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RILEM DRAFT RECOMMENDATION
PROJET DE RECOMMANDATION DE LA RILEM

129-MHT TEST METHODS FOR MECHANICAL PROPERTIES OF CONCRETE AT HIGH TEMPERATURES

Compressive strength for service and accident conditions

The text presented hereunder is a draft for general consideration. Comments should be sent to the TC Chairman, Professor Dr. Ulrich Schneider, Institut für Baustofflehre und Bauphysik, Technische Universität Wien, Karlplatz 13, A-1040 Wien, Austria, before 1 March 1996

1. SCOPE

This recommendation is valid for structural applications of concrete under service and accident conditions.

This document presents test parameters (material and environmental) and test procedures for measuring the compressive strength of concrete cylinders at high temperatures after first heating and also after cooling. Test temperatures range from 20°C to 750°C or above, depending on the capability of the test equipment [1].

2. SERVICE AND ACCIDENT CONDITIONS

2.1 Service conditions

Service conditions normally cover test temperatures in the range 20°C to 200°C and moisture states between the two boundary conditions:

Boundary condition 'd': Drying (unsealed) concrete,
Boundary condition 'nd': Moisture saturated (sealed) concrete.

In general, boundary condition 'd' applies to drying structures in air with a maximum thickness <400 mm, or structures with no point which is further away than 200 mm from a surface exposed to air.

Boundary condition 'nd' is defined for the following wet structures:

sealed structures independent of their dimensions,
zones of structures with a distance >200 mm from the surface exposed to air, or
structures under water

2.2 Accident conditions

Accident conditions normally cover temperatures in the range 20°C to 750°C or above and transient moisture states, i.e., the test specimens are unsealed and allowed to dry during heating [2]. In this case the moisture boundary condition is the same as condition 'd' above.

3. DEFINITION

The compressive strength of concrete is determined either in the hot state, i.e., at maximum test temperature T, or after cooling down to ambient temperature. Consequently, the strength of concrete is referred to as:

compressive strength at high temperature, or
residual compressive strength after cooling from high temperature.

The compressive strength of concrete may be determined from specimens loaded or without load during the total period of temperature exposure. Because the load level σ during heating influences the compressive strength of concrete, it is proposed to distinguish:

compressive strength and residual compressive strength of specimens which are without load during the temperature exposure, and
compressive strength and residual compressive strength of specimens which are loaded during the temperature exposure.

The compressive strength of concrete subjected to heating without loading is determined by the following equations:

$$f_c^T = \max F/A \ \text{(MPa)} \quad (1)$$

$$f_{c,\text{res}}^T = \max F/A \ \text{(MPa)} \quad (2)$$

where

f_c^T = compressive strength at maximum test temperature T (see Section 6),
$f_{c,\text{res}}^T$ = residual compressive strength after cooling from maximum test temperature T (see Section 6),

max F = maximum force in N obtained during the compressive test,
A = cross-sectional area in mm^2 of the concrete test specimen prior to heating,
T = maximum test temperature of the concrete specimen,
c = index for compressive,
res = index for residual.

The compressive strength of concrete subjected to heating and loading is determined by the following equations:

$$f_c^{\sigma,T} = \max F/A \text{ (MPa)} \quad (3)$$

$$f_{c,res}^{\sigma,T} = \max F/A \text{ (MPa)} \quad (4)$$

where

$f_c^{\sigma,T}$ = compressive strength at maximum test temperature T of concrete subjected to a constant uniaxial compressive load σ during heating and cooling (see Section 6),
$f_{c,res}^{\sigma,T}$ = residual compressive strength after cooling from maximum test temperature of concrete subjected to constant uniaxial compressive load σ during heating and cooling (see Section 6).

4. MATERIAL

4.1 Material type

The recommendation applies to all types of concrete used in construction, including high performance concrete.

4.2 Mix proportion

The mix proportion shall be determined according to the concrete design in use, with the two following provisos.

The maximum aggregate size must not exceed 25% of the specimen diameter, although for cast specimens a 20% limit would be preferred.
In cases where a smaller aggregate than the original maximum aggregate size in the real structure needs to be employed in the tests, the maximum aggregate size should not be less than 8 mm.

NOTE. The compressive strength depends on the type of aggregate and aggregate content by volume which normally comprises 60–80% by volume. Varying the aggregate content may result in significant variations in f_c^T. To allow comparisons to be made on the same basis, an aggregate content by volume of 70 ± 5% is advised for concrete.

5. SPECIMEN

5.1 Introduction

The specimens referred to below may be laboratory cast, field cast or taken as cores from sites, and should conform to the recommendations given below.

5.2 Specimen shape and size

The concrete specimens shall be cylindrical with a length/diameter ratio between 3 and 4 (slenderness).

The specimen minimum diameter shall be 4 times the maximum aggregate size for core samples, and 5 times for cast specimens.

The specimen maximum diameter should be related to the rate of heating and cooling as given in Section 6.3, Table 1.

