Mechanical & Thermal Properties of Materials

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2.3 Design values of material properties

Mechanical properties

$$X_{d,fi} = k_{\theta} X_k / \gamma_{M,fi}$$

Characteristic value of a mechanical property for normal temperature design to EN1993-1-1

Reduction factor for a mechanical property with respect to temperature = $(X_{k,\theta} / X_k)$

Material property at elevated temperatures

Check NA!

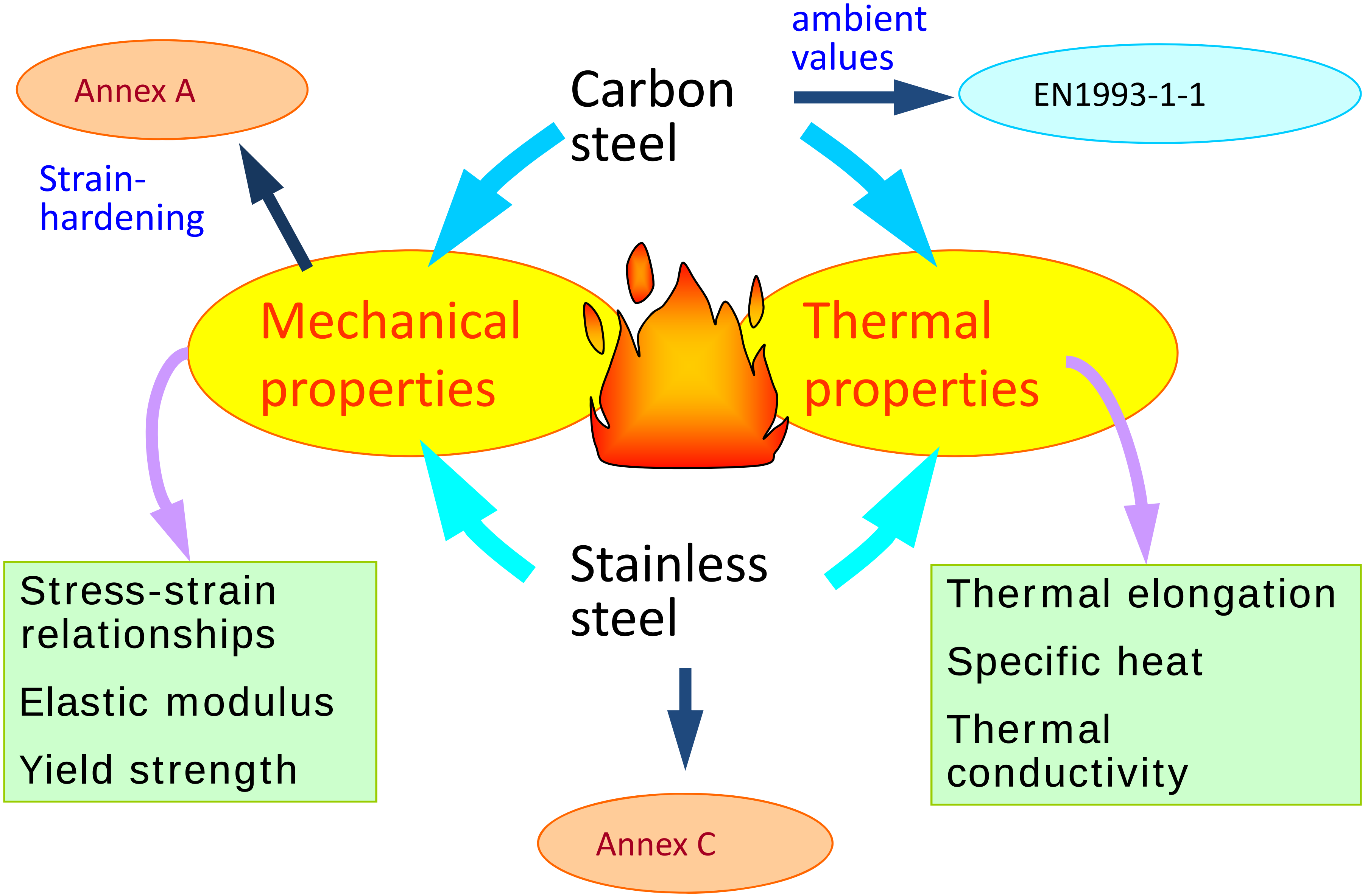
Partial material safety factor for fire situation; 1.0 recommended for thermal & mechanical properties

Thermal properties

$$X_{d,fi} = \begin{cases} X_{k,\theta} / \gamma_{M,fi} & \text{if an increase of the property is favourable for safety} \\ \gamma_{M,fi} X_{k,\theta} & \text{if an increase of the property is unfavourable for safety} \end{cases}$$

