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RILEM TC 129-MHT: Test methods for mechanical properties of concrete at high temperatures

Recommendations

The texts presented hereafter are drafts for general consideration. Comments should be sent to the TC Chairman: Prof. Dr. Ulrich Schneider, Institut für Baustofflehre, Bauphysik und Brandschutz, Technische Universität Wien, Karlplatz 13, A-1030 Wien, Austria.
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RILEM TECHNICAL COMMITTEES

Part 4: Tensile strength for service and accident conditions

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 direct tensile strength of concrete cylinders in the longitudinal direction, either at high temperatures after first heating or after cooling. Test temperatures range from 20 to 750°C or above depending on the capability of the test equipment, see Ref. 1.

2. SERVICE AND ACCIDENT CONDITIONS

2.1 Service conditions

Service conditions normally involve long-term exposure to temperatures in the range 20 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 farther than 200 mm away 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.
- Structures under water.

2.2 Accident conditions

Accident conditions normally involve short-term exposure to temperatures in the range 20 to 750°C or above and transient moisture states, *i.e.* the concrete is allowed to dry during heating and cooling. In this case the moisture boundary condition is the same as the condition "d" mentioned above, see Ref. 2 Part 3.

3. DEFINITION

3.1 General

Tensile strength is defined here as the strength of concrete under direct axial tension. The tensile strength is determined either in the hot state or at ambient temperature after heating and cooling.

Consequently the tensile strength of concrete is referred to as:

- tensile strength at high temperature T or
- residual tensile strength after cooling from T to ambient temperature.

3.2 List of symbols and notations

A = cross-sectional area within the reference part of the concrete test specimen in mm^2 prior to heating
D = thermal diffusivity
f_t^T = tensile strength at maximum test temperature T (see section 6),

$f^T_{t,res}$ = residual tensile strength after cooling from maximum test temperature T (see section 6)
max F = maximum force applied to the specimen during the tensile test in N
r = radius of specimen in the cylindrical part in mm
R = constant heating rate
res = subscript for residual
t = subscript for tensile
T = test temperature for the concrete specimen

3.3 Tensile strength

The tensile strength of concrete at temperature and after cooling is determined by the following equations:

$$f^T_t = \max F / A \text{ (MPa)} \qquad (1)$$

$$f^T_{t,res} = \max F_{res} / A \text{ (MPa)} \qquad (2)$$

4. MATERIAL

4.1 Material type

This 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 practice with the following proviso: the maximum aggregate size should not be less than 8 mm.

Note: To allow comparisons to be made on the same basis, it is recommended that the aggregate content by volume, aggregate size and surface texture be comparable.

5. SPECIMEN

5.1 Introduction

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

5.2 Specimen shape and size

The concrete specimens shall contain a cylindrical part that has a length/diameter ratio of 2 ± 0.5, see Fig. 1.

The diameter of the cylindrical part shall be in the range 4 to 6 times the maximum aggregate size for core samples and 5 to 7.5 times for cast specimens.

Note: For a given size of maximum aggregate, larger diameter specimens tend to give lower measured tensile strength due to size effects.

The recommended diameters of the cylindrical part are 150 mm, 100 mm, 80 mm and 60 mm to be taken as standard. Other diameters, when used, should be described as "non-standard".

The ends of the cylindrical part shall be extended in such a manner to allow the application of loads in the longitudinal direction.

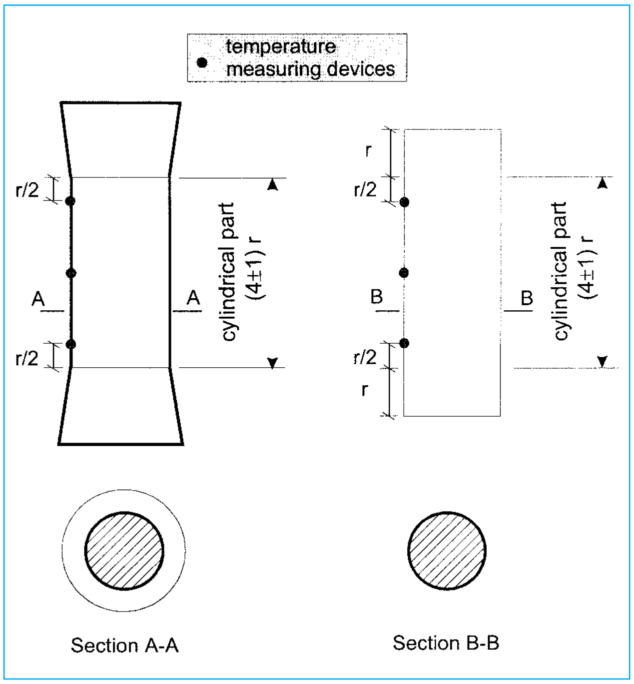

Fig. 1 – Examples of specimen shape with positions of the temperature measuring devices.

