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RILEM TECHNICAL COMMITTEE

Recommendation of RILEM TC 200-HTC: mechanical concrete properties at high temperatures—modelling and applications

Part 1: Introduction—General presentation*

RILEM Technical Committee**

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1 Preface

The present set of RILEM recommendations specifies test methodologies for determining the different mechanical properties of concrete at high temperatures. It applies to all types of concrete used in construction, including high strength concrete, but excluding refractory concrete [1].

This document, *Introduction—General Presentation*, is the umbrella providing the general intentions of all the subsequent ten parts, each one being a specific recommendation (see Ref. 2, parts 2–11).

2 Background

According to their function, concrete structures may be subjected to very different mechanical, thermal and environmental conditions.

Under service conditions, they are generally exposed to limited temperatures (below 200°C) for longer periods of time, the prestressed concrete pressure vessels of gas-cooled reactors are designed to sustain high pressure and temperatures around 65°C.

In case of accident conditions, concrete structures may be exposed to very high temperatures, but generally for short term, as for example in the case of a fire. In the past, two main domains have motivated a large amount of research:

- the fire resistance of buildings and tunnels
- the behaviour of nuclear reactor containments in case of an accident.

In order to be able to design concrete structures as well as to assess the safety with regard to some design thermal events or after a real accident, it is

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necessary to have detailed knowledge of the properties of concrete for temperatures ranging from 20°C to at least 750°C. In some cases, the data of concrete properties are needed up to melting.

In the future, the development of new innovative concretes requires concise knowledge about their behaviour and properties, under various environmental conditions including fire and high temperatures.

When heating concrete, different physical processes and chemical reactions occur, which highly depend on the specific material composition, on the loading and on the environmental conditions. The temperature rise causes temperature gradients and water migration. Besides, moisture loss, dehydration and crystal transformations take place. These reactions lead to significant changes in the micro and macro structure of concrete like changes in porosity and permeability.

Macroscopically large modifications of the mechanical concrete behaviour are observed. The respective material properties vary with temperature, for example loss of strength and thermal strain.

In order to enable accurate predictions of the behaviour of concrete structures under high temperatures, full scale experimental investigations have been carried out, which led to the needs for the development of analytical models and to the determination of material properties. These properties vary with temperatures, like e.g. the modulus of elasticity, compressive and tensile strength, thermal strain, creep e.c. and their determination requires well determined test procedures.

The present set of recommendations provides a framework of standards which describes the tests procedures for mechanical properties of concrete at high temperature.

3 Scope

This document specifies the environmental and testing conditions associated with service or accident conditions of structural concrete at high temperature. The recommendations are applicable to concrete in the temperature range of 20°C to at least 750°C.

The document contains also a list of symbols and definitions used in the different recommendations (parts 2–11).

This document specifies the mechanical properties to be measured directly or derived indirectly from uniaxial tests on cylindrical specimens. The detailed specifications for the determination of properties of concrete at high temperature are outlined in respective test procedures recommended and described in the following parts:

Part 2 Stress–strain relation
Part 3 Compressive strengh for service and accident conditions
Part 4 Tensile strength for service and accident conditions
Part 5 Modulus of elasticity for service and accident conditions
Part 6 Thermal strain
Part 7 Transient creep for service and accident conditions
Part 8 Steady-state creep and creep recovery for service and accident conditions
Part 9 Shrinkage for service and accident conditions
Part 10 Restraint stress
Part 11 Relaxation

Section 8 of this document provides a comprehensive list of specific material properties to be determined.

4 Test conditions

The results of the experimental investigations on the behaviour of concrete at high temperature depend on test conditions, which are described below:

- Properties, obtained during a transient heating process should be differenciated from those obtained under steady state conditions. Table 1 shows the recommended test procedures according to the heating regimes.
- In certain test procedures, the measured values are influenced by the applied load-temperature sequence. For example, steady-state creep is derived either from specimens heated before loading or from specimens loaded before heating.
- Some properties are determined either in hot state or at ambient temperature after heating and cooling (the latters are marked as residual). The results obtained by the different test regimes are usually not the same. This applies to the

Table 1 Recommended test procedures and related heating regimes

Heating regimes		Comments
Steady state	Transient	
Stress–strain relation	–	–
Compressive strength	–	–
Tensile strength	–	–
Modulus of elasticity	–	–
Shrinkage	Thermal strain	Strain variation without external load
Creep and creep recovery	Transient creep	Strain variation, at constant stress
Relaxation	Restraint stress	Stress variation, at constant strain

properties of stress–strain relation, compressive strength, tensile strength and modulus of elasticity. In the respective test results the subscript "res" is added for residual properties.

- The moisture transport during a test influences the material behaviour. Two boundary conditions have been selected to represent the extreme cases of the moisture states in concrete structures:
  Boundary condition '*d*': drying (unsealed) concrete
  Boundary condition '*nd*': non-drying (moisture saturated or sealed) concrete
  The first case characterizes the moisture state of thin concrete elements or in the surface layer of thick members, while the second case characterizes the moisture state in the core of concrete of thick members. In general, boundary condition '*d*' applies to drying structures in air with a maximum thickness $d < 400$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.
  The moisture states during the tests are also related to the initial moisture content prior to heating. To obtain reproducible results, the recommendations propose on the one hand specifications for moulds, casting, curing and storage and on the other hand the use of specimens with identical mix design and identical curing conditions. Usually the tests are carried out during or after the first heating of specimens.