STEEL EN 1993-1-2

3. Material Properties Steel



Annex A

Strain-hardening

Carbon steel

ambient values

EN1993-1-1

Mechanical properties

Thermal properties

Stress-strain relationships

Elastic modulus

Yield strength

Stainless steel

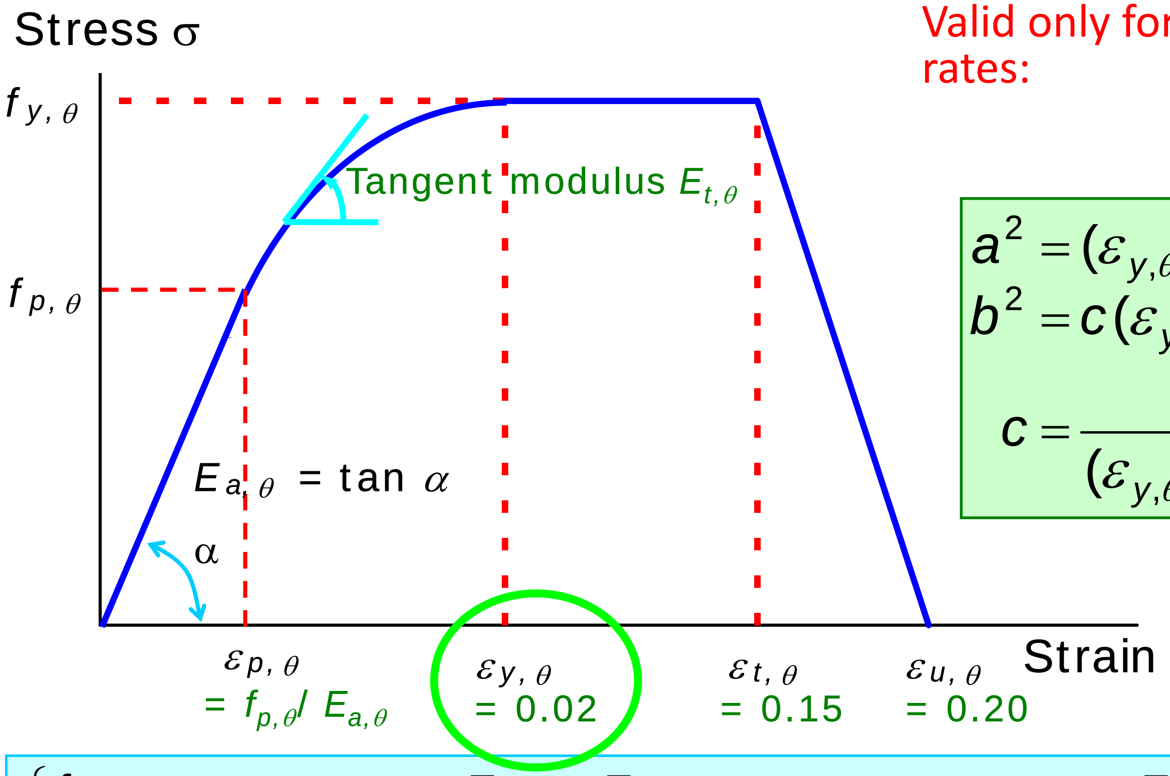
Thermal elongation

Specific heat

Thermal conductivity

Annex C

3.2.1 Stress-strain relationships



Valid only for heating rates:

2 ~ 50 K/min

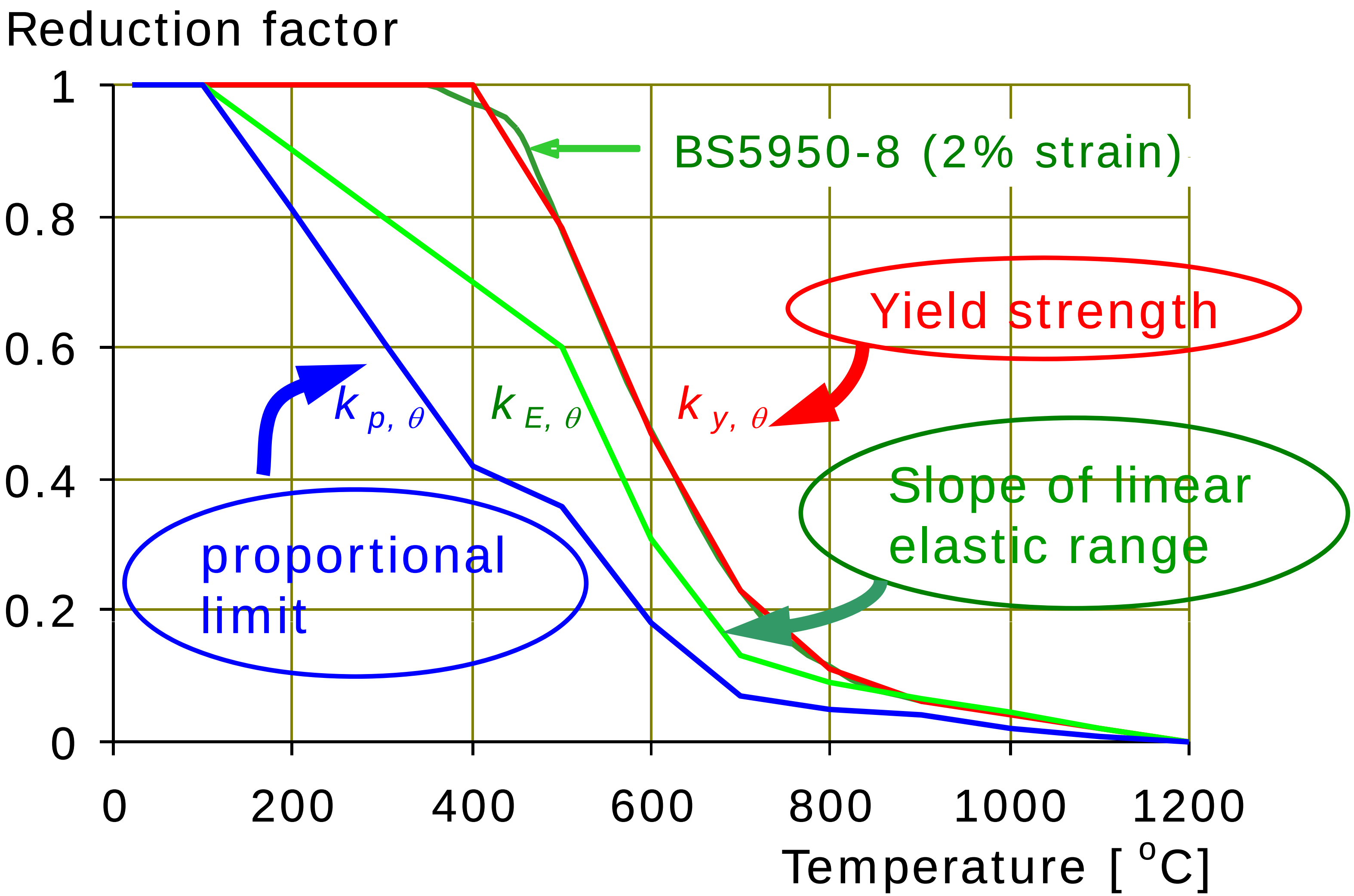
$$a^2 = (\varepsilon_{y,\theta}-\varepsilon_{p,\theta})(\varepsilon_{y,\theta}-\varepsilon_{p,\theta}+c/E_{a,\theta})$$

