



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.
Fax: + 43 1 58801 206 99; e-mail: ulrich.schneider@tuwien.ac.at, by 30 November 2000.

TC MEMBERSHIP: **Chairman:** Schneider, U., Austria; **Secretary:** Schwesinger, P., Germany; **Members:** Debicki, G., France; Diederichs, U., Germany; Felicetti, R. Italy; Franssen, J.-M., Belgium; Furumura, F., Japan; Jumppanen, U. M., Finland; Khoury, G. A., U.K.; Millard, A., France; Morris, W. A., U.K.; Phan, L., USA.

Part 9: Shrinkage 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 determining the *shrinkage* in the direction of the central axis, of a reference length of cylindrical concrete specimens under constant temperatures in the range of $20^\circ < T < 750^\circ\text{C}$.

Shrinkage tests can be carried out as accompanying tests for creep investigations (see Ref. 2, Part 7 and Part 8 respectively) or as independent tests. The *shrinkage* measurements of accompanying tests can start earlier than the commencement of the belonging *creep* tests.

2. SERVICE AND ACCIDENT CONDITIONS

2.1 Service conditions

Service conditions normally cover long time test temperatures in the range from 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 from 20 to 750°C or above and transient moisture states, *i.e.* the concrete is allowed to dry during heating. In this case the moisture boundary condition is the same as the condition "d" mentioned above.

3. DEFINITION

3.1 General

Shrinkage is defined as the deformation that occurs during the test period from t_1 to t_2 for a specimen at temperatures changing from T_n to T_{\max} without an external load. The times t_1 and t_2 respectively are identical to that of the accompanying creep test (see Ref. 2, Part 7 and Part 8 respectively). For comparative purposes additional *shrinkage* tests at $T = 20^\circ\text{C}$ can be advisable.

The test period in the case of an independent *shrinkage* test can be chosen dependent from the test objective. The specific definitions for non-drying and drying concrete are given in section 3.3.

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, mineralogi-

cal 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. Part 4: Tensile strength, Part 5: Modulus of elasticity, Part 6: Thermal strain, *Ibid.* (Supplement March 1997) 17-21. 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. Part 9: Shrinkage, Part 10: Restraint, Part 11: Relaxation.

3.2 List of symbols and notations

ε	= strain $((L - L_i)/L_i)$
σ	= stress level (constant)
D	= thermal diffusivity
L	= measured length (variable)
L_i	= initial reference length at ambient temperature (constant)
r	= radius of specimen
R	= constant heating rate (dT_s/dt)
RH	= relative humidity
t	= time (variable)
t_i	= time at initiation of test (latest commencement of an accompanying shrinkage test)
t_0	= time of start of steady state creep measurements
$t_{T_{\max}}$	= time, when T reaches T_{\max}
t_2	= time at end of test
t_b	= time at beginning of shrinkage measurements
T	= reference temperature (variable)
T_{ca}	= temperature at central axis of rotation of specimen (variable)
T_n	= normal temperature
T_{\max}	= maximum reference test temperature (constant)
T_s	= temperature at the surface of specimen (variable)
T_s^*	= surface temperature at which dT_s/dt starts to reduce from "R"
TTP	= transitional thermal period
ΔT	= temperature difference $T_s - T_{ca}$
0	= superscript index for zero stress ($\sigma = 0$) or subscript for time of loading
b	= subscript index for before
ca	= subscript index for location at central axis of rotation of specimen
co	= subscript index for constant temperature regime
d	= superscript index for drying (unsealed concrete)
el	= subscript index for elastic
i	= subscript index for initial
max	= subscript index for maximum
n	= subscript index for normal
nd	= superscript index for non-drying (sealed concrete)
s	= subscript index for location at surface of specimen
sh	= subscript index for shrinkage
th	= subscript index for thermal
tot	= subscript index for total