5.3 Moulds, casting and curing

Moulds shall be cylindrical and should meet the general recommendations of RILEM. The same applies for casting and curing the specimens.

The moulds should be constructed preferably from sufficiently stiff, cylindrical or semi-cylindrical, shells made from steel or polymer. The assembled moulds should be watertight so as to prevent leakage of cement paste or water during casting. If polymer moulds are used the polymer should not be water adsorbent.

The compaction of the concrete in the mould should be accomplished using a vibrating table. Casting should be performed in 2 or 3 steps.

All specimens shall be stored during the first 7 days after casting at a temperature of 20 ± 2°C as follows:

in their moulds – during the first 24 ± 4 hours after casting,
under conditions without any moisture exchange – during the next 6 days.

This can be achieved by several means. The recommended method is to keep the specimens in their moulds and adding a tight cap on the top. Other possibilities include storage

in a room with a vapour saturated environment (relative humidity >98%),
in an air tight plastic bag containing sufficient water to maintain 100% RH,
wrapped in self-adhesive aluminium sheaths, and
under water (preferably water saturated with $Ca(OH)_2$).

Further storage conditions up to the beginning of the strength test shall be chosen to simulate the moisture conditions of the concrete in practice. The following two storage conditions are proposed.

Moisture condition 'd' (drying concrete):
storage in air at 20 ± 2°C and relative humidity RH = 50 ± 5%.

Moisture condition 'nd' (non-drying concrete):
storage within sealed bags or moulds or wrapped in water diffusion tight and non-corrosive foils at a temperature of 20 ± 2°C.

In each case the moisture loss of specimens over the storage period should be determined by weighing. The weight loss should not exceed 0.5% of the concrete weight for the case of sealed specimens.

5.4 Specimen preparation

The length, diameter and weight of the specimen shall be measured before testing.

If necessary the concrete specimen shall be prepared so that its ends are nominally parallel, flat and orthogonal to its central axis. This shall be done at an age of at least 28 days and not later than 2 months before testing; alternatively the specimen could be tested by the sand box method.

Specimens representing non-drying concrete shall be sealed by polymer resin, metal or polymer foils or other suitable encasement, depending upon the maximum test temperature. The time for the preparation of sealed specimens under laboratory conditions should not exceed 4 hours.

5.5 Age at testing

The specimens should be at least 90 days old before testing.

6. TEST METHOD AND PARAMETERS

6.1 Introduction

The following test parameters are recommended as 'standard' to allow consistent generation and comparison of test results. However, other test parameters may be substituted when information is required for specific applications, bearing in mind the relationships given below. The 'non-standard' test conditions should be detailed carefully in the test report.

6.2 Test procedure

The specimen shall not be removed from the curing environment for more than 2 hours for unsealed specimens and 4 hours for sealed specimens before the commencement of testing.

A uniaxial compressive load is then applied continuously in the direction of the central axis of the specimen at a rate of 0.5 MPa s^{-1} to a constant load level up to the load level σ of the reference strength (see Section 6.3) at 20°C immediately prior to heating. The load level must be kept constant and should be specified in the report.

The specimen, with or without load, shall be subjected to heating at the appropriate rate, continuous or step-wise, to the required maximum test temperature. After reaching the maximum test temperature the specimen temperature shall be kept constant for a defined period of time (see Section 6.3.2). Thereafter, the specimen shall be loaded at a loading rate of 0.5 MPa s^{-1} until failure.

The specimens intended for residual compressive strength testing shall be cooled within the heating device at an appropriate rate (given in Table 1) to avoid significant cracking due to thermal stresses, or significant moisture pick up.

6.3 Test parameters

6.3.1 *Loading condition*

The load should be applied with a precision of $\pm 1\%$.

If the specimen is subjected to a load during heating the load level σ must be kept constant during heating (and cooling).

If a defined strain rate is applied it should be detailed in the report as a 'non-standard' test condition. In this case the initial deformation during the first loading should be measured if possible.

6.3.2 *Heating and cooling conditions*

The heating and cooling rates, and maximum test temperature, should be appropriate to the condition to be simulated. However, to avoid radial temperature differences of more than 20°C the rates given in Table 1 are recommended relating to the diameter of the specimen.

Temperature measurements shall be made during heating and, when required, during cooling at three axial points on the surface of the specimen (centre, and 25–50 mm from the top/bottom) by temperature measuring devices such as suitable thermocouples protected from direct radiation. The accuracy of temperature measurements should be at least ± 0.5°C or 1% of the measured values, whichever is the greater.

The mean surface temperature is considered to be the average temperature of the three readings on the surface of the specimen.

The temperature recording intervals shall be appropriate to the rates of heating and/or cooling.

The heating of the concrete specimen should be performed by a heating device that ensures a uniform temperature around the circumference of the test specimen.

Axial temperature differences over the length of the specimens must not exceed 1 deg C at 20°C, 10 deg C at 100°C and 20 deg C at 750°C. For in between temperatures, the maximum axial temperature differentials shall be calculated by linear interpolation.

