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RILEM TECHNICAL COMMITTEES

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

Recommendations: Part 7: Transient Creep for service and accident conditions

The text presented hereunder is a draft for general consideration. Comments should be sent to the TC Chairman, Prof. Dr. U. Schneider, Technische Universität Wien, Institut für Baustofflehere und Bauphysik, Karlsplatz 13/206, A-1040 Wien, Austria, Fax: +43 1 505 67 26, e-mail: uschneid@birisc.tuwien.ac.at, before December 1, 1998.

The draft of this document has been prepared by the following 10 Committee full members representing 7 countries.

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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 *transient creep* of concrete cylinders during first heating at a constant rate "R" in the range 20°C-750°C or above, under a constant uniaxial compressive external applied load prior to heating [1]. In special cases, higher temperatures may be used.

For the case when simulating service conditions at constant temperatures, this document also presents test parameters and test procedures for determining the total strain during the transitional thermal period when the rate of heating of the specimen reduces from the constant rate R to zero at a constant temperature level T_{max}, at which point steady-state temperature tests will commence [2], Part 8.

Note: Transient creep occurs during first heating under load, but not during subsequent cooling or immediate re-heating to the same maximum temperature.

2. SERVICE AND ACCIDENT CONDITIONS

2.1 Service conditions

Service conditions normally involve long-term exposure to temperatures in the range 20°C-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°C-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

Transient creep of concrete is defined as the creep that occurs during first time heating at a constant rate under load. The specific definitions for non-drying and drying concrete are given in Sections 3.3 and 3.4, respectively.

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
t_{Tmax} = time when T reaches T_{max}

T = reference temperature (variable)
T_{ca} = temperature at central axis of rotation of specimen (variable)
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 reduces from "R"
TTP = transitional thermal period
ΔT = temperature difference T_s - T_{ca}
0 = superscript index for zero stress (σ = 0)
ca = subscript index for location at central axis of rotation of specimen
co = subscript index for constant temperature regime
cr = subscript index for creep
d = superscript index for drying (unsealed concrete)
el = subscript index for elastic and plastic – see note below
i = subscript index for initial
max = subscript index for maximum
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
tr = subscript index for transient temperature regime

3.3 Non-Drying Concrete

Transient creep $\left(\varepsilon_{tr,\,cr}^{T,\,\sigma,\,nd}\right)$ of non-drying concrete during heating at a constant rate R (Table 2) under stress level σ is determined indirectly from three strain components by subtracting the *thermal strain* $\left(\varepsilon_{tr,\,th}^{T,\,0,\,nd}\right)$ and the *elastic strain* $\left(\varepsilon_{co,\,el}^{T,\,\sigma,\,nd}\right)$ from the *total strain* under load $\left(\varepsilon_{tr,\,tot}^{T,\,\sigma,\,nd}\right)$ *i.e.*:

$$\varepsilon_{tr,\,cr}^{T,\,\sigma,\,nd} = \varepsilon_{tr,\,tot}^{T,\,\sigma,\,nd} - \varepsilon_{tr,\,th}^{T,\,0,\,nd} - \varepsilon_{co,\,el}^{T,\,\sigma,\,nd} \quad (1)$$

For non-drying concrete heated without load (*i.e.* σ = 0) the *thermal strain* is equal to the *total strain*, *i.e.*:

$$\varepsilon_{tr,\,th}^{T,\,0,\,nd} = \varepsilon_{tr,\,tot}^{T,\,0,\,nd} \quad (2)$$

Transient Creep of non-drying concrete, therefore, becomes:

$$\varepsilon_{tr,\,cr}^{T,\,\sigma,\,nd} = \varepsilon_{tr,\,tot}^{T,\,\sigma,\,nd} - \varepsilon_{tr,\,tot}^{T,\,0,\,nd} - \varepsilon_{co,\,el}^{T,\,\sigma,\,nd} \quad (3)$$

Note: Transient creep of non-drying concrete is sometimes called "transitional thermal creep".

Note: The instantaneous strain comprises elastic and plastic strain compenents. For practical purposes, the instantaneous strain is referred to in this document simply as the "elastic" strain.