3.3 Drying concrete

For drying concrete, the measured *total strain* difference $\left(\varepsilon_{tot(t_2-t_i)}^{T,0,d}\right)$ during a period $\Delta t = (t_2 - t_i)$ at a temperature function starting at $T_n(t_i)$, followed by $T_{\max} - T_n(t_0 - t_i)$ as a heating period including TTP and reaching the constant temperature T_{\max} (see Fig. 1) is considered to be *shrinkage* and *thermal strain* of drying concrete. As a result

the *total strain* consists of the parts $\left(\varepsilon_{sh(t_0-t_i)}^{T_{\max}-T_n,0,d}\right)$, $\left(\varepsilon_{th(t_0-t_i)}^{T_{\max}-T_n,0,d}\right)$ and $\left(\varepsilon_{sh(t_2-t_0)}^{T_{\max},0,d}\right)$. Thereby the

shrinkage that belongs to a transient and/or *steady-state*

creep test (see Ref. 2, Part 7 and Part 8 respectively) of drying concrete for a period $\Delta t = (t_2 - t_i)$ is:

$$\left(\varepsilon_{tot(t_2-t_i)}^{T,0,d}\right) = \left(\varepsilon_{sh(t_0-t_i)}^{T_{\max}-T_n,0,d}\right) + \left(\varepsilon_{th(t_0-t_i)}^{T_{\max}-T_n,0,d}\right) + \left(\varepsilon_{sh(t_2-t_0)}^{T_{\max},0,d}\right) \quad (1)$$

For non-drying concrete *shrinkage* normally is not considered.

Note: The shrinkage is negative compared to thermal strain. It is influenced by temperature in so far as temperature influences moisture content. When testing high strength concrete, shrinkage can also occur with sealed specimens due to endogenous desiccation.

4. MATERIAL

4.1 Material type

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

4.2 Mix proportions

Mix proportions for accompanying *shrinkage* tests must be identical to the specimens of the original *creep* tests. They shall be determined according to the concrete design in practice with the following provisos: The maximum aggregate size should not be less than 8 mm.

5. SPECIMEN

5.1 Introduction

The specimens referred to in this recommendation may be laboratory cast, field cast or taken as cores, in the case of an accompanying test under identical conditions as the specimen of the belonging test; they should conform to the recommendations given below.

5.2 Specimen shape and size

The concrete specimens (Fig. 1) shall be cylindrical with a length/diameter ratio between 3 and 5 (slenderness).

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

The specimen's minimum diameter shall be four times the maximum aggregate size for cored samples and five times for cast specimens.

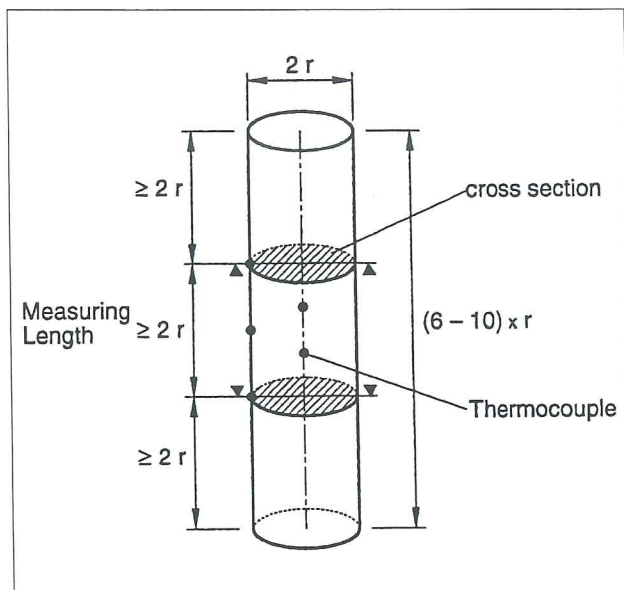


Fig. 1 – Geometrical relations of a cylindrical specimen and location of temperature measuring points.

5.3 Moulds, casting and curing

The moulds and the conditions and procedures of casting and curing should be identical to them used for manufacture the specimens for the related *creep* tests.