- Two situations for the design have been identified where concrete is exposed to elevated temperature:
  – *Service conditions* normally involve long-term exposure in the range 20–200°C and moisture states between the two boundary conditions defined above.
  – *Accident conditions* normally involve short-term exposure in the range 20–750°C and transient moisture states.
  These two conditions represent the framework which allows to link the range of maximum

Table 2 Test conditions included in the recommendations

Conditions	Range of temperature	Regime of temperature (Rate of heating: *R*)		Boundary condition	
				Drying concrete	Moisture sealed or satured concrete
Service conditions	$20°C < T < 200°C$	Transient	suitable *R*	"*d*"	"*nd*"
		Steady state	$R = 0$		
Accident conditions	$20°C < T < 750°C$	Transient	suitable *R*	"*d*"	
		Steady state	$R = 0$		

temperature, the heating rate and the moisture boundary conditions, as indicated in Table 2.

5 Symbols and notations

In order to identify the test conditions and the physical parameters for measured values, a system of notations is proposed. Some subscripts and superscripts have been added to the symbols, that define the material testing parameters and properties (see Table 3). Generally, the superscripts are related to the test conditions during the heating phase, while the subscripts are related to the physical nature of the parameter, to the special conditions during a mechanical test, or to the location of the measured temperature value.

The proposed system is summarized as an example in connection with strain (ε) in Fig. 1, the same system is also used with other parameters like stress in relaxation test (for the complete list of symbols and notations see Table 4).

As illustrative examples:

$\varepsilon_{tot(t_1-t_0)}^{T_{max},\sigma,d}$ represents the total strain (*tot*) of a drying (*d*) concrete, determined on a loaded (σ) specimen maintained at constant temperature (T_{max}), between the time period $t_1 - t_0$.

$\varepsilon_{tr,tot}^{T,0,nd}$ represents the total strain (*tot*) of a non-drying (*nd*) concrete, determined during heating (T and *tr*) without load ($\sigma = 0$).

The symbols used in the various parts of this set of recommendations are defined hereafter:

Table 3 List of symbols and notations

Superscripts		
Four superscripts, separated by a comma, are used when relevant. They are placed in the following order		
first	T	specifies the concrete temperature
	T_{max}	specifies the maximum reference test temperature (constant)
second	σ	specifies that a load has been applied during the hold time period of heating and cooling if relevant
	0	stands for a zero stress ($\sigma = 0$)
third	$\dot{\varepsilon}$	strain-rate controlled
	$\dot{\sigma}$	stress-rate controlled
fourth	d	specifies the drying moisture boundary condition
	nd	specifies the non-drying moisture boundary condition
Subscripts		
first	co	describes the constant temperature regime
	tr	describes the transient temperature regime
	$cr1$	indicates steady state creep measurements which commence at t_0, the number "1" denotes a heating without loading
	$cr2$	indicates steady state creep measurements which commence at t_0, the number "2" denotes a loading before heating
second	cr	creep
	el	elastic
	rc	recovery
	res	residual
	sh	shrinkage
	th	thermal
	tot	total
third	t_k	the presence of a subscript indicates a defined time; $k = 0, 1, 2$ or i (for initial)
	$(t_2 - t_1)$	refers to the time step $\Delta t = t_2 - t_1$ associated with the strain under consideration

Table 3 continued

α	stress ratio
ε	strain $(L - L_i)/L_i$
$\dot{\varepsilon}$	strain rate
ε_{c1}	strain at the peak of a stress–strain relation
ε_{cu}	strain at the end of the descending branch of a stress–strain relation
$\Delta\varepsilon$	strain increment
σ	stress or stress level
$\dot{\sigma}$	stress rate
σ_0	initial stress
$\Delta\sigma$	stress increment
Ψ	relaxation
A	cross sectional area of the specimen before heating
D	thermal diffusivity of concrete
E	modulus of elasticity
f	strength
f_t^T	tensile strength at temperature T_{max}

Table 3 (continued)

$f_{t,res}^{T}$	residual tensile strength after cooling from temperature T_{max}
f_c^T	compressive strength at temperature T_{max}
$f_{c,res}^{T}$	residual compressive strength after cooling from temperature T_{max}
$f_c^{\sigma,T}$	compressive strength at temperature T_{max}, for a specimen subjected to heating with load
$f_{c,res}^{\sigma,T}$	residual compressive strength after cooling from temperature T_{max}, for a specimen subjected to heating with load
F	applied force
$maxF$	maximum force applied on the specimen during strength test
$F_{r,tot}$	measured total restraint force
L	measured length (variable)
L_i	initial reference length of the specimen at ambient temperature (constant)
r	radius of the specimen before heating
R	constant heating rate $(\mathrm{d}T_s/\mathrm{d}t)$
RH	relative humidity
t	time (variable)
t_i	time at initiation of test
t_b	time at beginning of shrinkage measurements
$t_{T_{max}}$	time, when T reaches T_{max}
t_0	time at beginning of steady state regime, (e.g. time of start of steady state creep)
t_1	time of unloading
t_2	time at end of test
T	reference temperature (variable or constant in the parts related to compressive and tensile strength)
T_{ca}	temperature at central axis of rotation of specimen (variable)
T_{max}	maximum reference test temperature (constant)
T_n	standard reference condition of temperature at ambient
T_s	temperature at the surface of specimen (variable)
T_s^*	surface temperature at which $\mathrm{d}T_s/\mathrm{d}t$ starts to reduce from "R"
ΔT	temperature difference $T_s - T_{ca}$
TTP	transitional thermal period
Superscript index	
d	superscript index for drying (unsealed concrete)
nd	superscript index for non-drying (sealed concrete)
0	superscript index for zero stress (σ = 0)
T	superscript index for thermal
Subscript index	
b	subscript index for before
c	subscript index for compressive

