, compliance with the permitted rate of evaporation and permissible CO_2 concentration as per Section 4a) must be checked at regular intervals.

6.3 Presaturation

6.3.1 Sample preparation and sealing

The side surfaces of the test specimens must be sealed. The samples must be clean and dry, especially on the side surfaces. Before and after sealing, the test specimens are weighed with an accuracy of ± 0.1 g to determine the reference mass of the unsealed specimens required to calculate liquid absorption.

[7] Slow-curing concretes achieve the same performance as rapid-hardening concretes at a greater age. This also applies to freeze-thaw resistance and freeze-thaw and de-icing agent resistance. Accordingly, the duration of storage in a damp atmosphere/water or in the climate chamber may be extended to 14 days or 6 weeks respectively for concretes whose compressive strength class is verified at 56 days in accordance with ZTV-W LB 215 or ZTV-W LB 219. For cements with a high proportion of granulated blast furnace slag (its use in concrete with a high freeze-thaw and de-icing agent resistance being limited under DIN 1045-2) the positive effect of an extended curing period may be less pronounced as increased carbonation with a detrimental effect on surface scaling cannot be ruled out if the concrete is stored in the climate chamber for a longer period of time.

[8] A period of storage in a damp atmosphere or in water for longer than specified in Table 6.1 (e. g. up to the start of the test) may have a detrimental effect on frost resistance and freeze-thaw and de-icing agent resistance owing to the higher degree of water saturation of the pores at the start of freezing.

Before sealing, the side surfaces must be treated with an appropriate primer. One of the following two methods shall be used for sealing the lateral surfaces:

a) Sealing by aluminium foil with butyl adhesive (reference): The aluminium foil with butyl adhesive is rolled firmly onto the side surfaces with an overlap of 20 mm between three days prior to and immediately before the start of presaturation. The butyl tape shall be applied in such a way as to ensure a durable bond.

b) Sealing with epoxy resin (alternative): A solvent-free epoxy resin is applied to the side surfaces 2 to 4 days before the start of presaturation to ensure the epoxy resin is sufficiently hardened.

6.3.2 Presaturation with test liquid by capillary suction

After dry storage, the specimens are placed in the test containers on the 5 mm high spacers with the test surface at the bottom. The test liquid is then poured into the container up to a height of 10 ± 1 mm without the samples getting wet from above. The following test liquids are used:

- for the frost resistance test (CIF): demineralised water
- for the freeze-thaw and de-icing agent resistance test (CDF): 3% NaCl solution.

During capillary suction, the test container must be closed with a lid. During capillary suction, no condensate may drip from the lid onto the specimen.

Capillary suction lasts 7 days at a temperature of (20 ± 2) °C. The level of liquid must be checked and adjusted at regular intervals during capillary suction, depending on the suction capacity of the material. The increase in mass of the specimens is measured regularly every 2 - 3 days.

6.4 Freeze-thaw exposure

Freeze-thaw cycle testing is cyclic load. The test specimens are subjected to a temperature cycle as described in Section 4 (Temperatur, Zeit) in a temperature-controlled test chest. Generally speaking, 28 freeze-thaw cycles are required to test resistance to frost freeze-thaw and de-icing agent resistance.

Before the start of the freeze-thaw cycle, any loose particles or dirt must be removed from the test surface of the specimens by treatment in an ultrasonic bath as described in Section 7.2. Discard the material removed.

If the cyclic load is disrupted during the freeze-thaw cycle (equipment failure, etc.), the specimens must remain in the test solution and be protected from drying out. Long interruptions in particular can influence the test result and must be recorded in the test report and taken into account in the evaluation.

7 Measurements

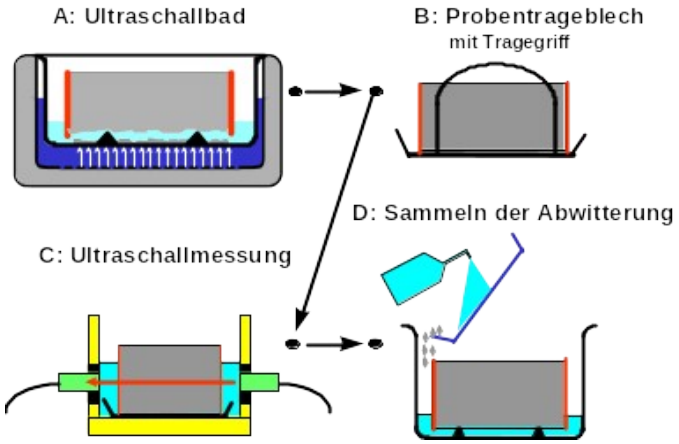
7.1 Sequence of measurements with regard to surface scaling, liquid absorption and ultrasonic transit time