5.4 Specimen preparation

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

5.5 Age at testing

The specimens of accompanying *shrinkage* tests should have the same age than the specimens of the belonging *creep* test. The time of beginning the *shrinkage* measurements t_b can be earlier than that of the related *creep* measurements ($t_b < t_i$).

5.6 Standard and reference strength

The standard cube or cylinder strength at ambient temperatures shall be determined at 28 days, and at the time of testing, according to national requirements. In addition, the characteristic compressive strength of the test specimen should be determined at 28 days and at the time of testing, using samples of same type cast from the same batch. The latter shall be used as the reference strength of the specimen (see Ref. 2, Part 3). For specimens of accompanying *shrinkage* tests this information will be available as a rule from testing the related specimens of the *creep* tests.

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. The “non-standard” test conditions should be carefully detailed in the test report.

6.2 Measurements

6.2.1 Length measurement

The measured length L is determined in the direction of the central axis of the cylindrical specimen by measuring the mean distance between two cross-sections at the surface of the specimen with at least two, preferably three, measuring points per cross-section. The cross-sections shall be perpendicular to the central axis and at least one diameter away from each flat end of the specimen.

At the beginning of the test the length between the two cross sections is defined as the initial reference length L_i and shall be at least one diameter. The initial reference length L_i shall be measured at $20 \pm 2^\circ\text{C}$ with a precision of at least 0.5%.

During the test, usually changes in length are measured. From these measurements strains are derived. For strains up to 1000 microstrain, the uncertainty should be less than 10 microstrain. For strains exceeding 1000 microstrain the uncertainty should be less than 20 microstrain.

6.2.2 Temperature measurement

Surface temperature measurements shall be made at three points on the surface of the specimen at the centre and at the level of the two cross-sections (see Fig. 1), by a temperature measuring system. Thermocouples or other types of temperature measuring devices may be used. In special cases it may be necessary to protect the thermocouples against radiation. Temperature measurements at the central axis of rotation shall be made at least at one point in the center of the specimen for service conditions, or two points located at one third points between the measuring length cross-sections respectively for accident conditions.

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

6.2.3 Moisture measurement

Moisture measurements are related to the moisture content of the specimen, determined by weighing, and to the ambient relative humidity RH. The latter must be measured in the testing room, so far *shrinkage* tests (accompanying tests or parts of them and independent tests) are performed at normal temperature T_n .

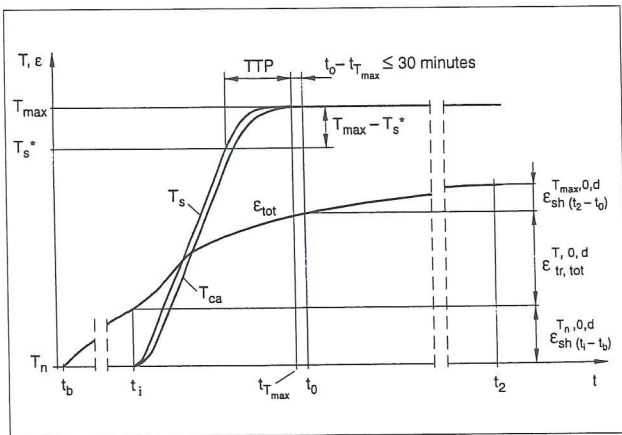


Fig. 2 – Definitions of a shrinkage test for drying concrete.

6.3 Test procedure

The test procedure of an accompanying shrinkage test starts at least with the commencement of the related creep test at t_i as shown in Fig. 2 (transient and/or steady state creep test; see Ref. 2, Part 7 and Part 8, respectively). An earlier beginning of such a shrinkage test (e.g. immediately after demoulding of the specimen) is permissible.

The shrinkage measurements start with the commencement of the test. One set of temperature and length or length change measurements shall be taken within 30 minutes after finishing the test preparations. Thereafter the measurements should be continued as follows:

- in the first day every hour
- in the first week every day
- later every week.

Additional sets of measurements shall be taken at all significant times of the related creep test as t_i , t_0 and t_2 .

The minimum duration of shrinkage tests following the procedure given in this document is 6 months and ends normally at t_2 .

