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RILEM TC 162-TDF : Test and design methods for steel fibre reinforced concrete

Recommendations

The text presented hereafter is a draft for general consideration. Comments should be sent to the TC Chairlady : Prof. dr. ir. Lucie Vandewalle, K. U. Leuven, Departement Burgerlijke Bouwkunde, de Croylaan 2, 3001 Heverlee, Belgium Fax : +32 16 321976; e-mail : lucie.vandewalle@bwk.kuleuven.ac.be, by 31 August 2000.

TC MEMBERSHIP: Chairlady: L. Vandewalle, Belgium; **Secretary:** D. Nemegeer, Belgium; **Members:** L. Balazs, Hungary; B. Barr, UK; P. Bartos, UK; N. Banthia, Canada; A. Brandt, Poland; M. Criswell, USA; E. Denarie, Suisse; M. Di Prisco, Italy; H. Falkner, Germany; R. Gettu, Spain; V. Gopalaratnam, USA; P. Groth, Sweden; V. Häusler, Germany; E. Katsaragakis, Greece; A. Kooiman, the Netherlands; K. Kovler, Israel; J. Lehtonen, Finland; B. Massicotte, Canada; S. Mindess, Canada;; H. Reinhardt, Germany; P. Rossi, France; S. Schaerlaekens, Belgium; B. Schnütgen, Germany; S. Shah, USA; A. Skarendahl, Sweden; H. Stang, Denmark; P. Stroeven, the Netherlands; R. Swamy, UK; P. Tatnall, USA; M. Teutsch, Germany; J. Walraven, the Netherlands; A. Wubs, the Netherlands.

BENDING TEST

1. SCOPE

This test method evaluates the tensile behaviour of steel fibre-reinforced concrete in terms of areas under the load-deflection curve obtained by testing a simply supported notched beam under three-point loading.

This test method is used for the determination of:
- the limit of proportionality (LOP), *i.e.* the stress which corresponds to the point on the load-deflection curve (=> F_u) defined in point 5 as limit of proportionality;
- two equivalent flexural tensile strengths which identify the material behaviour up to the selected deflection. These equivalent flexural tensile strengths are determined according to point 5.

Besides the necessary measurement of the mid-span deflection (δ), opening displacement of the mouth of the notch (CMOD) is optional. The purpose of both measurements is to formulate in a later phase:
- a relation between crack mouth opening displacement and mid-span deflection;
- a relation between the stress-crack mouth opening displacement relationship, recorded during the bending test, on the one hand and the stress-crack width relationship, measured during a uniaxial tensile test, on the other.

2. TEST SPECIMEN

Concrete beams of 150 × 150 mm cross section with a minimum length of 550 mm are used as standard test specimens.

The standard test specimens are not intended for concrete with steel fibres longer than 60 mm and aggregate larger than 32 mm.The procedure for casting of the specimens and filling of the mould is shown in Fig. 1. It is desirable that portion 1 is twice that of portion 2.

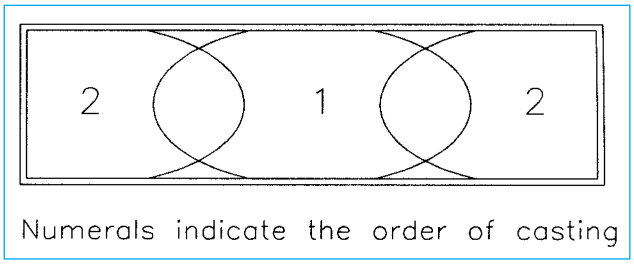

Fig. 1 – Production method for casting the specimen.

Compaction is normally carried out by means of external vibration as internal vibration or rodding may produce a non-uniform fibre distribution. Appropriate vibration should be used in accordance with the application proposed.

The specimens are demoulded between 24 and 48 hours after casting the concrete. Afterwards they are stored at + 20°C and R.H. ≥ 95% until preparation for testing.

The beams are notched using a saw. Each beam is turned 90° from the casting surface and then sawn through the width of the beam at midspan (see Fig. 2). The width of the notch is 2-3 mm and the depth is 25 mm ± 1 mm.

In the case of shotcrete, the samples are sawn out of test panels. Other dimensions for the test beams may be preferable. In the USA, normally beams of a 100 × 100 mm cross section and a span length of 300 mm are used. In Norway and Sweden and also in the Efnarc specification, beams with a height of 75 mm and a width of 125 mm are used.

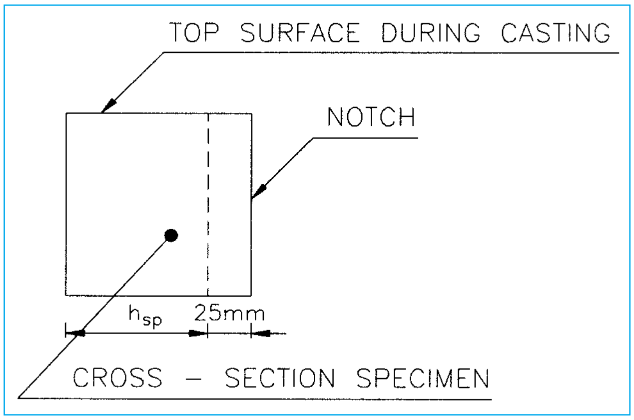

Fig. 2 – Position of the notch sawn into the test beam.