Measurements are taken at the beginning of the frost test (0 freeze-thaw cycles) and after every four to six freeze-thaw cycles. Depending on the agreed criterion, either 24 freeze-thaw cycles (quality test) or 28 freeze-thaw cycles (suitability test) are performed.

Measurements must be taken at temperatures above 15 °C (shaded area in Temperatur, Zeit).

The measurements must be carried out in the following order:

1. Determination of surface scaling
2. Measurement of liquid absorption
3. Measurement of ultrasonic transit time (internal damage)



A. Ultraschallbad — Ultrasonic bath

B. Probentrageblech mit Tragegriff — Specimen tray with handle

C. Ultraschallmessung — Ultrasonic measurement

D. Sammel der Abwitterung — Collection of scaled material

E.

Figure 8: Measurement sequence with test steps and test equipment A to D

After determining the surface scaling, place the test specimen on the specimen tray specified in Section 4(k) to collect any additional scaled material during subsequent measurements. The scaled material collected on the tray is returned to the test container and taken into account during the next measurement of surface scaling. If the measurement sequence is interrupted, the specimen must be placed in the test container with the test liquid to prevent drying out.

7.2 Determination of surface scaling

7.2.1 Procedure

The test container is immersed in the contact liquid of an ultrasonic bath and subjected to ultrasonic cleaning for three minutes to remove any loosely adhering scaled material from the test surface whenever measurements are taken (Prüfbehälter, Probekörper, Prüflösung, Wasser, Ultraschallbad).

Filter the test liquid containing the scaled material. The paper filter is then dried at (110 ± 5) °C for 24 hours and left to cool for at least one hour at (20 ± 2) °C and (60 ± 10)%. The mass of the filter, along with the dried scaled material μ_b, is measured with an accuracy of ± 0,01 g.

Before use, the empty paper filter is dried as described above and the mass μ_f of the empty filter is determined with the same accuracy.

The mass of the scaled material μ_s is then: $\mu_s = \mu_b - \mu_f$

7.2.2 Evaluation of surface scaling

Calculate the total quantity of scaled material m_n in relation to the test surface after the nth freeze-thaw cycle at each measurement and for each test specimen:

$$m_n = \frac{\sum \mu_s}{A} \quad (1)$$

m_n is the total mass of scaled material relative to the test surface at each test date in g/m2.

μ_s is the mass of scaled material at each test date with accuracy of ± 0.01 g. The total is the sum of all measurements up to the nth cycle.

A is the size of the test surface in mm2. It is calculated on the basis of the linear dimensions. These are determined by the mean values of at least two measurements rounded to the nearest 0.5 mm.

The mean value and the standard deviation must be determined. The result must be checked for outliers, for which a test suitable for small populations (e.g. T-test) must be applied.

7.3 Measurement of liquid absorption

7.3.1 Procedure

After the scaled material is removed, the test specimens are placed vertically on an absorbent surface (laboratory towel) to allow water to run off the test surfaces. Carefully dry the lateral surfaces and the upper surface of the test specimens with a laboratory towel. To avoid losing any scaled material, the balance is zeroed with the specimen tray in place (Section 7.1) and the test specimen is then weighed on the tray with an accuracy of ± 0.1 g.

7.3.2 Evaluation of liquid absorption

The liquid absorption of each test specimen Δw_n after the nth cycle is calculated as follows:

$$\Delta w_n \frac{w_n - w_1 + \Sigma \mu_s}{w_0} * 100 \qquad (2)$$

Δw_n is the liquid absorption of each test specimen at each test date in % by mass.

μ_s is the mass of the scaled material, in g, at each measurement, measured to an accuracy of 0.01 g. The total is the sum of all measurements up to the nth cycle.

w_0 is the reference mass of each specimen without the mass of the sealing material after dry storage, in g.

w_1 is the mass of each specimen including the mass of the sealing material before presaturation begins, in g.

w_n is the mass of each specimen at each test date, in g.