Table 3 continued

ca	subscript index for location at central axis of rotation of the 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
$c1$	subscript index for strain at compression peak
cu	subscript index for maximum strain
el	subscript index for elastic
i	subscript index for initial
max	subscript index for maximum
n	subscript index for normal
o	subscript index for start
r	subscript index for restraint
res	subscript index for residual
rc	subscript index for creep recovery
s	subscript index for location at the surface of the specimen
sh	subscript index for drying shrinkage
t	subscript index for tensile
th	subscript index for thermal
tot	subscript index for total
tr	subscript index for transient temperature regime

6 Definitions of individual properties and relationships

6.1 Stress–strain relation (Part 2)

The stress–strain relation is derived from the total experimental curve giving the material reaction recorded as the strain under increasing uniaxial compressive stress (stress-rate controlled), or as the stress under increasing strain (strain-rate controlled), as shown in Fig. 2. It can be determined either in hot state, which gives the hot stress–strain relation, or at ambient temperature after heating and cooling, which gives the residual stress–strain relation.

The stress–strain relation of concrete may be determined for specimens which are loaded or non-loaded prior to testing and during the thermal exposure. Because the stress level σ during heating influences the stress–strain relation of concrete, it is proposed to distinguish the two cases: specimen unstressed during the temperature exposure and

Fig. 1 Global symbols and notations system for strain ε (example)

Superscripts: ⇒	*Temperature* ,	*Stress* ,	*Test control* ,	*Moisture condition*
	T_{max} ,	0 ,	$\dot{\varepsilon}$,	nd
	T ,	σ ,	$\dot{\sigma}$,	d

ε

Subscripts: ⇒	*Temperature regime or creep history* ,	*Strain type* ,	*(Time, or time step)*
	co ,	tot ,	(t_0)
	tr ,	th ,	(t_1-t_0)
	cr1 ,	cr ,	(t_2-t_1)
	cr2 ,	el ,	(t_1)
		sh ,	(t_i)
		rc	

specimen stressed (at a constant load level) during the temperature exposure.

6.2 Compressive strength (Part 3)

The compressive strength of concrete (f_c^T) is determined either in the hot state, i.e. at test temperature T_{max}, or after cooling down to ambient temperature ($f_{c,res}^T$: residual compressive strength).

After reaching the maximum test temperature the specimen temperature shall be kept constant for a defined period of time to ensure a uniform temperature distribution in the specimen.

The compressive strength of concrete may be determined from specimens with or without a sustained load during the total period of temperature exposure. The sustained load level influences the compressive strength of the concrete. The load level (percentage of the reference strength at ambient

Table 4 List of experimental operations

Step	Operations	Comments
1	Basic choices and controls	Control of the testing equipments
		The boundary condition drying or sealed concrete
		Slenderness of specimens between 3 and 5
		Location of temperature measuring points on specimen
2	Reference tests Test preparations	Before testing the specimens should be cured and stored according to the recommandation
		Reference measurements should be performed (compressive strength, moisture determination...)
		Installation of the specimen according to the recommendations (centering control, pre-load...)
3	Loading at T_n	Application of a pre-load or a defined strain before heating according to the recommendation
4	Transient test (with heating)	During the first stage, the heating rate increases progressively to the prescribed value
		During the second stage, the heating rate is constant
		During the third stage, the device reduces progressively the heating rate to maintain a constant temperature T_{max}. This period is called TTP (Transitional Thermal Period)
		During the fourth stage T_{max} is maintained constant until the temperature inside the center of the specimen reaches T_{max}
5	Loading at T_{max}	According to the recommendation
6	Steady-state test at constant temperature T_{max}	Control the measurement and recording system
7	Unloading at T_{max}	According to the recommendation
8	Cooling	The specimens intended for residual testing shall be cooled within the heating device at an appropiate rate to avoid significant cracking due to thermal stresses or significant moisture absorption
9	Residual tests	Tests after cooling