The span length is 450 mm. The test beams are not notched and the samples are not turned on their side but tested as shot. Care must be taken to ensure the flatness of the support planes. If necessary, a capping to obtain a flat contact between sample and support must be used.

3. APPARATUS

A testing machine which is capable of operating in a controlled manner and produces a constant rate of increase of deflection (δ) of the test specimen, preferably a closed loop machine, should be used. A testing machine capable only of producing a constant rate of increase in load is not suitable for recording of the load-deflection curve after the maximum load has been reached.

The stiffness of the testing equipment has to be large enough to avoid unstable zones in the F-δ (F-CMOD) curve. Tests during which instabilities occur have to be rejected.

The two supports are rollers with a diameter of 30 mm which are free to rotate. The rollers must be installed on a steel plate which permits a horizontal movement during a test and eliminates transmission of any horziontal forces on the test specimens.

The load is applied through one roller with a diameter of 30 mm.

The necessary degrees of freedom that have to be provided for the rollers are shown in Fig. 3.

One of the three contacts (load and two supports) has to be fixed.

The apparatus measuring deflection should be capable of recording accurately the mid-span deflection, excluding extraneous deformations due to deformations of the machine and/or of the specimen supports. The deflection has to be measured at both sides of the specimen (=> δ_I, δ_{II}) and the transducers have to be carefully mounted in order to minimize the effect of rotation.

A schematic illustration of a possible measuring device set-up is shown in Fig. 4. The recording of the displacement due to the opening of the mouth of the notch by means of a linear displacement transducer is optional. The original distance between the reference points for such measurement is normally 40 mm (Fig. 4).

The accuracy of the load measuring device is required to be equal to 0.1 kN. The accuracy of the deflection and the notch mouth opening displacement measuring system requires to be 0.01 mm.

4. PROCEDURE

The span length of the three-point loading test is 500 mm (Fig. 4).

The testing machine should be operated so that the measured net-deflection of the specimen at mid-span increases at a constant rate of 0.2 mm/min until the specified end-point deflection is reached. During testing the value of the load and net-deflection at mid-span ($\delta = (\delta_I + \delta_{II}) / 2$) are recorded continuously. The measurement of the crack mouth opening displacement is optional.

At least 3 specimens should be tested.

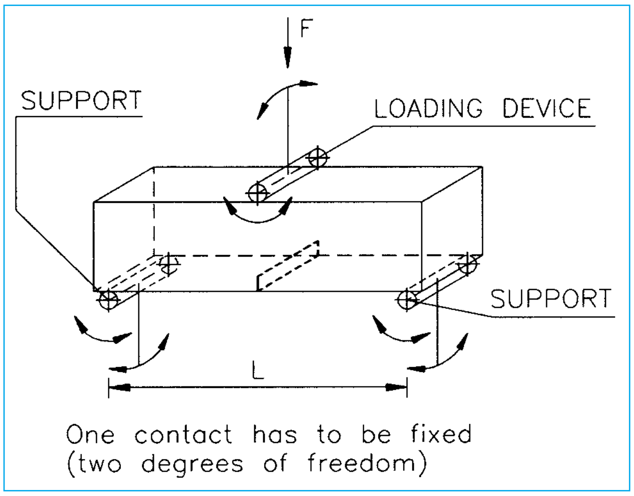

Fig. 3 – Position of the load and supports of the beam specimen.

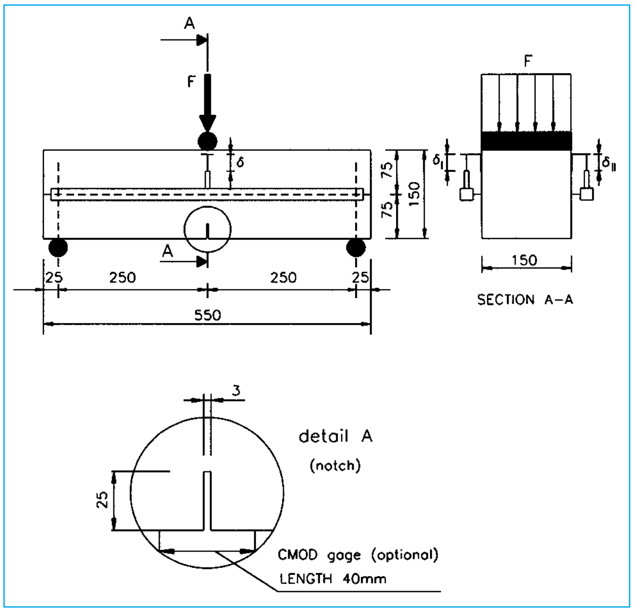

Fig. 4 – Arrangement of displacement monitoring gauges.