$$b^2 = c(\varepsilon_{y,\theta}-\varepsilon_{p,\theta})E_{a,\theta}+c^2$$

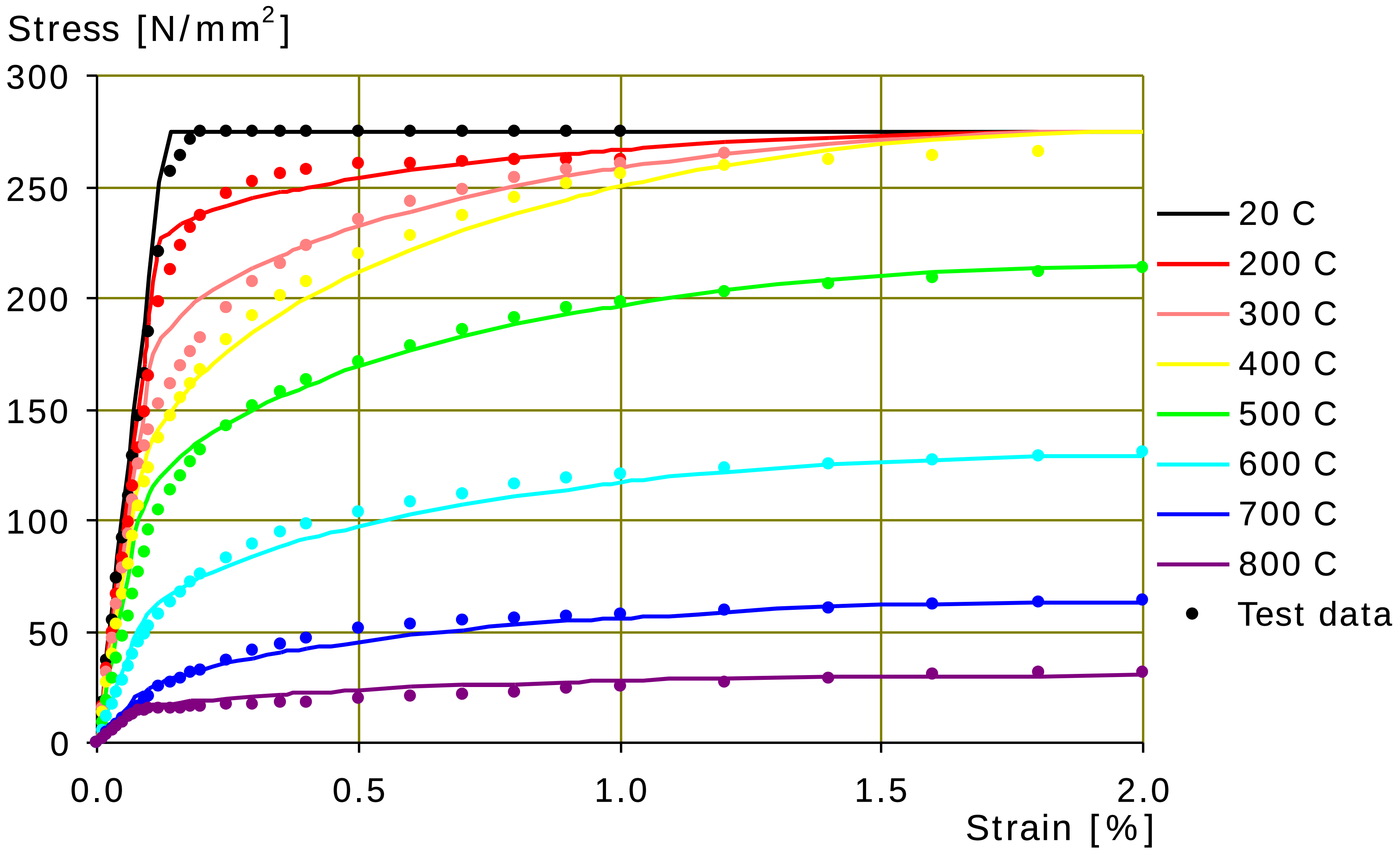
$$c = \frac{(f_{y,\theta}-f_{p,\theta})^2}{(\varepsilon_{y,\theta}-\varepsilon_{p,\theta})E_{a,\theta}-2(f_{y,\theta}-f_{p,\theta})}$$