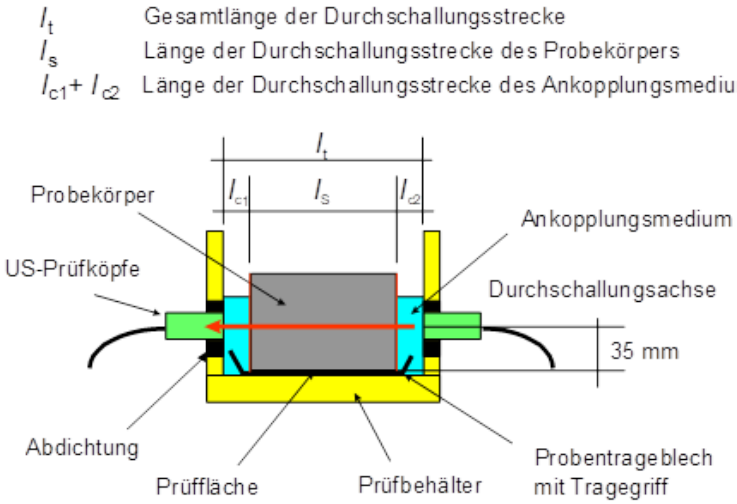
The mean value and the standard deviation of the increase in mass must be determined. The results must be checked for outliers.

7.4 Measurement of ultrasonic transit time (internal damage)

7.4.1 Measuring set-up

A container as per Section 4 (i) is used to measure the ultrasonic transit time. The coupling medium is the test liquid used. The temperature of the coupling medium and the specimen shall be 20 ± 5 °C.

The ultrasonic transit time is measured using an ultrasonic measuring instrument as defined in Section 4 h). The ultrasonic couplings are arranged so that the axis of the ultrasonic transit path is parallel to the test surface and at a distance of 35 mm. The container is filled with the coupling medium up to 10 mm above the ultrasonic couplings, but not above the top of the test specimen. The upper surface of the test specimens must be kept dry!



Gesamtlänge der Durch schallungsstrecke	Total length of the ultrasonic transit path
Länge der Durch schallungsstrecke des	Length of the ultrasonic transit path in the test specimen

Probeskörpers	
Länge der Durch schallungsstrecke des Ankonpplungsmedium	Length of the ultrasonic transit path in the coupling medium
Probeskörper, US Prüfköpfe, Abdichtung, Prüffläche, Prüfbehälter, Probentrageblech mit Tragegriff, Durchschallung Sache, Ankonpplungsmedium	Test specimen, US couplings, sealing, test surface, test container, specimen tray with handle, transit path axis, coupling medium

Figure 9: Measurement set-up for determining the ultrasonic transit time

In order to avoid interference with measurement, the ultrasonic bath as per Section 4 g) to determine surface scaling must not be operated at the same time as the transit path is measured or only spatially separated from the ultrasonic measuring device.

7.4.2 Calibration

Before the start of each measurement cycle, the measurement set-up must be checked as follows:

Reference measurement with calibration specimen

The ultrasonic measuring instrument is checked by coupling the measuring heads directly to the calibration test specimen using an appropriate coupling medium (e.g. grease). The ultrasonic transit time thus measured must be the same as the time stated on the calibration test specimen. If the times differ, the ultrasonic transit time must be calibrated (by setting it to the time stated on the calibration specimen).

Checking the transit time

The calibration test specimen is arranged in the container as per Figure 9. The couplings are then moved so that the transit path in the coupling medium is 5 mm (± 1 mm) on both sides (defined coupling spacing l_t). The transit time is the difference between the transit time measured for this arrangement and the transit time determined for the calibration specimen.

Alternatively, a defined coupling spacing l_t can be specified by moving the couplings so that the transit time actually measured corresponds to the transit time of the calibration specimen + 10 µs (± 0.1 µs).

7.4.3 Procedure

As shown in Figure 9, the test specimen is placed on the specimen tray and positioned in the test container to measure the ultrasonic transit time. The ultrasonic transit axes marked on the specimen during the first measurement must be used in all further tests. The transit time is measured for each test specimen on two transit axes perpendicular to one another.