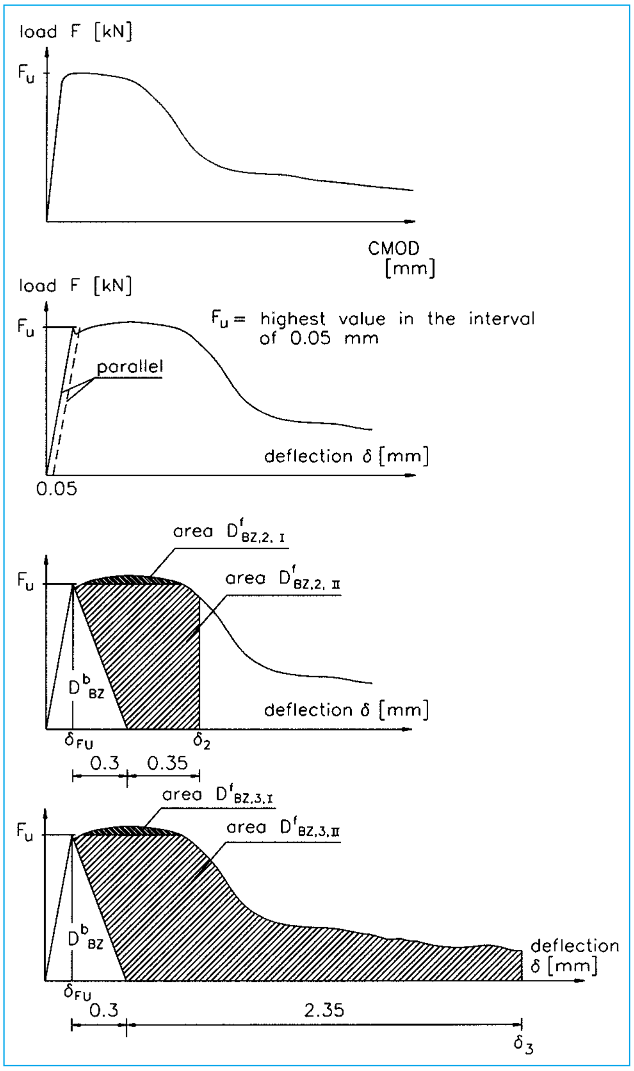

Fig. 5 – Diagrams.

5. CALCULATION

The load at the limit of proportionality (=F_u in N) is determined according to an appropriate diagram in Fig. 5. The moment at mid-span of the test beam corresponding to F_u is:

$$M_u = \frac{F_u}{2} \cdot \frac{L}{2} \quad \text{(Nmm)}$$

where L = span of the specimen (mm).

Assuming a stress distribution as shown in Fig. 6, the limit of proportionality $f_{fct,fl}$ can be calculated using the following expression:

$$f_{fct,fl} = \frac{3 F_u L}{2 b h_{sp}^2} \quad \text{(N/mm}^2\text{)}$$

where b = width of the specimen (mm); h_{sp} = distance between tip of the notch and top of cross section (mm).

The energy absorption capacity $D_{BZ,2}$ ($D_{BZ,3}$) is equal to the area under the load-deflection curve up to a deflection δ_2 (δ_3) (Fig. 5). $D_{BZ,2}$ ($D_{BZ,3}$) consists of two parts:

- plain concrete => D^b_{BZ} (Nmm)
- influence of steel fibres

=> $D^f_{BZ,2} = D^f_{BZ,2,I} + D^f_{BZ,2,II}$ (Nmm)
$D^f_{BZ,3} = D^f_{BZ,3,I} + D^f_{BZ,3,II}$ (Nmm).

The dividing line between the two parts can be simplified as a straight line connecting the point on the curve corresponding to F_u and the point on the abscissa "δ_{FU} + 0.3 mm". δ_{FU} is the deflection at the limit of proportionality. The deflections δ_2 and δ_3 are in turn defined as:

$\delta_2 = \delta_{FU} + 0.65$ mm (mm)
$\delta_3 = \delta_{FU} + 2.65$ mm (mm).

F_2 (F_3) is equal to the mean force recorded in the shaded area $D^f_{BZ,2}$ ($D^f_{BZ,3}$) and can be calculated as follows:

$$F_2 = \frac{D^f_{BZ,2,I}}{0.65} + \frac{D^f_{BZ,2,II}}{0.50} \quad \text{(N)}$$

$$F_3 = \frac{D^f_{BZ,3,I}}{2.65} + \frac{D^f_{BZ,3,II}}{2.50} \quad \text{(N)}$$

The moment at mid-span of the test beam corresponding to F_2 (F_3) is:

$$M_2 = \frac{F_2}{2}\frac{L}{2} = \left(\frac{D^f_{BZ,2,I}}{0.65} + \frac{D^f_{BZ,2,II}}{0.50}\right)\frac{L}{4} \quad \text{(Nmm)}$$

$$M_3 = \frac{F_3}{2}\frac{L}{2} = \left(\frac{D^f_{BZ,3,I}}{2.65} + \frac{D^f_{BZ,3,II}}{2.50}\right)\frac{L}{4} \quad \text{(Nmm)}$$

Assuming a stress distribution as shown in Fig. 6, the equivalent flexural tensile strength $f_{eq,2}$ and $f_{eq,3}$ can be determined by means of the following expressions :

$$f_{eq,2} = \frac{3}{2} = \left(\frac{D^f_{BZ,2,I}}{0.65} + \frac{D^f_{BZ,2,II}}{0.50}\right)\frac{L}{b h_{sp}^2} \quad \text{(N/mm}^2\text{)}$$

$$f_{eq,3} = \frac{3}{2} = \left(\frac{D^f_{BZ,3,I}}{2.65} + \frac{D^f_{BZ,3,II}}{2.50}\right)\frac{L}{b h_{sp}^2} \quad \text{(N/mm}^2\text{)}$$

Note: if the crack starts outside the notch, the test has to be rejected.