Fig. 1 shows two schematic examples of possible specimen shapes. The first one is a clamped specimen and the second one is a specimen which is glued directly on the end plates of the testing machine.

Note: The option of including a notch in the middle of the cylindrical part to initiate a crack is a "non standard" condition because it has been shown that the presence of a notch does not contribute significantly to the values of the tensile strength of unheated specimens. However, if the absence of a notch causes problems and the crack develops outside the cylindrical part, then it may be desirable to include a notch.

5.3 Moulds, casting, curing and storage

5.3.1 Moulds

Moulds shall have a cylindrical part as specified in section 5.2 and should meet the general recommendations of RILEM.

The moulds should preferably be constructed from sufficiently stiff shells made of *e.g.* 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 absorbent.

5.3.2 Casting

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

5.3.3 Curing

All specimens shall be cured during the first seven 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 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;
- under water (preferably water saturated with $Ca(OH)_2$).

5.3.4 Storage

Further storage conditions up to the beginning of testing shall be chosen to simulate the moisture conditions of the concrete in practice. The following storage conditions are proposed.
- *Moisture condition "d" (drying concrete)*: storage in air at 20 ± 2°C and RH of 50 ± 5%.
- *Moisture condition "nd" (non-drying concrete)*: storage within air tight bags or moulds or wrapped in water diffusion tight and non-corrosive foils at 20 ± 2°C.

In each case, the moisture loss of specimens over the storage period should be determined by weighing. For the case of non-drying concrete, the weight loss should not exceed 0.5% of the initial weight of the specimen determined before storage in a surface dry condition, *e.g.* by dabbing the specimen in water absorbent paper until no traces of humidity appears on the paper.

5.4 Specimen preparation

The dimensions and weight of the specimen shall be measured before testing.

Specimens representing non-drying concrete shall be sealed immediately after storage within 4 hours by polymer resin, metal or polymer foils depending upon the maximum test temperature.

The connection of the specimen to the testing machine can be done by glueing or clamping.

In the case of glueing the specimen to the end plate of the testing machine, the end surfaces shall be plane, parallel one to another, and normal to the axis of the specimen. The planeness required is 1‰. The angle between the end faces and the axis of the specimen shall not differ from 90° by more than 1°.

In the case of clamping, the specimen should have conical ends beyond the cylindrical parts. The clamping should be done in such a way that the stress concentrations in the conical parts are reduced as much as possible.

*Note: The clamping should be done by connecting the specimen and clamps by casting or by using a soft interlayer between the conical part and the clamp (*e.g. *Al.). An increase in friction in the interlayer and a radius between the conical and the cylindrical part of the specimen may be advantageous with respect to stress concentration.*

5.5 Age at testing

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

5.6 Standard compressive strength and reference tensile strength

The standard cube or cylinder compressive strength at ambient temperature shall be determined at 28 days, and at the time of testing, according to national requirements.

In addition, the tensile strength of the test specimens at ambient temperature should be determined at 28 days and at the time of testing using samples of the same type and of the same batch. The latter shall be used as the reference tensile strength of the specimens.

Note: In case where the aggregate size has been altered compared to the size in practice, then a control test at ambient temperatures should also be conducted using the actual aggregate size as in practice.

6. TEST METHOD AND PARAMETERS

6.1 Introduction

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

6.2 Measurements

6.2.1 Temperature measurement

Thermocouples or other types of temperature measuring devices may be used. In special cases it may be necessary to protect the surface thermocouples against radiation.

Surface temperature measurements shall be made during heating and, when required, during cooling at three points on the surface of the specimen (as shown in Fig. 1) by a temperature measuring device .

The precision of the temperature measurements should be at least 0.5°C or 1% of the measured values, whichever is the greater.

The mean surface temperature is the simple average temperature of the three measurements taken on the surface of the specimen.

6.2.2 Load Measurement

The load applied should be measured with a precision of ± 1%.

6.3 Test procedure

The specimen shall not be removed from the storage environment more than two hours (for unsealed specimens) and four hours (for sealed specimens) before the commencement of testing.

The specimen shall be placed in the testing machine and centred with an accuracy of 1% of the specimen's diameter.

The specimen shall be subjected to heating using a constant heating rate, see Table 1, to the required test temperature. After reaching the test temperature as indicated by the mean surface temperature, the temperature should be maintained for a period of 60 ± 5 minutes. If the hold time deviates from this period of 60 ± 5 minutes, this should be referred to as a "non-standard" test condition.

Thereafter, the specimen shall be loaded at a loading rate of 0.05 MPa/s until failure.

During loading, the rotation of the ends of the specimen shall not be restrained by the testing machine.

For the determination of residual tensile strength, it is allowed to heat and cool the specimen in a specific heating device and then to place it in the testing machine.

The specimens intended for residual tensile strength testing shall be cooled within the heating device in such a way that the cooling rate never exceeds the values given in Table 1 in order to avoid significant cracking due to thermal stresses, or significant moisture pick up.

The residual tensile strength shall be measured after cooling to 20 (+ 10, - 0)°C.