$$\left\{\begin{array}{lll}
\text{for } \varepsilon \le \varepsilon_{p,\theta} & E_{t,\theta} = E_{a,\theta} & \sigma = \varepsilon E_{a,\theta} \\
\text{for } \varepsilon_{p,\theta} < \varepsilon < \varepsilon_{y,\theta} & E_{t,\theta} = \dfrac{b\left(\varepsilon_{y,\theta}-\varepsilon\right)}{a\sqrt{a^2-\left(\varepsilon_{y,\theta}-\varepsilon\right)^2}} & \sigma = f_{p,\theta}-c+\dfrac{b}{a}\sqrt{a^2-\left(\varepsilon_{y,\theta}-\varepsilon\right)^2} \\
\text{for } \varepsilon_{y,\theta} \le \varepsilon \le \varepsilon_{t,\theta} & E_{t,\theta} = 0 & \sigma = f_{y,\theta} \\
\text{for } \varepsilon_{t,\theta} < \varepsilon < \varepsilon_{u,\theta} & - & \sigma = f_{y,\theta}\left[1-(\varepsilon-\varepsilon_{t,\theta})/(\varepsilon_{u,\theta}-\varepsilon_{t,\theta})\right] \\
\text{for } \varepsilon \ge \varepsilon_{u,\theta} & - & \sigma = 0.0
\end{array}\right.$$