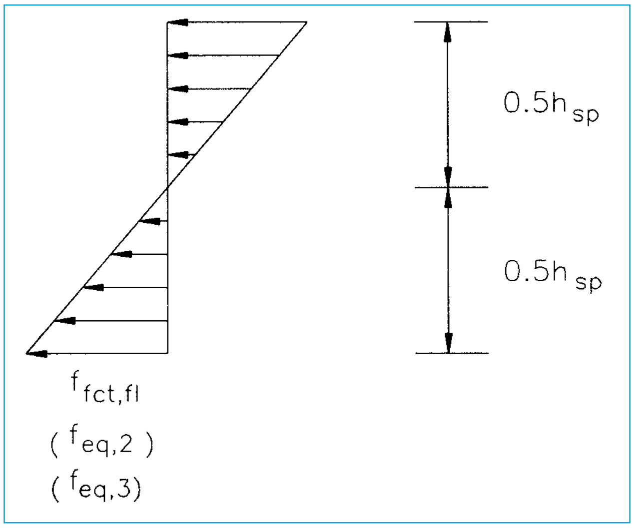

Fig. 6 – Stress distribution assumed.

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

Recommendations

The text presented hereafter are drafts for general consideration. Comments should be sent to the TC Chairman: Prof. Dr. Ulrich Schneider, Institut für Baustofflehre und Bauphysik Technische Universität Wien, Karlplatz 13, A-1030 Wien, Austria. Fax: + 43 1 58801 206 99; e-mail: uschneider@blrisc.tuwien.ac.at, by 31 August 2000.

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

Part 8: Steady-state creep and creep recovery 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 steady state creep and creep recovery, in the direction of the central axis, of a reference length of cylindrical concrete specimens under constant temperatures in the range of 20 °C $< T <$ 750 °C under a constant uniaxial compressive external applied load after heating or reaching the required temperature [1]. In special cases higher temperatures may be used.

For the case when a steady state creep test is carried out after a transient creep test, this document also presents test parameters and test procedures during the transitional thermal period when the rate of heating of the specimen reduces from a constant rate "R" of the transient creep test to zero at a constant temperature level T_{max}, at which point steady-state temperature tests will commence ([2], Part 7).

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

Steady-state creep is defined as the deformation that occurs during the test period from t_0 to t_1 for a specimen at constant temperature T_{max} and constant load. The specific definitions for non-drying and drying concrete are given in Sections 3.3 and 3.4 respectively.

Two cases of steady-state creep tests may be undertaken depending on the load-temperature sequence:

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Case 1: The specimen is first heated without load to T_{max} as in the thermal strain test ([2], Part 6) and then loaded at t_0.
Case 2: The specimen is loaded at ti before heating to T_{max} as in the transient creep test ([2], Part 7) and steady-state creep measurements commence at t_0.

Creep recovery is the deformation that occurs after unloading the specimen at t_1 while maintaining the temperature unchanged at T_{max} (see Figs. 2 and 3). It does not include the elastic strain, that occurs during the unloading process.

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_0 = time of start of steady state creep measurements
$^{t}T_{max}$ = time, when T reaches T_{max}
t_1 = time of unloading
t_2 = time at end of test
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 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
ca = subscript index for location at central axis of rotation of specimen
co = subscript index for constant temperature regime
cr = subscript index for creep
cr1 = subscript index for creep according to case 1
cr2 = subscript index for creep according to case 2
d = superscript index for drying (unsealed concrete)
el = subscript index for elastic
i = subscript index for initial
max = subscript index for maximum
nd = superscript index for non-drying (sealed concrete)
rc = subscript index for creep recovery
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 Non-drying concrete

3.3.1 Case 1 - Specimen is heated without load

For non-drying concrete *shrinkage* is not considered. The *total strain* difference $\varepsilon^{T_{\max},\sigma,nd}_{tot(t_1-t_0)}$, measured during the period $\Delta t = t_1 - t_0$, of concrete loaded at constant temperature T_{max} and time t_0 consists of non-drying creep $\varepsilon^{T_{\max},\sigma,nd}_{cr(t_1-t_0)}$, plus elastic strain $\varepsilon^{T_{\max},\sigma,nd}_{el(t_0)}$, *i.e.*:

$$\varepsilon^{T_{\max},\sigma,nd}_{tot(t_1-t_0)} = \varepsilon^{T_{\max},\sigma,nd}_{cr1(t_1-t_0)} + \varepsilon^{T_{\max},\sigma,nd}_{el(t_0)} \qquad (1)$$

Therefore, steady-state creep of non-drying concrete for a period $\Delta t = t_1 - t_0$ is:

$$\varepsilon^{T_{\max},\sigma,nd}_{cr1(t_1-t_0)} = \varepsilon^{T_{\max},\sigma,nd}_{tot(t_1-t_0)} - \varepsilon^{T_{\max},\sigma,nd}_{el(t_0)} \qquad (2)$$

This type of steady-state creep test is illustrated in Fig. 2.