In the case of rectangular specimens, the coupling points shall be centrally located between the two edges of the specimen. Before capillary suction begins, the length of the test specimen which is to be crossed by ultrasonic waves is measured to an accuracy of ± 0.1 mm. The sealing material on either side of the specimen is not taken into account.

The shortest ultrasonic transit time is measured to an accuracy of ± 0.1 µs after preliminary storage and after each predefined number of freeze-thaw cycles. During measurement, the test specimen shall be moved slightly and the shortest transit time recorded. Care must be taken to ensure that no air bubbles adhere to the couplings or sides of specimens and that the lateral sealing is in full contact with the specimen. During the measurement sequence, any wetting of the top of the specimen must be avoided. The measurement must be kept as brief as possible.

7.4.4 Evaluation of internal damage

The ultrasonic transit time in the coupling medium t_c is calculated from the transit length in the coupling medium l_c and the speed of the ultrasonic signal in the coupling medium v_c. The transit length in the coupling medium l_c is determined from the difference between the coupling spacing and the specimen dimension l_s for each transit axis to an accuracy of ± 0.1 mm (Figure 9).

$$t_c = \frac{l_c}{v_c} \tag{3}$$

T_c is the transit time in the coupling medium in µs.
l_c is the transit path of $l_{c1} + l_{c2}$ in the coupling medium in mm.
v_c is the speed of the ultrasonic signal in the coupling medium. It can be assumed to be (20 ± 5) °C at 1490 m/s.

The change in transit velocity τ_n after n freeze-thaw cycles is calculated separately for each specimen and for each transit axis where:[9]

$$\tau_n = \frac{t_{cs} - t_c}{t_n - t_c} \tag{4}$$

τ_n is the relative transit speed.
t_{cs} is the total transit time after capillary suction (cs) in µs, before the first freeze-thaw cycle.
t_n is the total transit time after n freeze-thaw cycles in µs.

It is useful to describe the internal damage by means of the relative dynamic modulus of elasticity $R_{u,n}$ from the ultrasonic transit time. In the present test method, the relative dynamic modulus of elasticity is calculated after n freeze-thaw cycles using the following equation: [10]

$$R_{u,n} = \tau_n^2 \tag{5}$$

The mean value calculated from the values of both transit axes expresses the relative dynamic modulus of elasticity of the test specimen. The relative dynamic modulus of elasticity may also be expressed as a percentage.

The mean value $R_{u,m}$ and the standard deviation of the relative dynamic modulus of elasticity of a test series are determined. The result must be checked for outliers, for which a test suitable for small populations (e.g. T-test) must be applied.

[9] The change in length can be disregarded.

[10] Density, size and Poisson's ratio are disregarded in this equation. This is not a serious limitation as the aim of the test is to identify damage and the ultrasonic transit time is the relevant parameter. The dynamic modulus of elasticity is just a parameter that is better-known to engineers.

8 Evaluation of frost resistance after the CIF test

8.1 Surface scaling acceptance criterion

Unless otherwise agreed in writing, the following acceptance criteria shall apply:

Table 8.2: Surface scaling CIF test acceptance criteria

	Suitability, quality and component testing
Average value of test series	≤ 1000 g/m² after 28 freeze-thaw cycles
95% quantile of the test series	≤ 1750 g/m² after 28 freeze-thaw cycles

8.2 Internal damage acceptance criterion

The concrete shall be considered damaged if the mean value of the test series is below a relative dynamic modulus of elasticity $R_{u,m}$ = 0.75 or 75%.[11] The decisive criterion for assessing internal damage is the number of freeze-thaw cycles until this damage criterion is reached.

The number of the freeze-thaw cycle change (cycle number) can be determined by linear interpolation between two adjacent measuring points, where the difference in the number of freeze-thaw cycles at each measuring point is less than 6.

As an acceptance criterion, a number of cycles must be agreed up to which the damage criterion must not be exceeded. Unless otherwise agreed in writing, the following acceptance criteria shall apply:

Table 8.3: Internal damage CIF test acceptance criterion

	Suitability inspection	Quality and component testing
Average value of test series	≥ 28 freeze-thaw cycles	≥ 24 freeze-thaw cycles

[11] A relative dynamic modulus of elasticity of 75% ensures sufficient differentiation with regard to the modulus of elasticity of undamaged concrete (100 %) in accordance with the precision data. See also the precision data in Section 12.2.1.