Reduction factors

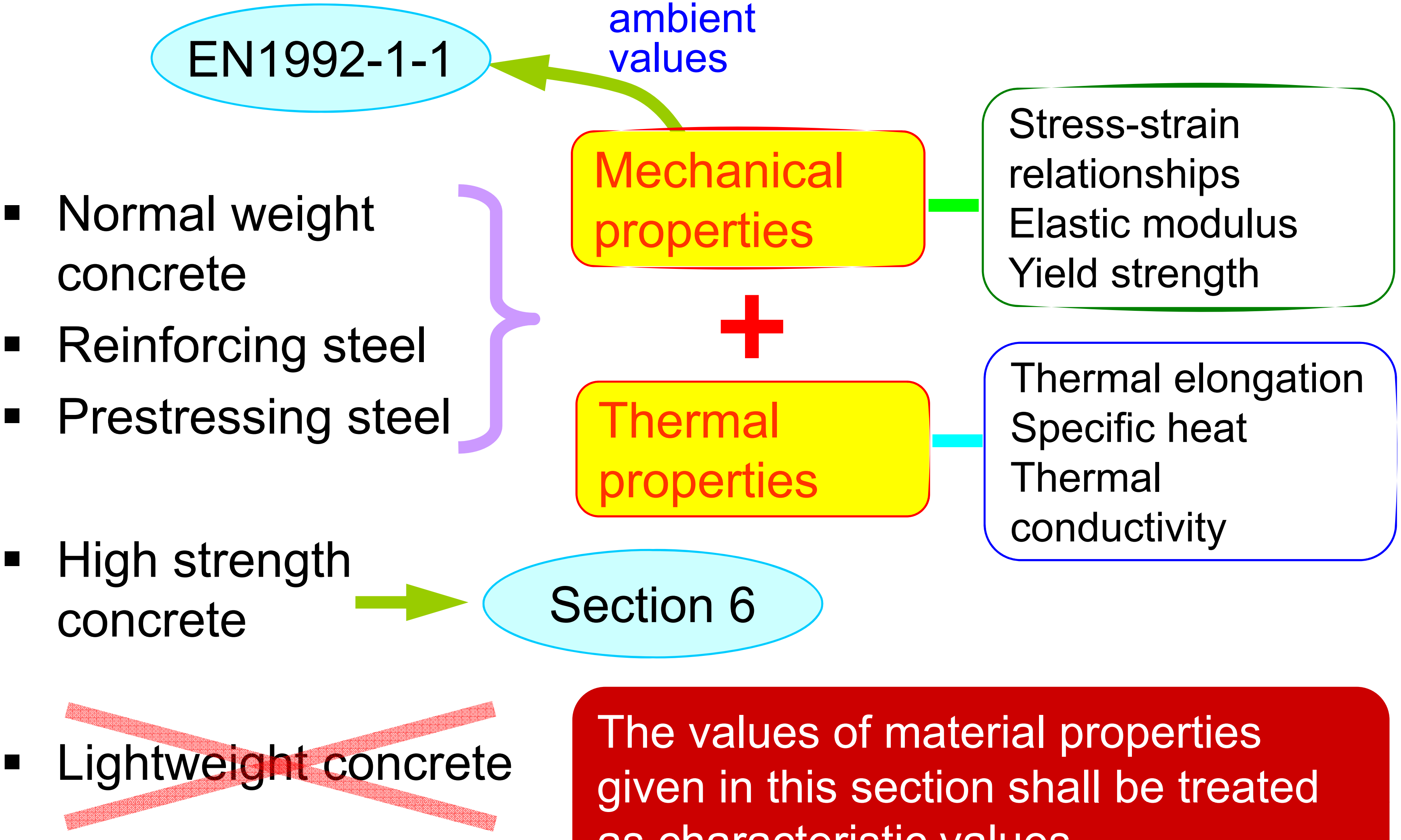


Stress-strain curves for S275



CONCRETE 1992-1-2

3. Material Properties Concrete



EN1992-1-1

ambient values

- Normal weight concrete
- Reinforcing steel
- Prestressing steel

Mechanical properties

Stress-strain relationships
Elastic modulus
Yield strength

\+

Thermal properties

Thermal elongation
Specific heat
Thermal conductivity

- High strength concrete

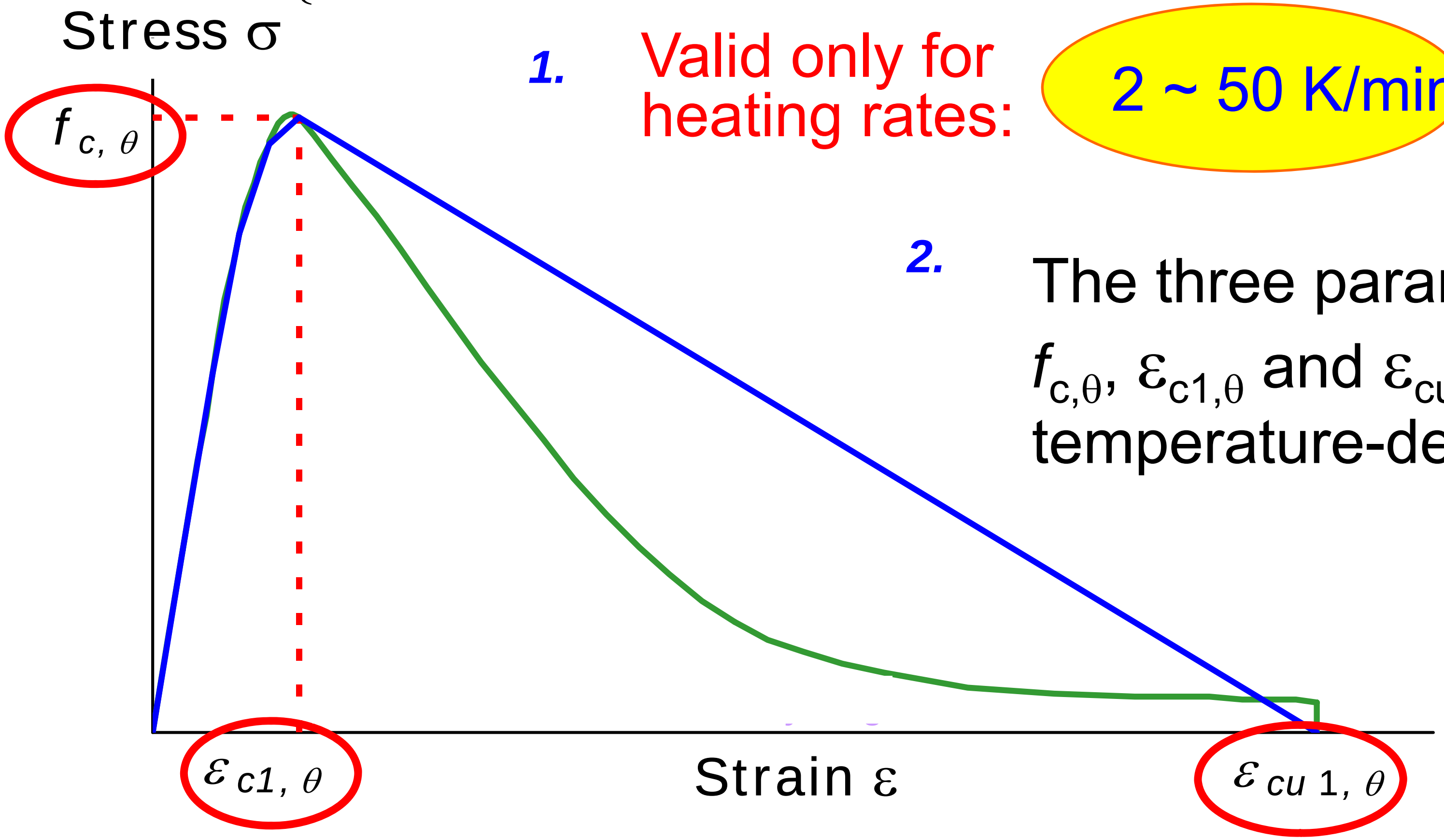
Section 6

- ~~Lightweight concrete~~

The values of material properties given in this section shall be treated as characteristic values.

3.2.2.1 Concrete under compression

$$\sigma(\theta) = \begin{cases} \dfrac{3\varepsilon\, f_{c,\theta}}{\varepsilon_{c1,\theta}\left[2 + (\varepsilon / \varepsilon_{c1,\theta})^3\right]} & \text{for } \varepsilon \le \varepsilon_{c1,\theta} \\ \text{Linear or non-linear models} & \text{for } \varepsilon_{c1,\theta} < \varepsilon \le \varepsilon_{cu1,\theta} \end{cases}$$