3.3.2 Case 2 - Specimen is heated under load

In this case, the measured *total strain* difference $\varepsilon^{T_{\max},\sigma,nd}_{tot(t_1-t_0)}$ of loaded concrete at constant temperature T_{max} during the period $\Delta t = (t_1 - t_0)$ is the creep $\varepsilon^{T_{\max},\sigma,nd}_{cr2(t_1-t_0)}$ of non-drying concrete:

$$\varepsilon^{T_{\max},\sigma,nd}_{cr2(t_1-t_0)} = \varepsilon^{T_{\max},\sigma,nd}_{tot(t_1-t_0)} \qquad (3)$$

This type of steady-state creep test is illustrated in Fig. 3. It should be noted that in case 2, the elastic strains are considered in the transient creep test ([2], Part 7).

3.3.3 Creep recovery

The measured *total strain* difference $\varepsilon^{T_{\max},0,nd}_{tot,rc(t_2-t_1)}$ of concrete at constant temperature during a period $\Delta t = (t_2 - t_1)$ after removal of the load at t_1, can be expressed for case 1 as follows:

$$\varepsilon^{T_{\max},0,nd}_{tot,rc(t_2-t_1)} = \varepsilon^{T_{\max},0,nd}_{cr1,rc(t_2-t_1)} + \varepsilon^{T_{\max},\sigma,nd}_{el(t_1)} \qquad (4.1)$$

For case 2, it becomes:

$$\varepsilon^{T_{\max},0,nd}_{tot,rc(t_2-t_1)} = \varepsilon^{T_{\max},0,nd}_{cr2,rc(t_2-t_1)} + \varepsilon^{T_{\max},\sigma,nd}_{el(t_1)} \qquad (4.2)$$

Therefore, *creep recovery* of non-drying concrete for a period $\Delta t = (t_2 - t_1)$ for case 1 is:

$$\varepsilon^{T_{\max},0,nd}_{cr1(t_2-t_1)} = \varepsilon^{T_{\max},0,nd}_{tot,rc(t_2-t_1)} + \varepsilon^{T_{\max},\sigma,nd}_{el(t_1)} \qquad (5.1)$$

For case 2, it becomes:

$$\varepsilon^{T_{\max},0,nd}_{cr2,rc(t_2-t_1)} = \varepsilon^{T_{\max},0,nd}_{tot,rc(t_2-t_1)} + \varepsilon^{T_{\max},\sigma,nd}_{el(t_1)} \qquad (5.2)$$

Note: The instantaneous strain comprises elastic and plastic components. For practical purposes the instantaneous strain is referred to in the document simply as “elastic strain”.

3.4 Drying concrete

3.4.1 Case 1 - Specimen is heated without load

For drying concrete, the measured *total strain* difference $\varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t_0)}$ during a period Δt = (t$_1$ - t$_0$) at constant temperature T$_{\max}$ is expressed in terms *shrinkage* of drying concrete $\varepsilon^{T_{\max},0,d}_{sh(t_1-t_0)}$ ([2], Part 9), *creep* of drying concrete $\varepsilon^{T_{\max},\sigma,d}_{cr(t_1-t_0)}$ and *elastic strain* $\varepsilon^{T_{\max},\sigma,d}_{el(t_0)}$, *i.e.*:

$$\varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t_0)} = \varepsilon^{T_{\max},0,d}_{sh(t_1-t_0)} + \varepsilon^{T_{\max},\sigma,d}_{cr1(t_1-t_0)} + \varepsilon^{T_{\max},\sigma,d}_{el(t_0)} \qquad (6)$$

Therefore, steady-state creep of drying concrete for a period Δt = (t$_1$ - t$_0$) is:

$$\varepsilon^{T_{\max},\sigma,d}_{cr1(t_1-t_0)} = \varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t_0)} - \varepsilon^{T_{\max},0,d}_{sh(t_1-t_0)} - \varepsilon^{T_{\max},\sigma,d}_{el(t_0)} \qquad (7)$$

3.4.2 Case 2 - Specimen is heated under load

In this case, the measured *total strain* difference $\varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t_0)}$ during a period Δt = (t$_1$ - t$_0$) of loaded concrete at constant temperature T$_{\max}$ is expressed in terms *shrinkage of drying concrete* $\varepsilon^{T_{\max},0,d}_{sh(t_1-t_0)}$ and *creep of drying concrete* $\varepsilon^{T_{\max},\sigma,d}_{cr(t_1-t_0)}$, *i.e.*:

$$\varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t_0)} = \varepsilon^{T_{\max},0,d}_{sh(t_1-t_0)} + \varepsilon^{T_{\max},\sigma,d}_{cr2(t_1-t_0)} \qquad (8)$$

Therefore *steady-state* creep of drying concrete for a period Δt = (t$_1$ - t$_0$) is:

$$\varepsilon^{T_{\max},\sigma,d}_{cr2(t_1-t_0)} = \varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t_0)} - \varepsilon^{T_{\max},0,d}_{sh(t_1-t_0)} \qquad (9)$$

It should be noted, that in case 2 the elastic deformations are considered in the transient creep test ([2], Part 7).

