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Testing the freeze-thaw resistance of concrete - Internal structural damage

Prüfung des Frost-Tauwiderstandes von Beton - Innere Gefügestörung

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Testing the freeze-thaw resistance of concrete - Internal structural damage

Prüfung des Frost-Tauwiderstandes von Beton - Innere Gefügestörung

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Foreword

This document (CEN/TR 15177:2006) has been prepared jointly by Technical Committee CEN/TC 51 "Cement and building limes", the secretariat of which is held by IBN/BIN and by Technical Committee CEN/TC 104 "Concrete and related products", the secretariat of which is held by DIN.

No existing European Standard is superseded.

It is based on the Austrian Standard ÖNORM B 3303 "Testing of Concrete" and on the RILEM recommendation "Test methods of frost resistance of concrete" of RILEM TC 176 IDC. These tests have since been developed by individual countries. This document takes into account those developments.

Introduction

Concrete structures exposed to the effects of freezing and thawing need to be durable, to have an adequate resistance to this action and, in cases such as road construction, to freezing and thawing in the presence of de-icing agents. It is desirable, especially in the case of new constituents or new concrete compositions, to test for such properties. This also applies to concrete mixes, concrete products, precast concrete, concrete elements or concrete in situ.

Many different test methods have been developed. No single test method can completely reproduce the conditions in the field in all individual cases. Nevertheless, any method should at least correlate to the practical situation and give consistent results. Such a test method may not be suitable for deciding whether the resistance is adequate in a specific instance but will provide data of the resistance of the concrete to freeze-thaw-attack and freeze-thaw-attack in the presence of de-icing agents.

If the concrete has inadequate resistance there are two types of concrete deterioration when a freeze-thaw attack occurs, internal structural damage and scaling. The three test methods in this document describe the testing for internal structural damage. The scaling is dealt with in prCEN/TS 12390-9.

This document contains three different test methods, which are well proved in different parts of Europe. Always they produce consistent results. For that reason no single test method can be established as reference test method. In the case that two laboratories will test the same concrete, they have to agree to only one test method with the same measurement procedure.

The application of limiting values will require the establishment of the correlation between laboratory results and field experience. Due to the nature of the freeze-thaw action, such correlation would have to be established in accordance with local conditions and still have to be done.

1 Scope

This document specifies three test methods for the estimation of the freeze-thaw resistance of concrete with regard to internal structural damage. It can be used either to compare new constituents or new concrete compositions against a constituent or a concrete composition that is known to give adequate performance in the local environment or to assess the test results against some absolute numerical values based on local experiences.

Extrapolation of test results to assess different concrete i.e. new constituents or new concrete compositions requires an expert evaluation.

NOTE Specification based on these test methods should take into account the behaviour of concrete under practical conditions.

There is no established correlation between the results obtained by the three test methods. All tests will clearly identify poor and good behaviour, but they differ in their assessment of marginal behaviour.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206-1, *Concrete – Part 1: Specification, performance, production and conformity*

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

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

EN 12504-4, *Testing concrete – Determination of ultrasonic pulse velocity*

3 Terms and definitions

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

3.1
freeze-thaw resistance
resistance against alternating freezing and thawing in the presence of water alone

3.2
freeze-thaw resistance with de-icing salt
resistance against alternating freezing and thawing in the presence of de-icing salt

3.3
scaling
loss of material at the surface of concrete due to freeze-thaw attack

3.4
internal structural damage
cracks developed inside concrete which may not be seen on the surface, but which lead to an alteration of concrete properties, e.g. reduction of the dynamic modulus of elasticity

4 Equipment

4.1 General

4.1.1 Equipment for making concrete specimens according to EN 12390-2.

4.1.2 Moulds for making concrete specimens according to EN 12390-1.

4.1.3 Freezing medium, consisting of de-ionised water and in special cases of 97 % by mass of tap water and 3 % by mass of NaCl (for test with de-icing salt).

4.1.4 A freezing chamber or a freeze-thaw chest with a cooling liquid or a flooding device. The freezing chamber or the freeze-thaw chest are equipped with a temperature and time controlled refrigerating and heating system with a capacity such that the time-temperature curve prescribed in Clauses 7, 8 and 9 can be followed. An automatically controllable frost chest and a water tank with thermostatic control can also be used instead of an automatically controlled freeze-thaw chest with a flooding device.

4.1.5 Thermocouples, or an equivalent temperature measuring device, for measuring the temperature at the appropriate prescribed points in the freezing chest with an accuracy within ± 0,5 K.

4.1.6 2 balances, with an accuracy within ± 1 g and ± 0,05 g.