6.4 Test parameters

6.4.1 Thermal condition

The recommended constant rates “R” for service and accident condition are given in Ref. 2, Part 6 and Part 7. The first measurement shall be taken simultaneous with the length measurements. After t_0 the specimen shall be maintained at temperature T_{max} until t_2 (see Fig. 2). Maximum differences between temperature T_{max} and any of the three surface temperature readings (section 6.2.2) shall not exceed the values as given in Table 1.

For intermediate values, the maximum temperature differences permitted shall be calculated by linear interpolation, between the two adjacent points.

6.4.2 Moisture condition

The moisture content shall be determined at the beginning of the test, at least at t_i (initial moisture con-

tent), at t_0 and at the end of the test.

The initial moisture content is determined as described for the thermal strain test (see Ref. 2, Part 6) and for the transient creep test (see Ref. 2, Part 7).

The moisture content at t_0 shall be determined by weighing the specimens at the end of TTP using companion specimens.

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

6.4.3 Number of tests

A minimum of two “replicate” specimens shall be tested for any unique combination of test and material parameters. The related specimens of the creep tests and for determining the initial moisture content should be taken from the same series of batches and should be tested under the same conditions.

7. APPARATUS

The test apparatus normally comprises a heating device and instruments for measuring temperatures and lengths of the specimen. The test apparatus must be capable of fulfilling the recommendations given in section 6 for the test conditions, test parameters and the levels of precision.

8. EVALUATION AND REPORTING OF RESULTS

8.1 Evaluation of the reference temperature

The reference temperature T_{max} during the transient part of the test is the simple averages of the measurements of T_s and T_{ca} .

8.2 Evaluation of strain results

All strains are evaluated as the arithmetic mean of two or more of the measured values.

The shrinkage strain of the different test parts and the thermal strain for the time interval $t_0 - t_i$ of an unsealed concrete specimen are evaluated in accordance with equation (1).

Table 1 – Maximum temperature differences at the specimen surface		
Temperature T_{max} (°C)	Maximum differences at	
	service conditions (°C)	accidental conditions (°C)
20	1	1
100	3	5
> 100	10	20

8.3 Test report

8.3.1 General

Normally the results of the *shrinkage* tests are part of the test reports on *transient* and/or *steady state creep* (see Ref. 2, Part 7 and Part 8 respectively). Therefore this document includes only the *shrinkage* relevant items. In general the report shall include the items highlighted by underlining below. The other items listed below should be reported when available.

8.3.2 Hardened concrete and specimen details

Curing regime, age at testing, initial moisture content of reference specimen and the moisture content of the tested specimen after the test, standard cube strength or cylinder strength, reference compressive strength, diameter and length of specimen, weight before and after testing (excluding the weight of items such as thermocouples).

8.3.3 Test apparatus

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

8.3.4 Test parameters

Time between removal of specimen from the curing environment and initiation of heating, Initial reference length, Test temperatures during the different test parts.

The following should be reported as functions of time during heating: individual temperature measurements, mean surface temperature, mean centre temperature, reference temperature, rate of heating, axial and radial temperature differences, and changes in the mea-

ured length (including any adjustments made for movements of any or all components of the length measuring device).

Any deviation from the recommended test parameters (e.g. heating rate, temperatures T_b , T_{max} , T_s and T_{ca} with time, shall also be reported separately as "non-standard".

8.3.5 Strain results

The total strain $\left(\epsilon_{tot}^{T, O, d}(t_2 - t_1) \right)$ of every specimen shall be reported in tabular and/or graphical form as functions of time, including the explicit values at t_i , t_0 and t_2 .

The "average curve" of each set of results shall also be reported.

8.3.6 Place, date, operator

Country, city and institution where the experiment was carried out. The dates of the experiment. 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. Part 4: Tensile strength, Part 5: Modulus of elasticity, Part 6: Thermal strain, *Ibid.* (Supplement March 1997) 17-21. 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. Part 9: Shrinkage, Part 10: Restraint, Part 11: Relaxation.