3.4.3 Creep recovery

The measured *total strain* difference $\varepsilon^{T_{\max},0,d}_{tot,rc(t_2-t_1)}$ during a period Δt = (t$_2$ - t$_1$) of concrete at constant temperature T$_{\max}$ after removal of the load at t$_1$, can be expressed for case 1 in terms of *shrinkage* $\varepsilon^{T_{\max},0,d}_{sh(t_2-t_1)}$, *creep recovery* $\varepsilon^{T_{\max},0,d}_{cr1,rc(t_2-t_1)}$ and *elastic strain* $\varepsilon^{T_{\max},\sigma,d}_{el(t_1)}$, *i.e.*:

$$\varepsilon^{T_{\max},0,d}_{tot(t_2-t_1)} = \varepsilon^{T_{\max},0,d}_{cr1,rc(t_2-t_1)} + \varepsilon^{T_{\max},\sigma,d}_{el(t_1)} + \varepsilon^{T_{\max},0,d}_{sh(t_2-t_1)} \qquad (10.1)$$

For case 2, it becomes:

$$\varepsilon^{T_{\max},0,d}_{tot(t_2-t_1)} = \varepsilon^{T_{\max},0,d}_{cr2,rc(t_2-t_1)} + \varepsilon^{T_{\max},\sigma,d}_{el(t_1)} + \varepsilon^{T_{\max},0,d}_{sh(t_2-t_1)} \qquad (10.2)$$

Therefore, *creep recovery* of drying concrete for a period Δt = (t$_2$ - t$_1$) for case 1 is:

$$\varepsilon^{T_{\max},0,d}_{cr1,rc(t_2-t_1)} = \varepsilon^{T_{\max},0,d}_{tot(t_2-t_1)} - \varepsilon^{T_{\max},\sigma,d}_{el(t_1)} - \varepsilon^{T_{\max},0,d}_{sh(t_2-t_1)} \qquad (11.1)$$

For case 2 follows:

$$\varepsilon^{T_{\max},0,d}_{cr2,rc(t_2-t_1)} = \varepsilon^{T_{\max},0,d}_{tot(t_2-t_1)} - \varepsilon^{T_{\max},\sigma,d}_{el(t_1)} - \varepsilon^{T_{\max},0,d}_{sh(t_2-t_1)} \qquad (11.2)$$

Note: Elastic strain $\varepsilon^{T,\sigma}_{el}$ for drying and non-drying concrete at t$_0$ and t$_1$ shall be 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 content. When testing high strength concrete, shrinkage can also occur with sealed specimens due to endogenous desiccation. For this case see section 3.4. Shrinkage strain is determined in accordance with the recommendations given in ([2], Part 9).

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 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 and 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.

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 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 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 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 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 encasement depending upon the maximum test temperature (see paragraph 6.4.2). 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.

> Note: When using impermeable encasements the air-vapour tightness of the encasement containing the specimen should be tested before initiation of the test by subjecting it to an over pressure of 1.2 times the expected maximum vapour pressure at T_{max}, *i.e.* using compressed air over a period of at least 24 hours. During this time the pressure loss shall be less than 10 %.

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 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 ([2], Part 3).

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 ± 2 °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.

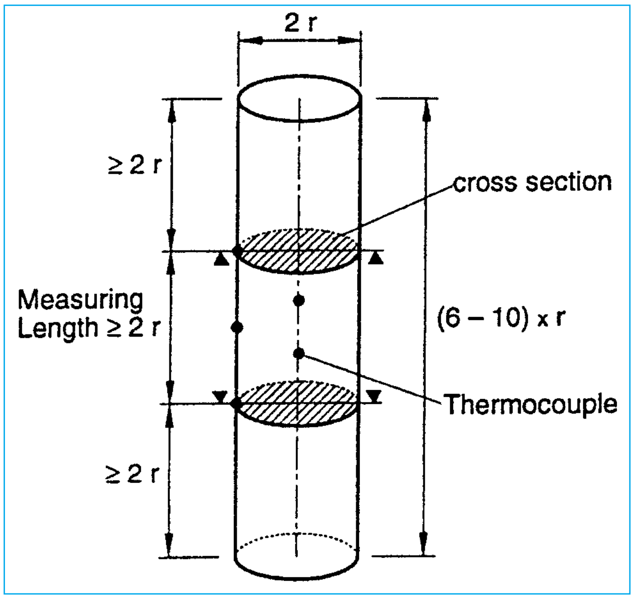

Fig. 1 – Geometrical relations of a cylindrical specimen and location of temperature measuring points.

6.2.3 Load measurement

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

6.2.4 Vapour Pressure Measurement

When using impermeable encasements for testing non-drying concrete the pressure in the space between encasement and specimen shall be measured during the test with a precision of 5% of the theoretical saturation vapour pressure, related to T_{max}.

6.3 Test procedure

6.3.1 Case 1 - Specimen is heated without load

The test procedure before the commencement of the steady-state creep measurements up to the end of the transitional thermal period TTP ([2], Part 7) shall follow the recommendations for thermal strain ([2], Part 6), and modulus of elasticity, ([2], Part 5).