The measured tensile strength of the specimen is valid if the failure occurs at least one maximum aggregate size apart from the upper and lower ends of the cylindrical part.

Table 1 – Recommended heating and maximum cooling rates and temperature recording intervals at the surface of the specimen in the cylindrical part

Maximum diameter of the cylindrical part (mm)	Rate (°C/min)	Temperature recording interval (min)
150	0.25	16
100	0.50	8
80	1.00	4
60	2.00	2

6.4 Test parameters

6.4.1 Loading condition

If a defined displacement rate is applied instead of the load rate it should be detailed in the report as a "non-standard" test condition.

6.4.2 Heating and cooling conditions

For normal weight concrete, the recommended heating and maximum cooling rates as well as the temperature recording intervals for service and accident conditions are given in Table 1. For all types of concrete, the radial temperature differences in the cylindrical part of the specimen should not exceed 10°C during heating or cooling.

Note: An approximation of this radial temperature difference during a heating or a cooling at a constant rate can be made using the formula $\Delta T = Rr^2/4D$, where D = Thermal diffusivity of the concrete, R = rate of heating. The thermal diffusivity D varies significantly with temperature and type of concrete.

The heating of the concrete specimen should be performed in a way that a uniform temperature is ensured around the circumference of the test specimen in the cylindrical part.

Maximum axial temperature differences between any of the three surface temperature readings shall not exceed 1°C at 20°C, 5°C at 100°C and 20°C at 750°C. For intermediate values, the maximum axial temperature differences permitted shall be calculated by linear interpolation between the two adjacent points.

Note: Concrete can spall explosively when heated. Precautions should therefore be taken to avoid damage or injury.

6.4.3 Moisture condition

The initial moisture content just before testing shall be determined using reference specimens cured and stored 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 specimens weight over a period of 24 ± 2 hours), and by measuring the maximum weight loss.

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

Non-drying specimens shall be heated and tested with a total moisture loss during the test less than 0.5% by weight of a similar specimen dried at 105°C.

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 drying 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 a boundary moisture condition "d" may comprise different absolute moisture values in this temperature range. At higher temperatures it can be assumed that 95% of the moisture loss occurs during heating at the hold time of one hour.*

6.4.4 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.

7. TEST APPARATUS

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

The test apparatus used must be capable of fulfilling the recommendations given in section 6 for the test parameters and levels of precision.

8. EVALUATION AND REPORTING OF RESULTS

8.1 Evaluation of strength results

The tensile strength of concrete for each combination of parameters is the simple average of all valid results obtained from the specimens tested for this combination.

8.2 Test report

8.2.1 General

The test report shall indicate that the tensile strength is obtained by a direct tension test.

The method of evaluating the tensile strength of the specimen shall be described including any deviation from the standard. The valid results for each specimen tested shall be reported together with the mean tensile strength as follows:

- tensile strength: $f_t^{T,d}$ or $f_t^{T,nd}$
- residual tensile strength $f_{t,res}^{T,d}$ or $f_{t,res}^{T,nd}$

The report shall include the items highlighted by underlining below. The other items listed below should be reported when available.

8.2.2 Mix proportion

Cement content, water/cement ratio, aggregate content by volume of concrete, aggregate grading, maximum aggregate size, aggregate/cement ratio, mineralogical type of aggregate, cement type and source, cement replacements, additives.

8.2.3 Fresh concrete data

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

8.2.4 Hardened concrete and specimen data

Standard cube strength or cylinder strength, reference compressive strength, reference tensile strength, curing regime, diameter and length of specimen, weight before and after testing (excluding the weight of items such as thermocouples), method of sealing if applicable, age at testing, initial moisture content of reference specimen.

8.2.5 Apparatus

The apparatus used shall be described unless it is in accordance with a published standard, in which case the standard should be referenced.

8.2.6 Test parameters

Time between removal of specimens from the curing environment and initiation of heating.

The following should be reported as functions of time during heating/cooling: individual temperature measurements, mean surface temperature, rate of heating and cooling.

Any deviation from the recommended test parameters (*e.g.* heating rate, cooling rate) shall also be reported separately as "Non-standard".

8.2.7 Place, date, operator

Country, city and institution where the experiment was carried out. The dates of the experiment and report. Name of the operator.

REFERENCES

[1] Schneider, U., 'Properties of materials at high temperatures – Concrete', RILEM-Report 44-PHT, 2nd edn, Kassel, June 1986.

[2] RILEM TC 129-MHT, 'Test methods for mechanical properties of concrete at high temperatures', Part 1: Introduction, Part 2: Stress-strain relation, Part 3: Compressive strength for service and accident conditions, *Mater. Struct.* **28** (181) (1995) 410-414.

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Part 7: Transient Creep for service and accident conditions, *Ibid.* **31** (June 1998) 290-295.

Part 8: Steady-State Creep and Creep Recovery, *Ibid.* **33** (January-February 2000) 6-13.

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