9 Evaluation of freeze-thaw and de-icing agent resistance after the CDF test

9.1 Surface scaling acceptance criterion

Unless otherwise agreed in writing, the following acceptance criteria shall apply:

Table 9.4: Surface scaling CDF test acceptance criteria

	Suitability, quality and component testing
Average value of test series	$\leq$ 1500 g/m² after 28 freeze-thaw cycles
95% quantile of the test series	$\leq$ 1800 g/m² after 28 freeze-thaw cycles

9.2 Internal damage acceptance criterion

The concrete shall be considered damaged if the mean value of the test series is below a relative dynamic modulus of elasticity $R_{u,m}$ = 0.75 or 75%. As an acceptance criterion, a number of cycles must be agreed up to which the damage criterion must not be exceeded. Unless otherwise agreed in writing, the following acceptance criteria shall apply:

Table 9.5: Internal damage CDF test acceptance criterion

	Suitability inspection	Quality and component testing
Average value of test series	$\geq$ 28 freeze-thaw cycles	$\geq$ 24 freeze-thaw cycles

10 Report

The test report must contain at least the following information:

1. A reference to this test specification.
2. Designation, origin, dimensions and mass of the specimens on receipt of the samples /after production and after drying.
3. Client and body responsible for the production of test specimens.
4. Reference to the type of testing, e.g. suitability or quality testing.
5. Information on concrete composition and starting materials with product name.
6. Fresh concrete characteristics: Bulk density, compaction time and compacting factor, air content.
7. Duration of storage in water and dry storage.
8. Composition of test liquid.
9. Number of freeze-thaw cycles carried out.
10. Change in the relative dynamic modulus of elasticity from the ultrasonic transit time for each test specimen, as well as the mean value and standard deviation in %, rounded to the nearest 1% depending on the number of freeze-thaw cycles performed, the intermediate measurements and the final measurement.
11. Mass of the scaled material for each test specimen, the mean value and the standard deviation in g/m^2, rounded to the nearest 1 g/m^2, depending on the number of freeze-thaw cycles performed, the intermediate measurements and the final measurement.
12. Mass of the solution absorbed during capillary suction and during the freeze-thaw resistance test (frost suction) for each test specimen, the mean value and the standard deviation in percentage by mass, rounded to the nearest 0.01 % by mass, depending on the number of freeze-thaw cycles performed, the intermediate measurements and the final measurement.
13. Visual assessment (cracks, scaling of aggregate particles) before the start and at least after the end of the test. The test report shall include a photograph of the test surface before and after the test for one representative test specimen at least by way of illustration.
14. Any deviation from the procedure described here.
15. Assessment of freeze-thaw and de-icing agent resistance according to the acceptance criteria.

11 Requirements for laboratories and reference samples

The test laboratory in which suitability and quality tests are carried out must have sufficient experience with the test method. At least the following documents must be archived in the testing laboratory:

1. Test protocol and test report
2. Graphs showing the temperature development during the test period

In addition, the reference samples must be stored or handed over to the client as agreed.

12 Precision data

12.1 General

There are two ways of stating precision: repeatability and reproducibility. The precision of the CIF and CDF tests was determined for concretes in accordance with Section 5.2.1 on the basis of ISO 5725.

12.2 Precision of CIF test for concrete mixtures

12.2.1 Measurement of internal damage – ultrasonic transit time

The precision data for the relative dynamic modulus of elasticity (RDM) are shown in Table 12 .6. These data apply to laboratory concrete tested in accordance with Section 7.4, where s_r and s_R are the standard deviations of repeatability and reproducibility respectively and can be calculated from the functional correlation with the relative dynamic modulus of elasticity $R_{u,m}$ using the equations in Table 12.1.

Table 12.6: Precision data for the measurement of internal damage – ultrasonic transit time in the CIF test

rel. dyn. e-modulus (RDM)	Repeatability s_r	Reproducibility s_R
	Standard deviation	
Where RDM = 100 %	0,7 %	0,9 %
Where RDM = 75 %	5,9 %	7,6 %
Equation *	$s_r = -0.2046\ R_{u,m} + 0.2122$	$s_R = -0.2656\ R_{u,m} + 0.2750$

* Proven range $R_{u,m}$ = 0,70 to 1.0 with R^2 = 0.85 for s_r and R^2 = 0.73 for s_R. These data apply to laboratory concrete produced in accordance with Section 5.2.1.