The steady-state creep measurements start at t_0 which is within 30 minutes of the temperature reaching T_{max} (see Fig. 2). One set of temperature and length or length change measurements shall be taken with 30 s before the beginning of the loading process. The load should be applied continuously in the direction of the central axis of the specimen, as quickly as possible, at least at a rate of 5 MPa/s to the chosen load level (see section 6.4.3). The load level must be kept constant according to section 6.2.3. Another set of measurement shall also be taken immediately after reaching the chosen load level. Thereafter the measurements should be continued as follows:

- in first five minutes, each minute
- in first hour, every five minutes
- in first day, every hour
- later, every day.

In the case of service conditions the duration $\Delta t = (t_1 - t_0)$ of a steady-state creep test shall be at least 6 months.

> Note: The upper bound of steady-state creep is attained when the specimen is loaded within 30' of reaching T_{max}. Less steady creep could be attained, if loading is delayed beyond 30' because of possible greater stabilisation of the concrete.

6.3.2 Case 2 - Specimen is heated under load

The test procedure before the commencement of the steady-state creep measurements up to end of the transitional thermal period TTP ([2], Part 7) shall follow the recommendations for thermal strain ([2], Part 6) and modulus of elasticity ([2], Part 5).

The load of the previous transient creep test shall be kept unchanged. The steady-state creep test starts at t_0 within 30 min after the end of the transitional thermal period TTP (see Fig. 3).

First recordings of temperatures and lengths or length changes shall be taken at t_0 and thereafter as follows:

- in the first hour: every five minutes
- in the first day: every hour and later every day.

The total test duration shall be the same as for case 1.

6.3.3 Creep recovery

To determine the creep recovery, the temperature T_{max} of the previous steady-state creep test shall be kept unchanged until reaching t_2. The applied load shall be removed at t_1 with a rate of 1 MPa/s until a small load or a compressive stress not exceeding 0.2 MPa is reached. The applied small load is necessary to maintain the alignment of the specimen.

Recordings of temperatures and length or length changes shall be taken 30 s before t_1 is reached and immediately after removing the applied load. The recordings shall be continued according to the procedure as described for the measurements section 6.3.1.

The test duration for determining the creep recovery for the cases 1 and 2 shall be at least 1 month.

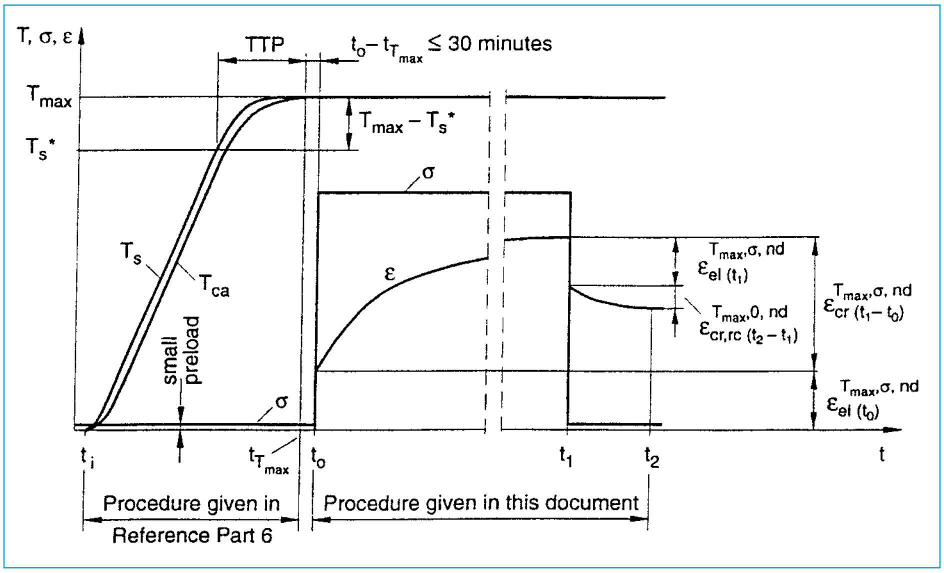

Fig. 2 – Definitions of a steady-state creep test, case 1, example of non-drying concrete.