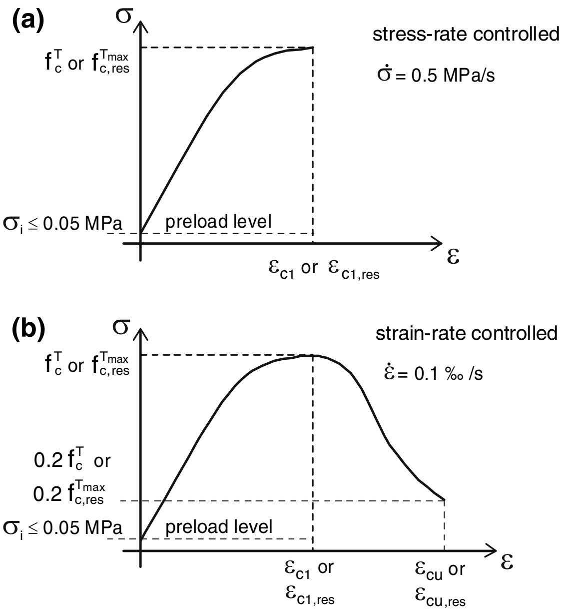

Fig. 2 Stress–strain relation of concrete under uniaxial compression determined by (**a**) stress-rate controlled test, (**b**) strain-rate controlled test

temperature) must be kept constant during heating ($f_c^{T,\sigma}$) or heating and cooling ($f_{c,res}^{T,\sigma}$).

6.3 Tensile strength (Part 4)

The tensile strength of concrete is defined as the strength of concrete under direct axial tension. The tensile strength is determined either in the hot state (f_t^T), i.e. at test temperature T, or after heating and cooling down to ambient temperature ($f_{t,res}^T$). The specimens are usually not loaded during heating or cooling.

6.4 Modulus of elasticity (Part 5)

The modulus of elasticity of concrete is defined here as "secant" modulus, as described in Fig. 3. It is determined either in the hot state, i.e. at test temperature T, or after cooling down to ambient temperature (residual modulus of elasticity).

Because the stress level σ, during thermal treatment, influences the modulus of elasticity of concrete, two separate cases are considered: the modulus of elasticity of specimens may be determined without load during heating or heating and

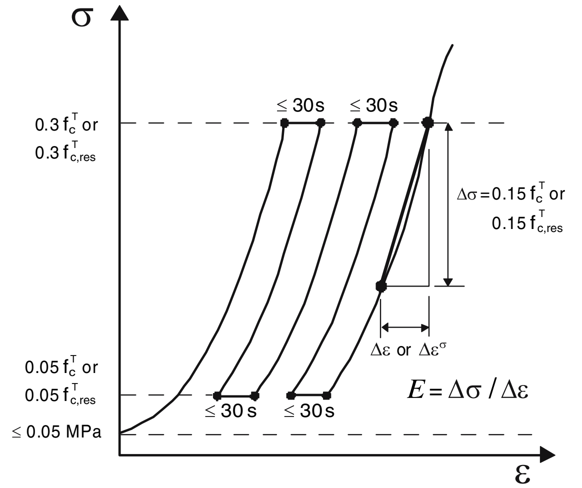

Fig. 3 Schematic presentation of the test procedure showing the determination of the hot or residual modulus of elasticity

cooling (E^T or E_{res}^T), or by applying a constant load during heating or heating and cooling ($E^{T,\sigma}$ or $E_{res}^{T,\sigma}$).

6.5 Thermal strain (Part 6)

Thermal strain of concrete is defined as the strain determined during heating without load.

Thermal strain $\varepsilon_{tr,th}^{T,0,nd}$ of non-drying concrete is the total strain $\varepsilon_{tr,tot}^{T,0,nd}$ determined during heating at a constant rate without external load and without moisture loss ($\varepsilon_{tr,th}^{T,0,nd} = \varepsilon_{tr,tot}^{T,0,nd}$).

Under transient temperature conditions, the drying shrinkage part of the strain cannot be determined easily by a single test. Therefore, in practice the thermal strains and shrinkage strains are determined together and are normally not separable. In practice the thermal strain of drying concrete is taken as the total strain, although it contains a drying shrinkage component: ($\varepsilon_{tr,th}^{T,0,d} = \varepsilon_{tr,tot}^{T,0,d}$).

6.6 Transient creep (Part 7)

Transient creep of concrete is defined as the creep that occurs during the first heating period under load.

Transient creep of non-drying concrete $\varepsilon_{tr,cr}^{T,\sigma,nd}$ or of drying concrete $\varepsilon_{tr,cr}^{T,\sigma,d}$ during heating at a constant rate R under stress level σ is determined indirectly from three strain components by subtracting the thermal strain $\varepsilon_{tr,th}^{T,0,nd}$ or $\varepsilon_{tr,th}^{T,0,d}$, as defined in Sect. 6.5, and the elastic strain $\varepsilon_{co,el}^{T,\sigma,nd}$ or $\varepsilon_{co,el}^{T,\sigma,d}$ from the total strain under load $\varepsilon_{tr,tot}^{T,\sigma,nd}$ or $\varepsilon_{tr,tot}^{T,\sigma,d}$ as follows:

– for the non-drying case:

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

– for the drying case:

$$\varepsilon_{tr,cr}^{T,\sigma,d} = \varepsilon_{tr,tot}^{T,\sigma,d} - \varepsilon_{tr,th}^{T,0,d} - \varepsilon_{co,el}^{T,\sigma,d} \quad (2)$$

These equations are strictly valid only in the elastic range. If the applied load leads to plastic strain, it should be measured and substracted as well.

The elastic strain is determined in accordance with recommendation for the modulus of elasticity, as indicated in Sect. 6.4.

6.7 Steady state creep and creep recovery (Part 8)

Steady state creep is defined as the creep that occurs during the test period from t_0 to t_1 for specimens heated up to T_{max} before loading at t_0 (see Figs. 4 and 5).