NOTE: The precision data and the equations in Table 12.1 are based on the results of the RILEM Round Robin Test of the TC IDC, carried out with 9 institutes and three different concrete series.

12.2.2 Liquid absorption

The precision data for liquid absorption are shown in Table 12 .7. These data apply to laboratory concrete tested in accordance with Section 7.3, where s_r and s_R are the standard deviations of repeatability and reproducibility and can be calculated from the functional correlation with the liquid absorption Δw_n during the frost test using the equations in Table 12.2.

Table 12.7: Measurement method for measuring liquid absorption

Liquid absorption	Repeatability s_r	Reproducibility s_R
	Standard deviation	
up to 0.5 % by mass	0.014 % by mass	0.029 % by mass
0.5 to 1.5 % by mass	0.027 % by mass	0.058 % by mass
> 1.5 % by mass	0.054 % by mass	0.115 % by mass
Equation*	$s_r = 0.0265\ \Delta w_n + 0.0005$	$s_R = 0.0569\ \Delta w_n + 0.0008$
* For the proven field of application Δw_n 0 to 2,5 where $R^2 = 0.30$ for s_r and $R^2 = 0.30$ for s_R. These data apply to laboratory concrete produced in accordance with Section 5.2.1.		

NOTE: The precision data and the equations in Table 12.2 are based on the results of the RILEM Round Robin Test of the TC IDC, carried out with 7 institutes and three different concrete series.

12.2.3 Surface scaling

The precision data for surface scaling are shown in Table 12 .8. The precision data apply to laboratory concrete tested in accordance with Section 7.2. The precision data for surface scaling obtained in round robin testing solely with freeze-thaw attack are currently only available in the range of 0 to 500 g/m².

Table 12.8: Precision data for measuring surface scaling in the CIF test

Surface scaling	Repeatability s_r	Reproducibility s_R
	Standard deviation	
0 to 500 g/m²	120 g/m² (ν = 24 %)	160 g/m² (ν = 32 %)

NOTE: The precision data and the equations are based on the results of the RILEM Round Robin test of the TC IDC, carried out with 9 institutes and three different concrete series.

12.3 Precision of CDF test for concrete mixtures

12.3.1 Surface scaling

The precision data for surface scaling are shown in Table 12 .9. The precision data apply to laboratory concrete tested in accordance with Section 7.2. The precision data can be calculated with equation (6) and the parameters from *Table 12 .10* for the acceptance criterion m_0 = 1500 g/m².

Table 12.9: Precision data for measuring surface scaling in the CDF test

Surface scaling	Repeatability s_r	Reproducibility s_R
	Standard deviation	
1500 g/m²	156 g/m² (ν = 10.4 %)	262 g/m² (ν = 17.5 %)

The coefficient of variation ν depends on the mean scaling m relative to the acceptance criterion m_0 = 1500 g/m².

$$\nu = \nu_0 \bullet \left(\frac{m}{m_0} \right)^d \qquad (6)$$

ν Coefficient of variation
m average scaling
m_0 acceptance criterion (level of resistance)

The parameters ν_0 and d for repeatability and reproducibility respectively as an exponential function of the mean scaling m are shown in *Table 12 .10*.

Table 12.10: Parameters ν_0 and d for scaling in the CDF test as per /1/

	Repeatability	Reproducibility
d	- 0,33	- 0,29
ν_0	10.4 % (ν_r)	17.5 % (ν_R)

Annex 1: Statistical Characteristics

A1. Mean value and standard deviation of a test series

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{A1}$$

$$s = \sqrt{s^2} \tag{A2}$$

$$s^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} ¿¿ \tag{A3}$$

x_i Individual values

n Number of samples in test series

$\bar{x}$ Average value of test series

s Standard deviation of test series

A2. 95% quantile of a test series

$$Percentile\,value\,(p) = \bar{x} + t \cdot s \tag{A4}$$

p Statistical security (significance level 95 %)

$\bar{x}$ Average value of test series

t Student distribution parameters for unilateral confidence range, n-1 degrees of freedom

s Standard deviation of test series