4.1.7 Vernier callipers, with an accuracy within ± 0,1 mm.

4.1.8 Absorbent laboratory towel.

4.2 Special equipment for beam test

4.2.1 Thermometric frost resistance reference beam according to EN 206-1 with a dimension of 400 mm x 100 mm x 100 mm. A tolerance in length of ≤ 10 % will be permissible. A thermocouple (4.1.5) is installed near the geometric centre of the thermometric reference beam in order to measure the temperature variations during freeze-thaw cycles.

4.2.2 Equipment for ultrasonic pulse transit time (UPTT)

Ultrasonic pulse transit time (UPTT) measurement device which is suitable for determining the transit times of longitudinal waves in porous building materials according to EN 12504-4. The transducers operate in frequency range between 50 kHz and 150 kHz.

4.2.3 Equipment for fundamental transverse frequency (FF)

a) Equipment for measurement the resonance frequency: a Fourier analyser, a modally tuned impact hammer and an accelerometer.

b) Specimens pad consists of a soft and absorbing material (e.g. foam or sponge rubber) to store the specimens planar. The specimens pad uncoupled the specimen of its surroundings, so that the waves run only by the specimen.

4.3 Special equipment for slab test

4.3.1 Climate controlled room or chamber with a temperature of (20 ± 2) °C and an evaporation of (45 ± 15) g/(m² h). Normally this is obtained with a wind velocity ≤ 0,1 m/s and a relative humidity of (65 ± 5) %. The evaporation is measured from a bowl with a depth of approximately 40 mm and a cross section area of (225 ± 25) cm^2. The bowl is filled up to (10 ± 1) mm from the brim.

4.3.2 Diamond saw for concrete cutting.

4.3.3 Rubber sheet, (3 ± 0,5) mm thick which is resistant to the freezing medium used and sufficiently elastic down to a temperature of – 27 °C.

4.3.4 Adhesive for gluing the rubber sheet to the concrete specimen. The adhesive is resistant to the environment in question.

NOTE Contact adhesive has proved to be suitable.

4.3.5 Expanded Polystyrene cellular plastic, (20 ± 1) mm thick with a density of (18 ± 2) kg/m^3 or alternative thermal insulation with at least a heat conductivity of 0,036 W/(m·K).

4.3.6 Polyethylene sheet, 0,1 mm to 0,2 mm thick.

4.3.7 Equipment for length change (reference measuring procedure)

a) Length extensometer for measuring length change of specimens with a dial gauge to read in 0,01 mm and an accuracy within ± 0,001 mm. The extensometer is designed to accommodate the size of the specimens.

NOTE In consideration of specimens geometry the dimension of a suitable length extensometer is 170 mm or more.

b) Studs made of stainless steel or other corrosion-resistant materials being designed which secured a good contact with the specimen surface.

c) Invar or an equivalent reverence bar with a length which is comparable to the average specimen length.

4.3.8 Equipment for ultrasonic pulse transit time (alternative measuring procedure)

Ultrasonic pulse transit time (UPTT) measurement device which is suitable for determining the transit times of longitudinal waves in porous building materials according to EN 12504-4. The transducers operate in frequency range between 50 kHz and 150 kHz.

4.3.9 Equipment for fundamental transverse frequency (alternative measuring procedure)

a) Equipment for measurement the resonance frequency: a Fourier analyser, a modally tuned impact hammer and an accelerometer.

b) Specimens pad consists of a soft and absorbing material (e.g. foam or sponge rubber) to store the specimens planar. The specimens pad uncoupled the specimen of its surroundings, so that the waves run only by the specimen.

4.4 Special equipment for CIF-test

4.4.1 PTFE plate (Polytetrafluorethylene) or other materials with an equivalent hydrophobic surface serving as mould for the test surface. The geometry of the plate is adapted to the 150 mm cube mould and the thickness has to be less than 5 mm.

4.4.2 Climate controlled room or chamber with a temperature of (20 ± 2) °C and an evaporation of (45 ± 15) g/(m² h). Normally this is obtained with a wind velocity ≤ 0,1 m/s and a relative humidity of (65 ± 5) %. The evaporation is measured from a bowl with a depth of approximately 40 mm and a cross section area of (225 ± 25) cm^2. The bowl is filled up to (10 ± 1) mm from the brim.

4.4.3 Lateral sealing consists of solvent-free epoxy resin or aluminium foil with butyl rubber, durable to temperatures of - 20 °C and resistant against the attack of the de-icing solution.

4.4.4 Test containers. The specimens are stored in stainless steel containers during the freeze-thaw cycles. The stainless sheet metal is (0,7 ± 0,01) mm thick. The size of the test container is selected in such a way that the thickness of the air layer between the vertical side of the specimen and the test container is restricted to (30 ± 20) mm.

Other containers can be used for capillary suction if they assure an equivalent arrangement. During the capillary suction the test container is closed with a cover. The cover has an incline to prevent any possible condensation water from dripping onto the specimens.