1. Valid only for heating rates: 2 ~ 50 K/min

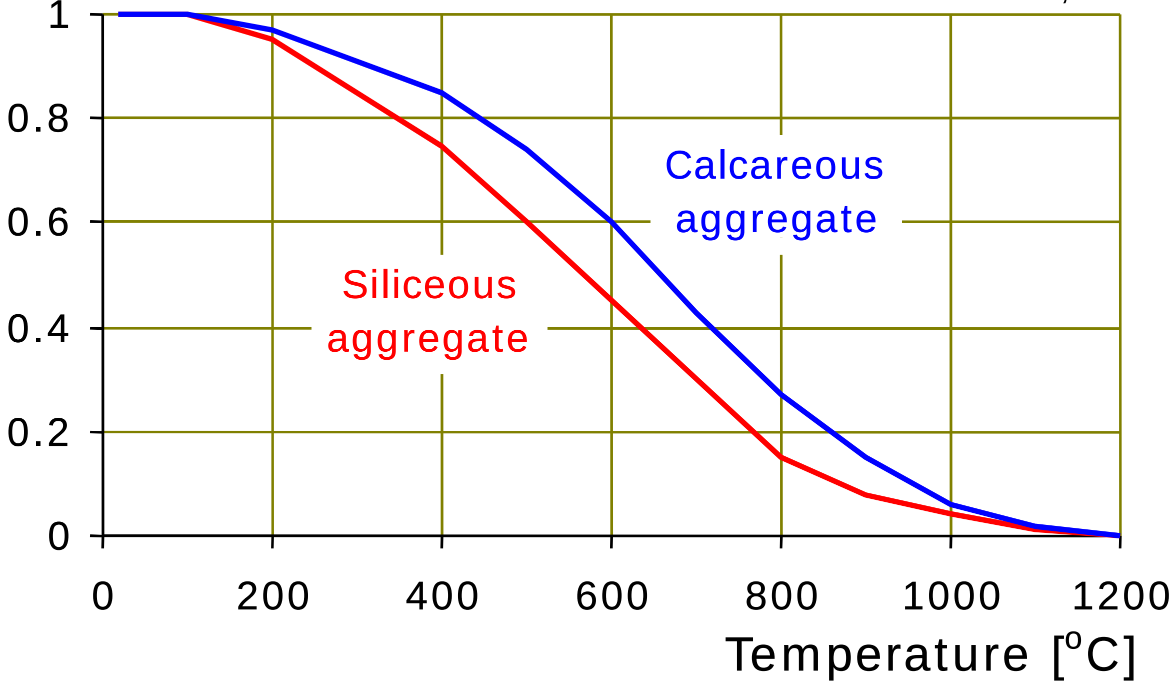
2. The three parameters, $f_{c,\theta}$, $\varepsilon_{c1,\theta}$ and $\varepsilon_{cu1,\theta}$, are temperature-dependent

Concrete compressive strength parameters

θ [°C]	Siliceous & calcareous	
	$\varepsilon_{c1,\theta}$	$\varepsilon_{cu1,\theta}$
20	0.0025	0.0200
100	0.0040	0.0225
200	0.0055	0.0250
300	0.0070	0.0275
400	0.0100	0.0300
500	0.0150	0.0325
600	0.0250	0.0350
700	0.0250	0.0375
800	0.0250	0.0400
900	0.0250	0.0425
1000	0.0250	0.0450
1100	0.0250	0.0475
1200	-	-

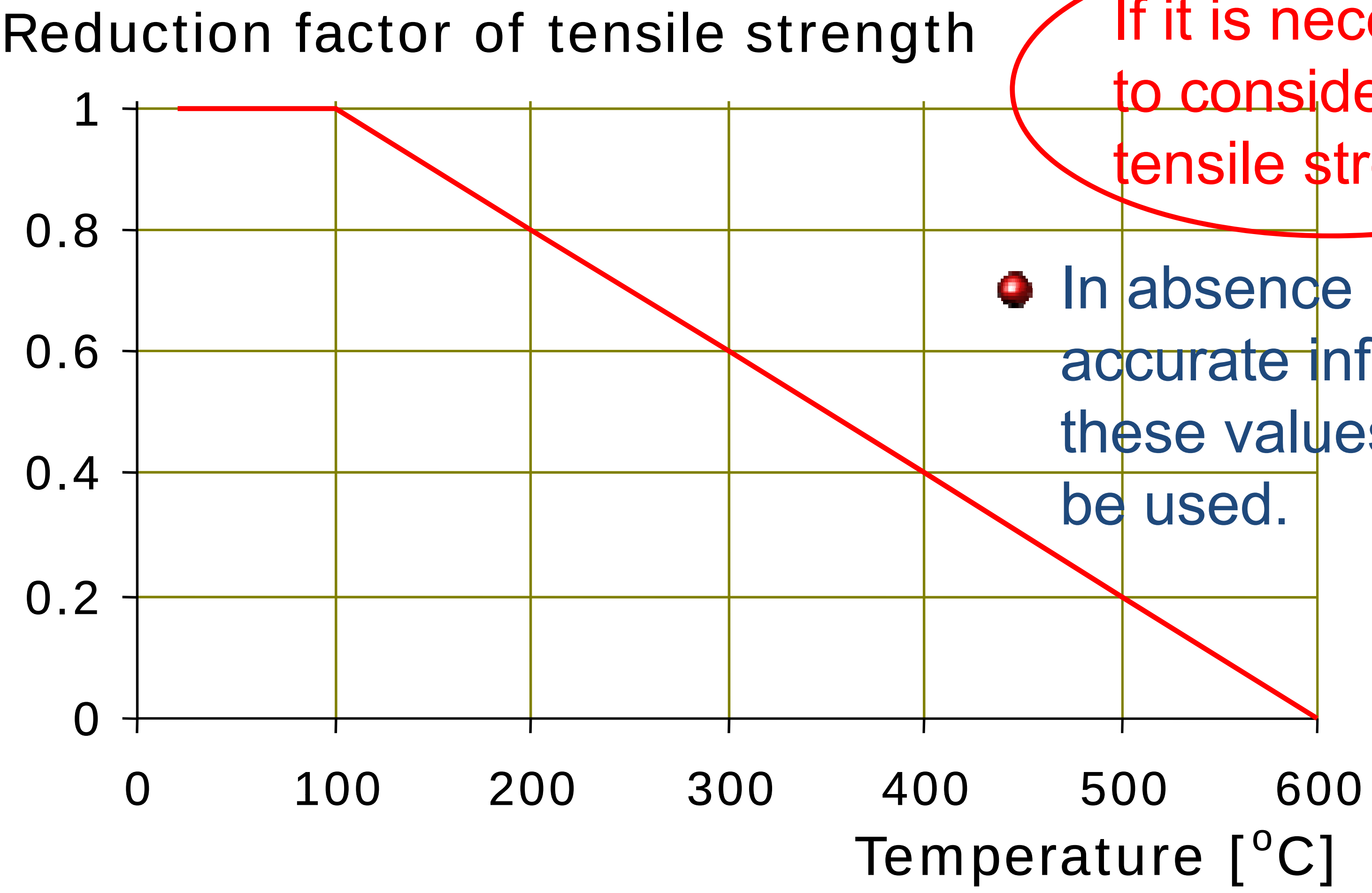
- Siliceous concrete has larger strength reduction than calcareous concrete.
- Variation of strains $\varepsilon_{c1,\theta}$ and $\varepsilon_{cu1,\theta}$ with temperatures are the same for both concrete types.