Two cases of steady-state tests should be distinguished depending on the load-temperature sequence. In addition the drying and non-drying conditions of specimen must be considered.

- In the case 1 (subscript: $cr1$), the specimen is first heated without load to T_{max} as in the thermal strain test and then loaded at t_0 (see Fig. 4). Steady state creep is determined as follows:
  – for non-drying case:

$$\varepsilon_{cr1(t_1-t_0)}^{T_{max},\sigma,nd} = \varepsilon_{tot(t_1-t_0)}^{T_{max},\sigma,nd} - \varepsilon_{el(t_0)}^{T_{max},\sigma,nd} \quad (3)$$

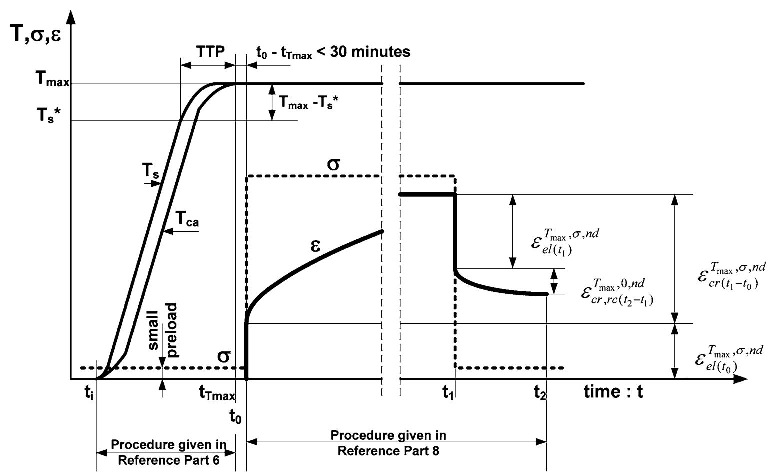

Fig. 4 Definitions of a steady-state creep test, case 1 (non-drying concrete)

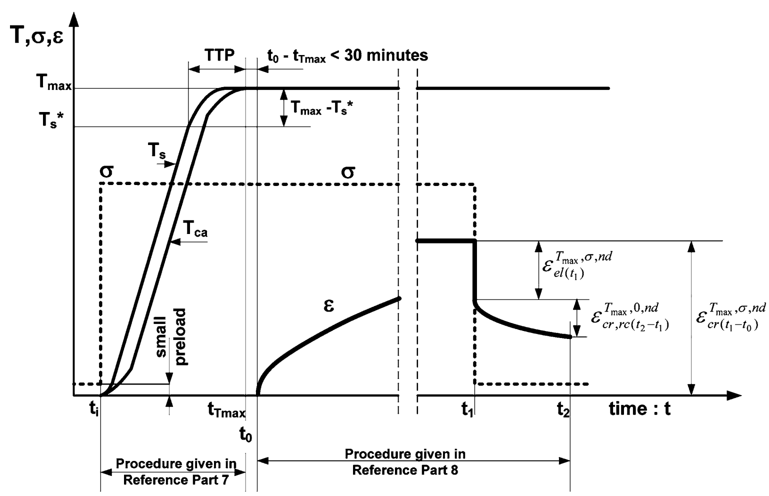

Fig. 5 Definitions of a steady-state creep test, case 2 (non-drying concrete)

– for drying case:

$$\varepsilon^{T_{max},\sigma,d}_{cr1(t_1-t_0)} = \varepsilon^{T_{max},\sigma,d}_{tot(t_1-t_0)} - \varepsilon^{T_{max},0,d}_{sh(t_1-t_0)} - \varepsilon^{T_{max},\sigma,d}_{el(t_0)} \quad (4)$$

- In the case 2 (subscript: *cr*2), the specimen is loaded at t_i before heating to T_{max} as in the transient creep test and the steady-state creep measurements commence at t_0 (see Fig. 5).
  – for non-drying case:

$$\varepsilon^{T_{max},\sigma,nd}_{cr2(t_1-t_0)} = \varepsilon^{T_{max},\sigma,nd}_{tot(t_1-t_0)} \quad (5)$$

– for drying case:

$$\varepsilon^{T_{max},\sigma,d}_{cr2(t_1-t_0)} = \varepsilon^{T_{max},\sigma,d}_{tot(t_1-t_0)} - \varepsilon^{T_{max},0,d}_{sh(t_1-t_0)} \quad (6)$$

Creep recovery is the deformation that occurs after unloading the specimen at t_1 while maintaining the temperature unchanged at T_{max}. It does not include the elastic strain, that occurs during the process of unloading and it is determined as follows:

– for the non-drying case:

$$\varepsilon^{T_{max},0,nd}_{cr,rc(t_2-t_1)} = \varepsilon^{T_{max},0,nd}_{tot,rc(t_2-t_1)} - \varepsilon^{T_{max},\sigma,nd}_{el(t_1)} \quad (7)$$

– for the drying case:

$$\varepsilon^{T_{max},0,d}_{cr,rc(t_2-t_1)} = \varepsilon^{T_{max},0,d}_{tot,rc(t_2-t_1)} - \varepsilon^{T_{max},\sigma,d}_{el(t_1)} \quad (8)$$

6.8 Shrinkage (Part 9)

Shrinkage is the drying induced strain of specimen without load at constant temperature.