3.4 Drying concrete

Transient creep $\left(\varepsilon_{tr,\,cr}^{T,\,\sigma,\,d}\right)$ of drying concrete during heating at a constant rate R (Table 2) under stress level σ is determined indirectly from four strain components by subtracting the *thermal strain* $\left(\varepsilon_{tr,\,th}^{T,\,0,\,d}\right)$, *drying shrinkage strain* $\left(\varepsilon_{tr,\,sh}^{T,\,0,\,d}\right)$ and the *elastic strain* $\left(\varepsilon_{co,\,el}^{T,\,\sigma,\,d}\right)$ from the *total strain* under load $\left(\varepsilon_{tr,\,tot}^{T,\,\sigma,\,d}\right)$, *i.e.*:

$$\varepsilon_{tr,\,cr}^{T,\,\sigma,\,d} = \varepsilon_{tr,\,tot}^{T,\,\sigma,\,d} - \varepsilon_{tr,\,th}^{T,\,0,\,d} - \varepsilon_{tr,\,sh}^{T,\,0,\,d} - \varepsilon_{co,\,el}^{T,\,\sigma,\,d} \quad (4)$$

For drying concrete heated without load (*i.e.* σ = 0), the *thermal strain* plus the *drying shrinkage strain* equal the *total strain*:

$$\varepsilon_{tr,\,th}^{T,\,0,\,d} + \varepsilon_{tr,\,sh}^{T,\,0,\,d} = \varepsilon_{tr,\,tot}^{T,\,0,\,d} \quad (5)$$

Transient Creep of drying concrete, therefore, becomes:

$$\varepsilon_{tr,\,cr}^{T,\,\sigma,\,d} = \varepsilon_{tr,\,tot}^{T,\,\sigma,\,d} - \varepsilon_{tr,\,tot}^{T,\,0,\,d} - \varepsilon_{co,\,el}^{T,\,\sigma,\,d} \quad (6)$$

Note: Thermal strain $\left(\varepsilon_{tr,\,th}^{T,\,0}\right)$ *for drying and non-drying concrete is determined in accordance with the recommendations given in [2], Part 6.*

Note: Elastic strain $\left(\varepsilon_{co,\,el}^{T,\,\sigma}\right)$ *for drying and non-drying concrete is determined in accordance with the recommendations given in [2], Part 5.*

Note: The shrinkage strain is influenced by temperature in so far as temperature influences moisture loss. Strictly, shrinkage strains are related to moisture loss.

3.5 Transitional thermal period

When simulating service conditions at a constant temperature T_{max}, the *transitional thermal period* is defined as the time between the end of the constant rate of heating R period and the beginning of the constant temperature T_{max} period.

4. MATERIAL

4.1 Material type

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

4.2 Mix proportions

Mix proportions 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.

Note: The transient creep strain of concrete originates in the cement paste and is sensitive to the aggregate content which normally comprises 60-80% by volume. Varying the aggregate content may result in significant variations in $\varepsilon_{tr,\,cr}^{T,\,\sigma}$.

5. SPECIMEN

5.1 Introduction

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

5.2 Specimen Shape and Size

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

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

The recommended diameters of the test specimen 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".

5.3 Moulds, casting, and curing

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

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

The compaction of the concrete in the mould should be done using a vibrating table. Casting should be performed in two or three stages.

All specimens shall be stored 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 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 top. Other possibilities include storage:

- in a room with a vapour saturated environment (relative humidity > 98%);
- in a plastic bag containing sufficient water to maintain 100% RH;
- after wrapping in metal foil to prevent moisture loss;
- under water (preferably water saturated with $Ca(OH)_2$).

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 sealed bags or moulds or wrapped in water diffusion tight and non-corrosive foil at 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 0.2% 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.

The concrete specimen shall be prepared so that each end is 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.

Non-drying concrete specimens shall be sealed by polymer resin, metal or polymer foils, or impermeable encasements depending upon the maximum test temperature. The encasement shall not influence the deformation of the specimen or the contact between the specimen and the strain measuring device. The time for the preparation of sealed specimens under laboratory conditions should not exceed 4 hours.