4.4.5 Spacer (5 ± 0,1) mm high placed on the container bottom to support the specimen and to guarantee a defined thickness of the liquid layer between the test surface and the container bottom.

4.4.6 Unit for adjusting liquid level, i.e. a suction device. The suction device may consist of a capillary tube with a spacer of (10 ± 1) mm that is connected with e.g. a water jet pump to suck up the excessive liquid in the test containers.

4.4.7 Ultrasonic bath. The size of the ultrasonic bath is sufficiently large. The test container does not have a mechanical contact to the ultrasonic bath. The minimum distance between the test container and the lower surface of the bath amounts to 15 mm. The bath should provide the following power data: ERS power in the range of 180 W to 250 W; HF peak power under double half-wave operation in the range of 360 W to 500 W; frequency in the range of 35 kHz to 41 kHz.

4.4.8 Equipment for ultrasonic pulse transit time (reference measuring procedure)

a) Ultrasonic pulse transit time (UPTT) measurement device which is suitable for determining the transit times of longitudinal waves in porous building materials according to EN 12504-4. The transducers operate in frequency range between 50 kHz and 150 kHz.

b) A rectangular measuring container (e.g. PMMA) is used for UPTT measurement. The transducers are mounted in recesses in two opposite faces of the container so that the transit axes lies parallel to and at a distance of (35 ± 1) mm from the test surface. The size of the container is so large that the total thickness of the coupling medium (l_{c1} + l_{c2} see Figure 13) is approximately 10 mm.

c) A stainless steel plate for collecting scaled particles of the specimens during the measurement of the UPTT. The size of the steel plate is sufficient large and the edges are bent up approximately 5 mm to ensure that all scaled particles can be collected.

4.4.9 Equipment for fundamental transverse frequency (alternative measuring procedure)

a) Equipment for measurement the resonance frequency: a Fourier analyser, a modally tuned impact hammer and an accelerometer.

b) Specimens pad consists of a soft and absorbing material (e.g. foam or sponge rubber) to store the specimens planar. The specimens pad uncoupled the specimen of its surroundings, so that the waves run only by the specimen.

4.4.10 Equipment for length change (alternative measuring procedure)

a) Length extensometer for measuring length change of specimens with a dial gauge to read in 0,01 mm and an accuracy within ± 0,001 mm. The extensometer is designed to accommodate the size of the specimens.

b) Studs made of stainless steel or other corrosion-resistant materials being designed which secured a good contact with the specimen surface.

c) Invar or an equivalent reverence bar with a length which is comparable to the average specimen length.

5 Making of test specimens

Except where details are specified in Clauses 7, 8 and 9 the test specimens, cubes or beams, have to be prepared in accordance with EN 12390-2.

The inner surfaces of the moulds are lightly greased with mould oil and wiped with an absorbent towel (4.1.8) immediately before filling so that the test results are not affected by a thick layer of mould oil.

Concrete that requires vibrating for compaction is compacted on a vibrating table.

The prestorage conditions concerning temperature and moisture are documented.

The maximum aggregate size Dmax is restricted to one third of the mould length.

6 Principle of measurement the internal structural damage

6.1 Relative dynamic modulus of elasticity

Generally the dynamic modulus of elasticity is defined according to Equation 1.

Equation 1: $E_{dyn} = (X)^2 \times l^2 \times \rho \times C$

where

E_{dyn} is the dynamic modulus of elasticity in kN/mm²;

X is the measured value;
- fundamental transverse frequency: natural frequency in Hz;
- ultrasonic pulse transit time: reciprocal of the ultra sonic pulse transit time in µs;

l is the length of the specimen in mm;

ρ is the density in kg/m³;

C is a correction factor contains the Poisson's ratio µ.

The value of the internal structural damage is calculated as relative dynamic modulus of elasticity (RDM). For this reason the specimens length l, the density ρ and the correction factor C can be neglected so that the RDM_{UPTT} is calculated according to Equation 2.

Equation 2: $RDM_n = \left(\frac{X_n}{X_0}\right)^2 \times 100\ [\%]$

where

RDM is the relative dynamic modulus of elasticity in %;

index n characterise the measure after a number of freeze-thaw cycles;

index 0 characterise the initial measure.

6.2 Length change

The internal structural damage due to repeated freeze-thaw cycles can be proofed by measuring the length change. The relative length change is the change in length after n freeze-thaw cycles based on the initial length according to Equation 3.

Equation 3: $\varepsilon_n = \frac{\Delta l}{l_0} \times 100\ [\%]$

where

ε_n is the dilation of the specimen after n freeze-thaw cycles in %;

Δl is the change in length after n freeze-thaw cycles in mm;

l_0 is the initial length in mm.