Reduction factor of compressive strength $f_{c,\theta}$



3.2.2.2 Concrete under tension

- Conservatively, tensile strength of concrete should normally be ignored.



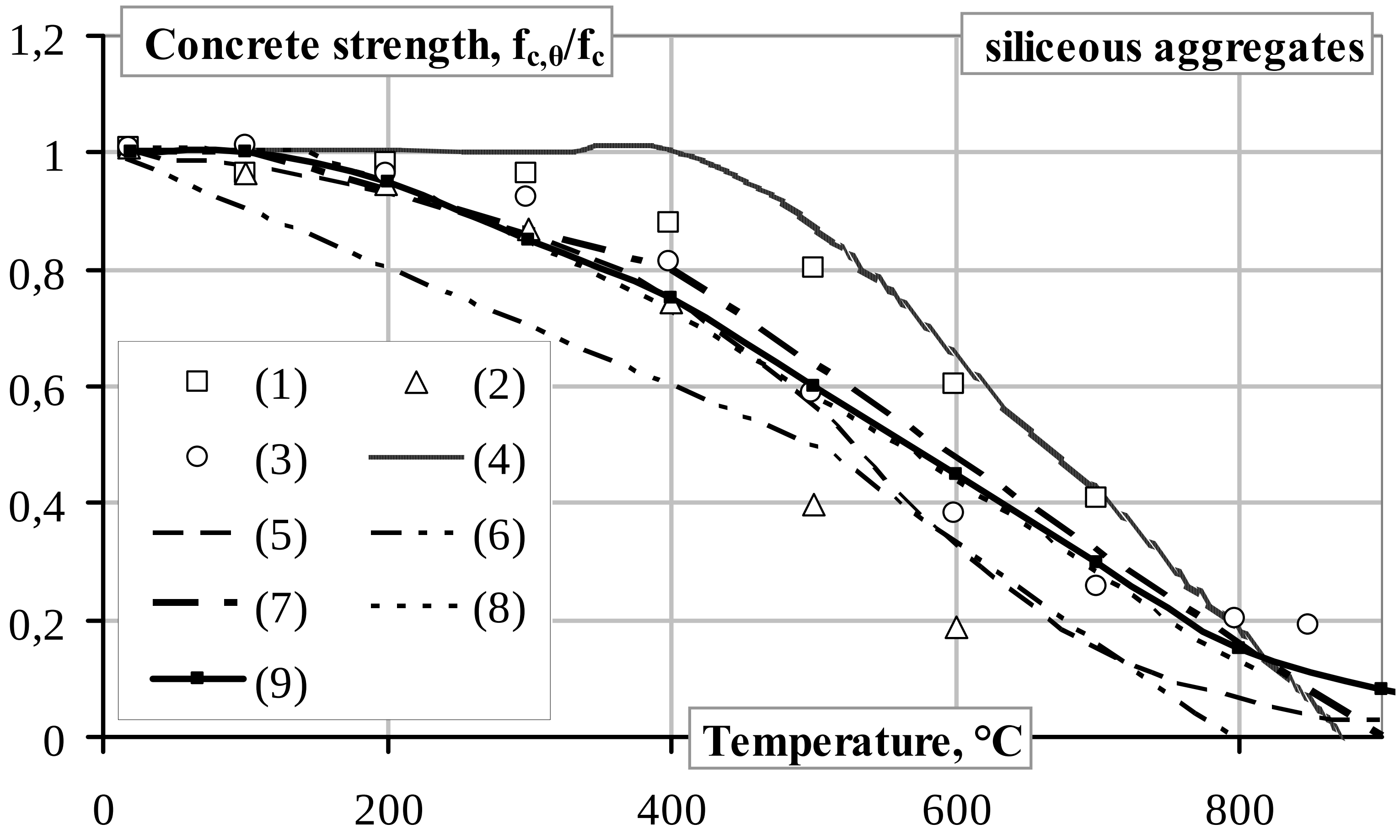
If it is necessary to consider the tensile strength

- In absence of more accurate information, these values should be used.