For drying concrete, shrinkage is derived from the deformations that occur during the test period from t_i to t_2 for a specimen at temperatures changing from T_n to T_{max} without an external load (see Fig. 6):

$$\varepsilon^{T_{max},0,d}_{sh(t_2-t_0)} = \varepsilon^{T,0,d}_{tot(t_2-t_b)} - \varepsilon^{T_n}_{sh(t_i-t_b)} - \varepsilon^{(T_{max}-T_n),0,d}_{th(t_0-t_i)} \quad (9)$$

When the shrinkage of the specimen, before the initiation of the test, is not known, the shrinkage is determined in accordance with the equation:

$$\varepsilon^{T_{max},0,d}_{sh(t_2-t_0)} = \varepsilon^{T,0,d}_{tot(t_2-t_i)} - \varepsilon^{(T_{max}-T_n),0,d}_{th(t_0-t_i)} \quad (10)$$

For non-drying concrete, shrinkage is not considered.

6.9 Restraint stress (Part 10)

Restraint ($F_{r,tot}$) of concrete is defined as the stress resulting from dimensional constraint in the axial direction of a specimen during first time of heating at a constant rate with any initially applied stress (α_i). The restraint stress is resulting from maintaining the measuring length of a concrete specimen constant during the heating process. The restraint stress is determined as follows:

– for the non-drying case:

$$\sigma_r^{T,\alpha_i,nd} = \frac{F_{r,tot}}{A} \quad (11)$$

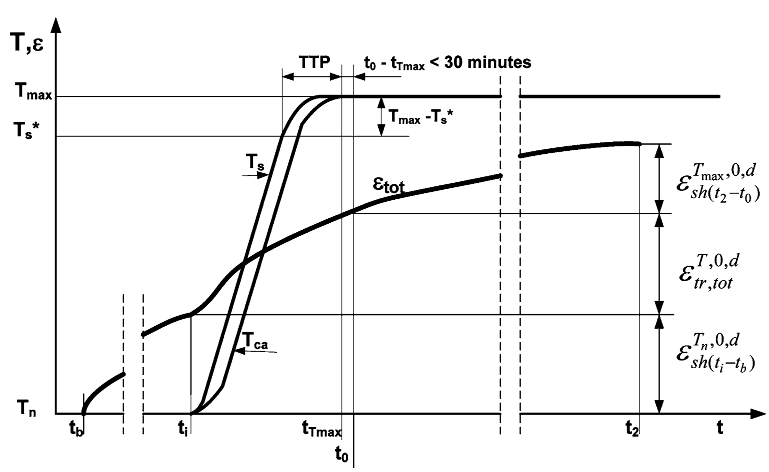

Fig. 6 Definitions of shrinkage during isothermal or transient tests for drying concrete

– for the drying case:

$$\sigma_r^{T,\alpha_i,d} = \frac{F_{r,tot}}{A} \tag{12}$$

6.10 Relaxation (Part 11)

Relaxation of concrete is defined as the time dependent stress reduction which occurs at constant temperature and constant strain.

The results of relaxation tests depend on the load temperature sequence. Three different regimes may be distinguished (see Fig. 7):

- Regime 1: The specimem is first heated without load to T_{max} as in the thermal strain tests and then loaded at t_0.
- Regime 2: The specimen is first loaded at t_i before heating to T_{max} as in the transient creep tests and relaxation measurements commence at t_0.
- Regime 3: The specimen is loaded at t_i before heating to T_{max} as in the restraint stress tests and relaxation measurements commence at t_0.

Relaxation from drying and non-drying concrete is derived from the following equations:

– for the non-drying case:

$$\Psi_{(t-t_0)}^{T_{max},\alpha_0,nd} = \frac{\Delta\alpha_{(t-t_0)}^{T_{max},nd}}{\alpha_0} = \frac{\Delta\sigma_{(t-t_0)}^{T_{max},nd}}{\sigma_0} \tag{13}$$

– for the drying case:

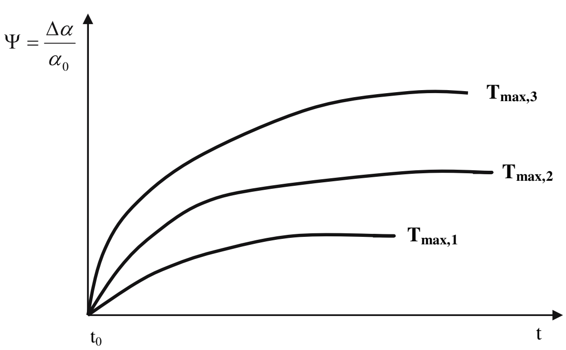

Fig. 7 Schematic representation of the relaxation test results

$$\Psi_{(t-t_0)}^{T_{max},\alpha_0,d} = \frac{\Delta\alpha_{(t-t_0)}^{T_{max},d}}{\alpha_0} = \frac{\Delta\sigma_{(t-t_0)}^{T_{max},d}}{\sigma_0} \tag{14}$$

$\Delta\sigma$ is defined as : $\quad \Delta\sigma_{(t-t_0)}^{T_{max}} = \sigma_0 - \sigma_t^{T_{max}}$ (15)

7 Test management

7.1 The notion of standard test parameters

Each recommendation proposes standards for test parameters, test procedures and the degree of accuracy of the measurements.