5.5 Age at testing

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

5.6 Standard and reference strength

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

In addition, the compressive strength of the test specimens should be determined at 28 days and at the time of testing, using samples of the same type and batch. The latter shall be used as the reference strength of the specimens [2], Part 3.

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 Length measurement

The measured length 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 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 (Fig. 1). At the beginning of the test, the length between the two cross-section is defined as the initial reference length, L_i. It shall be at least one diameter in length. The initial reference length L_i shall be measured at 20 ± 2°C with a precision of at least 0.5%.

During the test usually changes in the length are measured. From these measurements strains are derived. For strains up to 1 000 microstrain, the uncertainty should be less than 10 microstrain. For strains exceeding 1 000 microstrain, the uncertainty should be less than 20 microstrain.

6.2.2 Temperature measurement

Thermocouple, *e.g.* Pt 100 or other types of thermocouples, may be used. In special cases it may be necessary to protect the surface thermocouples against radiation.

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 (Section 6.2.1), by a temperature measuring system. Temperature measurements at the central axis of rotation shall be made at two points located at one third points between the measuring length cross-sections (Fig. 1).

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 Load measurement

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

6.3 Test procedure

The initial moisture content just before testing shall be determined using control specimens (sealed or unsealed) from the same batch 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's weight over a period of 24 ± 2 hours), and by measuring the maximum weight loss.

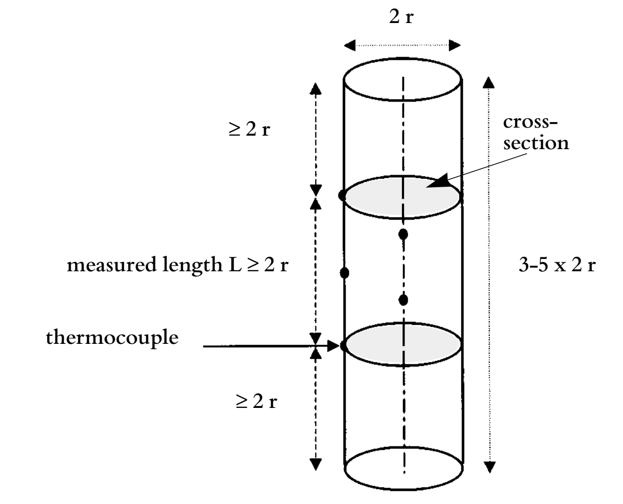

Fig. 1 – Cylindrical specimen showing location of five temperature measuring points.

The specimen shall not be removed from the curing environment more than two hours for unsealed specimens and four hours for sealed specimens before the commencement of heating.

If necessary, a small "pre-load" compressive stress not exceeding 0.01 MPa can be applied in the direction of the specimen's central axis.

During installation, the specimen shall be subjected to two load cycles between the pre-load level and 20% of the reference strength. The rate of loading and unloading should be the same as for the modulus of elasticity tests [2], Part 5. During this process, the difference in length change is recorded at the different locations. It shall not exceed 20%. If this difference exceeds 20%, then the following should be checked: strain measuring device; centering of the specimen; flatness and orthogonality of the flat ends of the specimen. Appropriate adjustments should be made and the test repeated until this criterion is met. If this is not possible within one hour, the specimen should be excluded from the test.

A uniaxial compressive load is then applied continuously in the direction of the central axis of the specimen at a rate of the order of 1.0 MPa/s to the required constant load level (Section 6.4.3) at 20°C immediately prior to heating. The load level must be kept constant according to Section 6.2.3.

The specimen shall then be subjected to heating at the appropriate constant rate (Section 6.4.1), commencing not later than 1 minute after the application of load.

When simulating accident conditions up to a maximum reference test temperature T_{max}, the test should terminate when the temperature at the central axis T_{ca} reaches T_{max} thus ensuring that the reference temperature of the specimen T (Section 8.1) has also reached T_{max}.