After reaching the maximum test temperature as indicated by the mean surface temperature, the temperature should be maintained for a period of 60 $\pm$ 5 minutes. If the hold time deviates from this period

Table 1 Recommended heating and cooling rates at the surface of the specimen

Diameter (mm)	Rate (deg C min^{-1})
150	≤ 0.5
100	≤ 1.0
75	≤ 2.0
50	≤ 4.0

of 60 ± 5 minutes, then this should be referred to as a 'non-standard' test condition.
NOTE. Concrete can spall explosively when heated. Precautions should therefore be taken to avoid damage or injury.

6.3.3 *Moisture condition*

The initial moisture content shall be determined using reference specimens (sealed or unsealed) cured under the same conditions as the test specimens. The evaporable moisture content is determined by drying at 105°C until constant weight is achieved (when moisture loss does not exceed 0.1% of the specimen weight over a period of 24 ± 2 hours), and by measuring the maximum weight loss.

Unsealed specimens shall be heated in a heating device where the moisture can escape freely from the specimen and the heating device.

Sealed specimens shall be heated and tested with a total moisture loss of less than 0.5% by weight during the test.

In the case of autoclave testing, sufficient water should be present to ensure that there is no moisture loss from the specimens during the heating process.
NOTE. Moisture gradients develop during heating which are related to temperature differentials and to the ratio of the exposed surface area to the volume of the concrete specimen.
NOTE. In the test temperature range from 20°C to 150°C the determination of moisture loss after the test is recommended in the case of unsealed concrete specimens. This is because during the hold time of 1 hour the evaporable moisture is unlikely to escape totally from the specimens, i.e., specimens with boundary moisture condition 'd' may comprise different absolute moisture values in this temperature range. At higher temperatures it may be assumed that 95% of the moisture loss occurs while heating during the hold time of 1 hour.

6.3.4 *Number of tests*

A minimum of 3 specimens shall be tested for each combination of test parameters.

For each batch a minimum of 2 specimens shall be tested. The total number of specimens tested shall be at least 3 for one batch and at least 4 for more than one batch.

6.4 Control tests

The standard cube or cylinder strength at ambient temperature shall be determined at the time of testing in accordance with national requirements.

In addition, the compressive strength of the test specimens should be determined at 28 days and at the time of testing. The latter shall be used as the reference strength for the specimens.

NOTE. In cases where the aggregate size has been altered, then a control test at ambient temperatures should also be conducted using the actual aggregate size as used in practice.

7. TEST APPARATUS

The test apparatus normally comprises a heating device, a loading device and instruments for measuring temperature, load and deformation, if possible.

The test apparatus used must be capable of fulfilling the recommendations given in Section 6 regarding the test parameters and test accuracy.

8. EVALUATION AND REPORTING OF RESULTS

8.1 Evaluation of strength results

The method of evaluating the strength of the specimen shall be described, including any deviation from the recommended test parameters, e.g., test temperature, heating rate, loading rate, and load level during heating and cooling. The strength as measured should be stated clearly as follows.

Specimen subjected to heating without loading:

compressive strength f_c^T, or
residual compressive strength $f_{c,res}^T$

Specimen subjected to heating with loading:

compressive strength $f_c^{\sigma,T}$, or
residual compressive strength $f_{c,res}^{\sigma,T}$

In addition to this, the moisture condition shall be indicated by adding the index 'd' or 'nd' as appropriate, i.e., $f_c^{\sigma,T,d}$.

8.2 Reporting of results

In addition to all the points mentioned under Section 8.1 the report should include when available the information specified in the following 6 categories.

8.2.1 *Mix proportion*

Cement content; water/cement ratio; aggregate content; aggregate grading; mineralogical type of aggregate; cement type and source; cement replacements; additives.

8.2.2 *Fresh concrete data*

Air content; bulk density; slump (or equivalent).

8.2.3 *Hardened concrete and specimen data*

Standard cube strength or cylinder strength; reference compressive strength; curing regime; diameter and length of specimen; mode of preparation of the top and bottom surfaces of the specimen; method of sealing if applicable; age at testing; moisture content.

8.2.4 *Apparatus*

The test apparatus used shall be described unless it is in accordance with a published standard.

8.2.5 *Test parameters*

Time between removal of specimens from the curing environment and installation in the heating device; time between placing of specimens in the heating device and loading and initiation of heating; load level for specimens heated under load; average surface test temperature as a function of time; heating and cooling rates.

'Non-standard' test conditions should be reported separately.

8.2.6 *Place, date, operator*

Country, city and institution where experiment carried out; date of experiment; name of operator.

REFERENCES

1. Schneider, U., 'Properties of materials at high temperatures – Concrete', RILEM-Report 44-PHT, 2nd Edn, Kassel, June 1986.
2. Schneider, U. and Schwesinger, P., 'Mechanical testing of concrete at high temperatures', RILEM Transaction 1, Report 74-THT, Kassel/Weimar, February 1990.