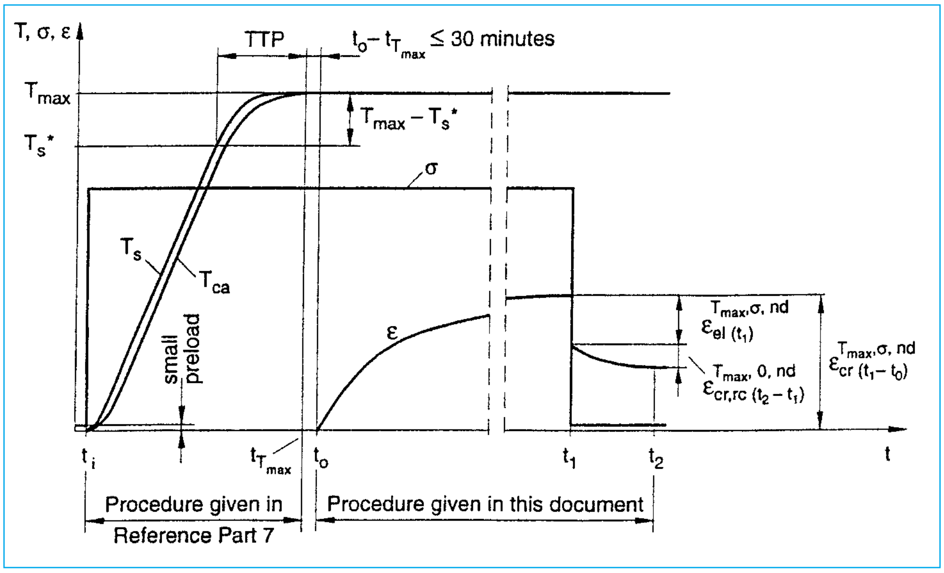

Figure 3 – Definitions of a steady-state creep test, case 2, example of non-drying concrete.

6.4 Test parameters

6.4.1 Thermal condition

The recommended constant rates “R“ for service and accident condition are given in ([2], Part 6 and 7). The first measurement shall be taken at t_0. The specimen shall be maintained at temperature T_{max} until t_1 or t_2 (see Fig. 2 or 3). 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.

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

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 ti (initial moisture content), at t_0 and at the end of the test.

The initial moisture content is determined as described for the thermal strain test ([2], Part 6) and for the transient creep test ([2], Part 7) for case 1 and case 2.

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

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

Sealed and autoclaved specimens shall be tested with a total moisture loss from t_i to the end of the test of less than 0,3% by the weight.

Note: It is difficult to avoid moisture transport from the specimen into the free space between encasement and specimen and opposite during heating and cooling respectively. Therefore when the specimen is sealed by an impermeable encasement, the difference of the specimens diameter and the clearance of the encasement should be a minimum and at most 1 mm.

6.4.3 Load condition

During a steady-state creep test, the specimen shall be subjected 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 specimens for determining the initial moisture content, shrinkage ([2], Part 9) and compressive strength ([2], Part 3) should come from the same series of batches and should be tested under the same conditions.

7. APPARATUS

The test apparatus normally comprises a heating device, a loading device, 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 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 steady-state part of the test is the simple average of the measurements of T_s and T_{ca}.

8.2 Evaluation of strain results

8.2.1 General

All strains are evaluated as the arithmetic mean of two or more of the measured values. The *shrinkage strain* $\varepsilon_{sh}^{T_{max},0,d}$ and the *elastic strain* $\varepsilon_{el}^{T_{max},\sigma,nd}$ or $\varepsilon_{el}^{T_{max},\sigma,d}$ are evaluated in accordance with Ref. 2, Part 9 and Part 5 respectively.

8.2.2 Non-drying concrete

The *steady-state creep strain* $\varepsilon_{cr(t_1-t_0)}^{T_{max},\sigma,nd}$ and the *creep recovery strain* $\varepsilon_{cr,rc(t_2-t_1)}^{T_{max},0,nd}$ of a sealed concrete specimen for case 1 are evaluated in accordance with equations (2) and (5.1) respectively. The corresponding strains for case 2 are evaluated in accordance with equations (3) and (5.2) respectively.

8.2.3 Drying concrete

The *steady-state creep strain* $\varepsilon_{cr(t_1-t_0)}^{T_{max},\sigma,d}$ and the *creep recovery strain* $\varepsilon_{cr,rc(t_2-t_1)}^{T_{max},0,d}$ of an unsealed concrete specimen for case 1 are evaluated in accordance with equations (7) and (11.1) respectively. The corresponding strains for case 2 are evaluated in accordance with equations (9) and (11.2) respectively.

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 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, mode of preparation of the flat surfaces of the specimen, method of sealing, weight before and after testing (excluding the weight of items such as thermocouples).

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 loading and heating. Time between end of TTP, start of loading and loading rate. Initial reference length. Duration of TTP, maximum constant test temperature T_{max}.

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, maximum constant temperature T_{max}, T_s and T_{ca} with time, loading rate, load level during heating, moisture loss of sealed specimen) shall also be reported separately as "non-standard".

8.3.7 Strain results

The total strain $\varepsilon^{T_{\max},\sigma,nd}_{tot(t_1-t_0)}$ or $\varepsilon^{T_{\max},\sigma,d}_{tot(t_1-t0)}$, the steady-state creep $\varepsilon^{T_{\max},\sigma,nd}_{cr(t_1-t_0)}$ or $\varepsilon^{T_{\max},\sigma,d}_{cr(t_1-t0)}$ and the creep recovery $\varepsilon^{T_{\max},0,nd}_{cr,rc(t_2-t_1)}$ *or* $\varepsilon^{T_{\max},\sigma,d}_{cr,rc(t_2-t_1)}$ for case 1 or case 2 of every, specimen shall be reported in tabular and/or graphical form as functions of time.

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

8.3.8 Place, date, operator

The following information shall be included in the report:

- Country, city and institution where the experiment was carried out;
- Date of the experiment;
- Name of the operator.

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, 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, Part 9 Shrinkage, Part 10 Restraint, Part 11 Relaxation'.