However, other values for the test parameters and procedures may be used when information is required for special applications. Any deviation from the recommended test parameters and procedures shall be reported separately as non-standard.

7.2 Material

The behaviour of concrete depends mainly on the nature, size and shape of aggregates and the cement paste type and content. The mix proportions should be fixed according to the concrete design in practice. The maximum aggregates size of ordinary concrete should not be less than 8 mm.

The recommendations may be applied to all types of concrete used in constructions and to cement mortar.

7.3 Test operations

The sequences of the operations to manage and run the tests are given in Table 4.

8 Tables giving tests results and materials properties

The tests results and materials properties are given in Table 5.

Table 5 The tests results and materials properties

Title of the test recommendation	Options				Mechanical tests		Properties, relationships derived	Other tests required (part-reference)
	Reference	Moisture condition	Stress sustained during heating	Compatibility with other procedure (part-reference)	Under temperature (T_s)	After cooling (T_n)		
Part 2: Stress–strain relation	1	*nd*	0	(6–2)	$\sigma = \sigma^{T,\dot{\sigma},nd}(\varepsilon)$		$f_c^{T,nd}$, ε_{C1}	
	2	*nd*	σ	(7–2)	$\sigma = \sigma^{T,\sigma,\dot{\sigma},nd}(\varepsilon)$		$f_c^{T,\sigma,nd}$, ε_{C1}	
	3	*nd*	0	(6–2)		$\sigma = \sigma_{res}^{T_{max},\dot{\sigma},nd}(\varepsilon)$	$f_{c,res}^{T,nd}$, $\varepsilon_{C1,res}$	
	4	*nd*	σ	(7–2)		$\sigma = \sigma_{res}^{T_{max},\sigma,\dot{\sigma},nd}(\varepsilon)$	$f_{c,res}^{T,\sigma,nd}$, $\varepsilon_{C1,res}$	
	5	*d*	0	(6–1)	$\sigma = \sigma^{T,\dot{\sigma},d}(\varepsilon)$		$f_c^{T,d}$, ε_{C1}	
	6	*d*	σ	(7–1)	$\sigma = \sigma^{T,\sigma,\dot{\sigma},d}(\varepsilon)$		$f_c^{T,\sigma,d}$, ε_{C1}	
	7	*d*	0	(6–1)		$\sigma = \sigma_{res}^{T_{max},\dot{\sigma},d}(\varepsilon)$	$f_{c,res}^{T,d}$, $\varepsilon_{C1,res}$	
	8	*d*	σ	(7–1)		$\sigma = \sigma_{res}^{T_{max},\sigma,\dot{\sigma},d}(\varepsilon)$	$f_{c,res}^{T,\sigma,d}$, $\varepsilon_{C1,res}$	
	9	*nd*	0	(6–2)	$\sigma = \sigma^{T,\dot{\varepsilon},nd}(\varepsilon)$		$f_c^{T,nd}$, ε_{C1}	
	10	*nd*	σ	(7–2)	$\sigma = \sigma^{T,\sigma,\dot{\varepsilon},nd}(\varepsilon)$		$f_c^{T,\sigma nd}$, ε_{C1}	
	11	*nd*	0	(6–2)		$\sigma = \sigma_{res}^{T_{max},\dot{\varepsilon},nd}(\varepsilon)$	$f_{c,res}^{T,nd}$, $\varepsilon_{C1,res}$	
	12	*nd*	σ	(7–2)		$\sigma = \sigma_{res}^{T_{max},\sigma,\dot{\varepsilon},nd}(\varepsilon)$	$f_{c,res}^{T,\sigma,nd}$, $\varepsilon_{C1,res}$	
	13	*d*	0	(6–1)	$\sigma = \sigma^{T,\dot{\varepsilon},d}(\varepsilon)$		$f_c^{T,d}$, ε_{C1}	
	14	*d*	σ	(7–1)	$\sigma = \sigma^{T,\sigma,\dot{\varepsilon},d}(\varepsilon)$		$f_c^{T,\sigma,d}$, ε_{C1}	
	15	*d*	0	(6–1)		$\sigma = \sigma_{res}^{T_{max},\dot{\varepsilon},d}(\varepsilon)$	$f_{c,res}^{T,d}$, $\varepsilon_{C1,res}$	
	16	*d*	σ	(7–1)		$\sigma = \sigma_{res}^{T_{max},\sigma,\dot{\varepsilon},d}(\varepsilon)$	$f_{c,res}^{T,\sigma,d}$, $\varepsilon_{C1,res}$	
Part 3: Compressive strength	1	*d*	0	(6–1)	$f_c^{T,d}$			
	2	*nd*	0	(6–2)	$f_c^{T,nd}$			
	3	*d*	0	(6–1)		$f_{c,res}^{T,d}$		
	4	*nd*	0	(6–2)		$f_{c,res}^{T,nd}$		
	5	*d*	σ	(7–1)	$f_c^{T,\sigma,d}$			
	6	*nd*	σ	(7–2)	$f_c^{T,\sigma,nd}$			
	7	*d*	σ	(7–1)		$f_{c,res}^{T,\sigma,nd}$		
	8	*nd*	σ	(7–2)		$f_{c,res}^{T,\sigma,nd}$		
Part 4: Tensile Strength	1	*d*	0	(6–1)	$f_t^{T,d}$			
	2	*nd*	0	(6–2)	$f_t^{T,nd}$			
	3	*d*	0	(6–1)		$f_{t,res}^{T,d}$		
	4	*nd*	0	(6–2)		$f_{c,res}^{T,nd}$		