When simulating service conditions at a constant temperature T_{max}, the transitional thermal period starts at $T_s = T_s^*$ when dT_s/dt reduces from R (Fig. 2). The temperature difference $T_{max} - T_s^*$ should be less than 1°C at 20°C,

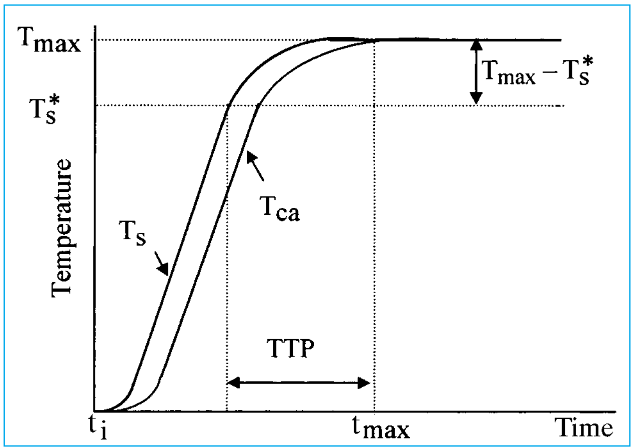

Fig. 2 – Definition of the Transitional Thermal Period (TTP).

less than 3°C at 100°C, and less than 20°C at 750°C. For intermediate temperatures, the maximum permitted value for $T_{max} - T_s^*$ shall be calculated by linear interpolation.

Changes in length (Section 6.2) are measured in the direction of the central axis of the specimen from at least two points on the surface of the specimen per cross-section. These points should be at least one diameter away from each flat end of the specimen.

Recording of length change shall be taken during initial load cycling [2], Part 2. Recordings of length change and temperature shall be taken during heating and during the transitional thermal period at the intervals given in Table 1.

Table 1 – Maximum recommended intervals for recording length change and temperature for service and accident conditions

Specimen diameter (mm)	Service interval (min)	Accident interval (min)
150, 100	20	4
80, 60	20	1

Note: Specimen failure could occur during heating before the maximum test temperature is reached (e.g. for high load levels). Appropriate safety measures should be taken.

6.4 Test Parameters

6.4.1 Heating Conditions

The recommended constant heating rates R for service and accident conditions are given in Table 2.

Table 2 – Recommended heating rates R at the surface of the specimen for service and accident conditions

Specimen diameter (mm)	Service R (°C/min)	Accident R (°C/min)
150, 100	0.1	0.5
80, 60	0.1	2.0

Maximum axial temperature differences between any two of the three surface temperature readings (Section 6.2.2) 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: The maximum specimen radial temperature differences should be preferably below 20°C during heating (Sections 6.2.2 and 8.1).

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

6.4.2 Moisture condition

The moisture content shall be determined at t_i according to Section 6.3.

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

Sealed and autoclaved specimens shall be heated and tested with a total moisture loss during the test of less than 0.3% by weight of a control specimen dried at 105°C.

6.4.3 Load condition

The specimen shall be subjected during heating to a constant uniaxial compressive load applied in the direction of the specimen's central axis.

For comparison of data between different laboratories, a constant load of 30% of the reference strength (Section 5.6) is recommended.

6.4.4 Number of tests

A minimum of two "replicate" specimens shall be tested for any unique combination of test and material parameters. The related thermal strain specimens [2], Part 6 and reference strength specimens [2], Part 3, should come from the same set of batches and should be tested under the same conditions.

7. APPARATUS

The test apparatus normally comprises a heating device, a loading devise, and instruments for measuring temperatures, load, and lengths of the specimen.

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

8. EVALUATION AND REPORTING OF RESULTS

8.1 Evaluation of the reference temperature

The reference temperature of the specimen T is calculated, during the period of heating at a constant rate and during the transitional thermal period, from the mean surface and central axis temperatures using:

$$T = T_s - 2\,\Delta T / 3 \qquad (7)$$

where ΔT represents the temperature difference between the surface temperature T_s and the temperature at the central axis of rotation T_{ca}, *i.e.*:

$$\Delta T = T_s - T_{ca} \qquad (8)$$

where T_{ca} is the simple average of the two measurements taken on the central axis of rotation of the specimen at one third points between the measuring length cross-sections (Section 6.2.2), and T_s is the mean surface temperature of the specimen calculated as a weighted average of the three temperature readings (Section 6.2.2) according to the formula:

$$T_s = (T_1 + 2T_2 + T_3)/4 \qquad (9)$$

where T_2 is the measured centre surface temperature.