Table 5 continued

Title of the test recommendation	Options				Mechanical tests		Properties, relationships derived	Other tests required (part-reference)
	Reference	Moisture condition	Stress sustained during heating	Compatibility with other procedure (part-reference)	Under temperature (T_s)	After cooling (T_n)		
Part 5: Modulus of elasticity	1	*d*	0	(6–1)	$E^{T,d}$			(3–1)
	2	*nd*	0	(6–2)	$E^{T,nd}$			(3–2)
	3	*d*	0	(5–1)		$E_{res}^{T,nd}$		(3–3)
	4	*nd*	0	(5–2)		$E_{res}^{T,nd}$		(3–4)
	5	*d*	σ	(7–1)	$E^{T,\sigma,d}$			(3–5)
	6	*nd*	σ	(7–2)	$E^{T,\sigma,nd}$			(3–6)
	7	*d*	σ	(5–5)		$E_{res}^{T,\sigma,nd}$		(3–7)
	8	*nd*	σ	(5–6)		$E_{res}^{T,\sigma,nd}$		(3–8)
Part 6: Thermal srain	1	*d*	0		$\varepsilon_{tr,th}^{T,0,d} = \varepsilon_{tr,tot}^{T,0,d}$			
	2	*nd*	0		$\varepsilon_{tr,th}^{T,0,nd} = \varepsilon_{tr,tot}^{T,0,nd}$			
Part 7: Transient creep	1	*d*	σ		$\varepsilon_{tr,cr}^{T,\sigma,d}$		$\varepsilon_{tr,tot}^{T,0,d}$, $\varepsilon_{co,el}^{T,\sigma,d}$	(6–1) + (5–5)
	2	*nd*	σ		$\varepsilon_{tr,cr}^{T,\sigma,nd}$		$\varepsilon_{tr,th}^{T,0,nd}$, $\varepsilon_{co,el}^{T,\sigma,nd}$	(6–2) + (5–6)
Part 8: Steady state creep and creep recovery	1	*d*	0	(6–1)	$\varepsilon_{cr1(t_1-t_0)}^{T_{max},\sigma,d}$		$\varepsilon_{el(t_0)}^{T_{max},\sigma,d}$, $\varepsilon_{tr,tot}^{T,0,d}$	
	2	*nd*	0	(6–2)	$\varepsilon_{cr1(t_1-t_0)}^{T_{max},\sigma,nd}$		$\varepsilon_{el(t_0)}^{T_{max},\sigma,nd}$, $\varepsilon_{tr,th}^{T,0,nd}$	
	3	*d*	σ	(7–1)	$\varepsilon_{cr2(t_1-t_0)}^{T_{max},\sigma,d}$			
	4	*nd*	σ	(7–2)	$\varepsilon_{cr2(t_1-t_0)}^{T_{max},\sigma,d}$			
	5	*d*	0	(8–1)	$\varepsilon_{cr1,rc(t_2-t_1)}^{T_{max},0,d}$		$\varepsilon_{el(t_1)}^{T_{max},\sigma,d}$	
	6	*nd*	0	(8–2)	$\varepsilon_{cr1,rc(t_2-t_1)}^{T_{max},0,nd}$		$\varepsilon_{el(t_1)}^{T_{max},\sigma,nd}$	
	7	*d*	0	(8–3)	$\varepsilon_{cr2,rc(t_2-t_1)}^{T_{max},0,d}$		$\varepsilon_{el(t_1)}^{T_{max},\sigma,d}$	
	8	*nd*	0	(8–4)	$\varepsilon_{cr2,rc(t_2-t_1)}^{T_{max},0,nd}$		$\varepsilon_{el(t_1)}^{T_{max},\sigma,nd}$	
Part 9: Shrinkage	1	*d*	0	(6–1)	$\varepsilon_{sh(t-t_0)}^{T_{max},0,d}$			
Part 10: Restraint stress	1	*d*	ε		$\sigma_r^{T,\alpha_i,d}$			
	2	*nd*	ε		$\sigma_r^{T,\alpha_i,nd}$			
Part 11: Relaxation	1	*d*	0	(6–1)	$\Psi_{(t-t_0)}^{T_{max},\alpha_0,d}$			
	2	*nd*	0	(6–2)	$\Psi_{(t-t_0)}^{T_{max},\alpha_0,nd}$			
	3	*d*	σ	(7–1)	$\Psi_{(t-t_0)}^{T_{max},\alpha_0,d}$			
	4	*nd*	σ	(7–2)	$\Psi_{(t-t_0)}^{T_{max},\alpha_0,nd}$			
	5	*d*	ε	(10–1)	$\Psi_{(t-t_0)}^{T_{max},\alpha_0,d}$			
	6	*nd*	ε	(10–2)	$\Psi_{(t-t_0)}^{T_{max},\alpha_0,nd}$			

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