Note: An approximation to T_{ca} can be made for the *period during heating at a constant rate using the formula $\Delta T = Rr^2/4D$, where D = Thermal diffusivity of the concrete, r = radius of the specimen, R = rate of heating. The thermal diffusivity D varies significantly with temperature and type of concrete.*

8.2 Evaluation of strain results

8.2.1 Non-drying concrete

The *transient creep strain* $\left(\varepsilon_{tr,\,cr}^{T,\,\sigma,\,nd}\right)$ of a non-drying sealed concrete specimen is evaluated, as the arithmetic mean of two or more of the recorded strain values, in accordance with equation (3) from the *total strain* determined in accordance with the procedures given in Section 6 and from the *thermal strain* [2], Part 6 and the elastic strain [2], Part 2.

8.2.2 Drying concrete

The *transient creep strain* $\left(\varepsilon_{tr,\,cr}^{T,\,\sigma,\,d}\right)$ of a drying unsealed concrete specimens is evaluated, as the arithmetic mean of two or more of the recorded strain values, in accordance with equation (6), from the *total strain* determined in accordance with the procedures given in Section 6 and from the *thermal strain* [2], Part 6 and the *elastic strain* [2], Part 2.

Note: Due to the contribution of shrinkage, it is possible for $\varepsilon_{tr,\,tot}^{T,\,0,\,d}$ *to have negative values when a concrete of low thermal expansion is heated.*

8.2.3 Average transient creep

The transient creep of the concrete is the *average transient creep* evaluated as the arithmetic mean of the transient creep values of the replicate specimens (Section 6.4.4).

8.3 Test report

8.3.1 General

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

8.3.2 Mix proportions

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

8.3.3 Fresh concrete

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

8.3.4 Hardened concrete and specimen details

Curing regime, age at testing, initial moisture content of reference specimen, assumed thermal diffusivity D, standard cube strength or cylinder strength, reference compressive strength, diameter and length of specimen, moisture of the tested specimen, weight before and after testing (excluding the weight of items such as thermocouples), mode of preparation of the flat surfaces of the specimen, method of sealing (if applicable).

8.3.5 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.

8.3.6 Test parameters

Time between removal of specimen from the curing environment and initiation of heating. Time between end of loading and start of heating. Initial reference length. Level of the restraining load (if applicable).

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 measured 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, loading rate, load level during heating) shall be reported separately as "non-standard".

For service conditions: Transitional thermal period, Maximum constant test temperature T_{max}, $T_{max} - T_s^*$. Deviation from T_{max} with time of both T_s and T_{ca}.

8.3.7 Strain during initial load cycling

Strains during initial two load cycles measured for each location at ambient temperature (Section 6.3).

8.3.8 Strain results

The total strain $\varepsilon_{tr,tot}^{T,\sigma,nd}$, $\varepsilon_{tr,tot}^{T,\sigma,d}$ and transient creep (Section 8.2) results $\varepsilon_{tr,cr}^{T,\sigma,nd}$, $\varepsilon_{tr,cr}^{T,\sigma,d}$ of every specimen shall be reported in tabular and/or graphical form as function of the reference temperature. The elastic strain $\varepsilon_{co,el}^{T,\sigma,nd}$, $\varepsilon_{co,el}^{T,\sigma,d}$ used in calculating the transient creep shall also be reported (Sections 3.2 and 3.3). The average transient creep (Section 8.2.3) shall also be reported.

8.3.9 Place, date, operator

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

9. REFERENCES

[1] Schneider, U., and Schwesinger, P. (Ed.) 'Mechanical testing of concrete at high temperatures', RILEM Transaction 1, February 1990, ISBN: 3-88122-565-X, pp.72.

[2] RILEM TC 129-MHT 'Test methods for mechanical properties of concrete at high temperatures'.
The Committee is in the process of preparing the following documents: Part 1 – Introduction; Part 2 – Stress-strain relation; Part 3 – Compressive strength; Part 4 – Tensile strength; Part 5 – Modulus of elasticity; Part 6 – Thermal strain; Part 7 – Transient creep; Part 8 – Steady-state creep and creep recovery; Part 9 – Shrinkage; Part 10 – Restraint; Part 11 – Relaxation.