Factors affecting strength of concrete

- Mix proportions
- Water cement ratio
- Aggregate cement ratio
- Type of aggregate
  - (Schneider and Horvath 2003)

Comparison exper (1-3) predicted (4-9) compressive concrete under fire



The strain components

$$\varepsilon_{tot} = \varepsilon_{\sigma}\left(\bar{\sigma}, \sigma, \theta\right) + \varepsilon_{th}\left(\theta\right) + \varepsilon_{tr,cr}\left(\sigma, \theta, t\right)$$

ε_{tot}	the total strain
ε_{σ}	the stress–related strain
ε_{th}	the thermal strain
$\varepsilon_{tr,cr}$	the transient creep strain (*load induced thermal strain)*

The thermal strain of concrete

- The thermal strain is the free thermal expansion from the fire
- Mainly influenced by the type and amount of aggregate
- The coarse aggregate plays an important role (Schneider and Horvath 2003)

Transient creep strain

- develops during first heating under load. It is unique to concrete.
- Lits is much larger than the elastic strain, contributes to a significant relaxation and redistribution of thermal stresses in heated concrete structures. (*Khoury 2000*).
- factors affecting the transient strain are type of aggregate, aggregate/cement ratio, curing conditions, loading level (*Schneider and Horvath 2003*). Mathematical models for transient thermal strain calculations are reviewed by Youssef and Moftah (2007).

Shrinkage strain

- Could be added to the eq. of strain
- However, since all experimental high temperature data are reported from unsealed test conditions the shrinkage component can be viewed as being included in the thermal strain.
- shrinkage is assumed to be independent of loading (*Nielsen et al 2004*).

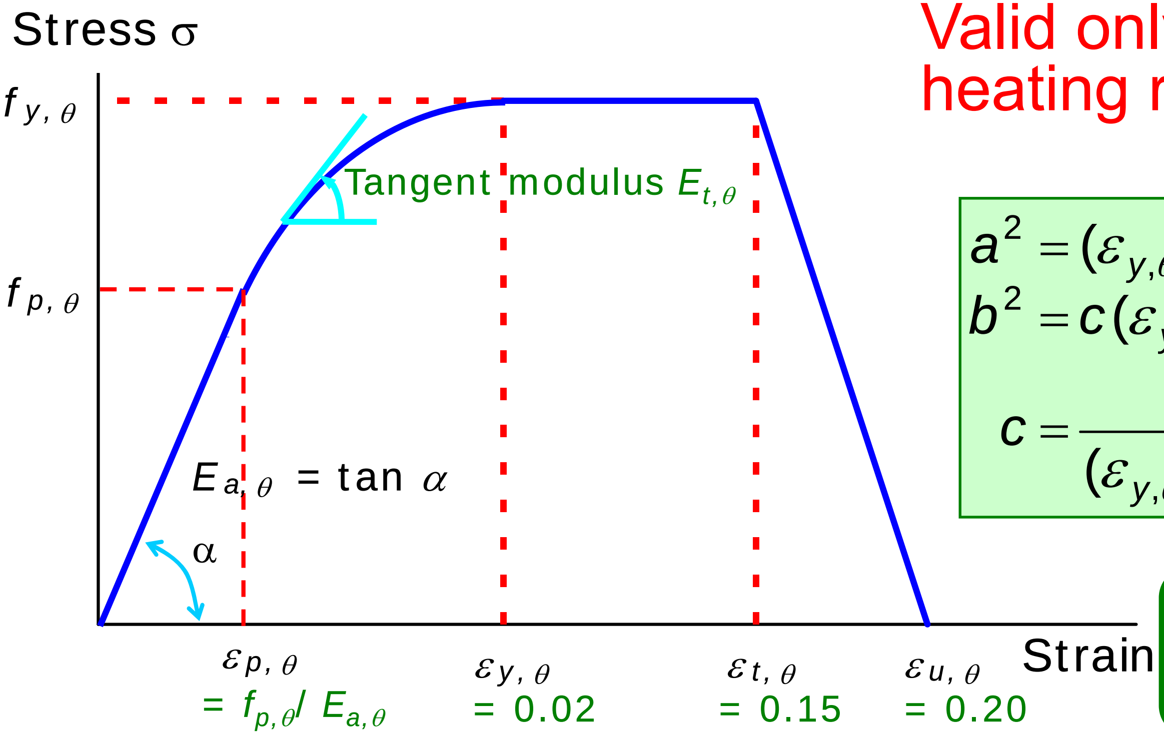
Explosive spalling

- When the moisture content is less than 3% by weight explosive spalling is unlikely to occur. Above 3% more accurate assessments, moisture content, type of aggregate, permeability of concrete and heating rate should be considered.
- Spalling can be grouped into four categories: (a) aggregate spalling; (b) explosive spalling; (c) surface spalling; (d) corner/sloughing-off spalling. The first three occur during the first 20–30 min into a fire and are influenced by the heating rate, while the fourth occurs after 30–60 min of fire and is influenced by the maximum temperature.

Explosive spalling (contd.)

- The main parameters affecting the spalling effect are content of moisture in concrete, the heating condition, compressive stresses, thickness of concrete, position of reinforcement, mix proportion, fibre volume (*Schneider and Horvath 2003*).
- The prediction of spalling is now becoming possible with the development of thermo-hydro-mechanical nonlinear finite element models capable of predicting pore pressures (*Khoury 2000*).

3.2.3 Reinforcing steel



Valid only for heating rates: 2 ~ 50 K/min

$$a^2 = (\varepsilon_{y,\theta}-\varepsilon_{p,\theta})(\varepsilon_{y,\theta}-\varepsilon_{p,\theta}+c/E_{a,\theta})$$

$$b^2 = c(\varepsilon_{y,\theta}-\varepsilon_{p,\theta})E_{a,\theta}+c^2$$

$$c = \frac{(f_{y,\theta}-f_{p,\theta})^2}{(\varepsilon_{y,\theta}-\varepsilon_{p,\theta})E_{a,\theta}-2(f_{y,\theta}-f_{p,\theta})}$$

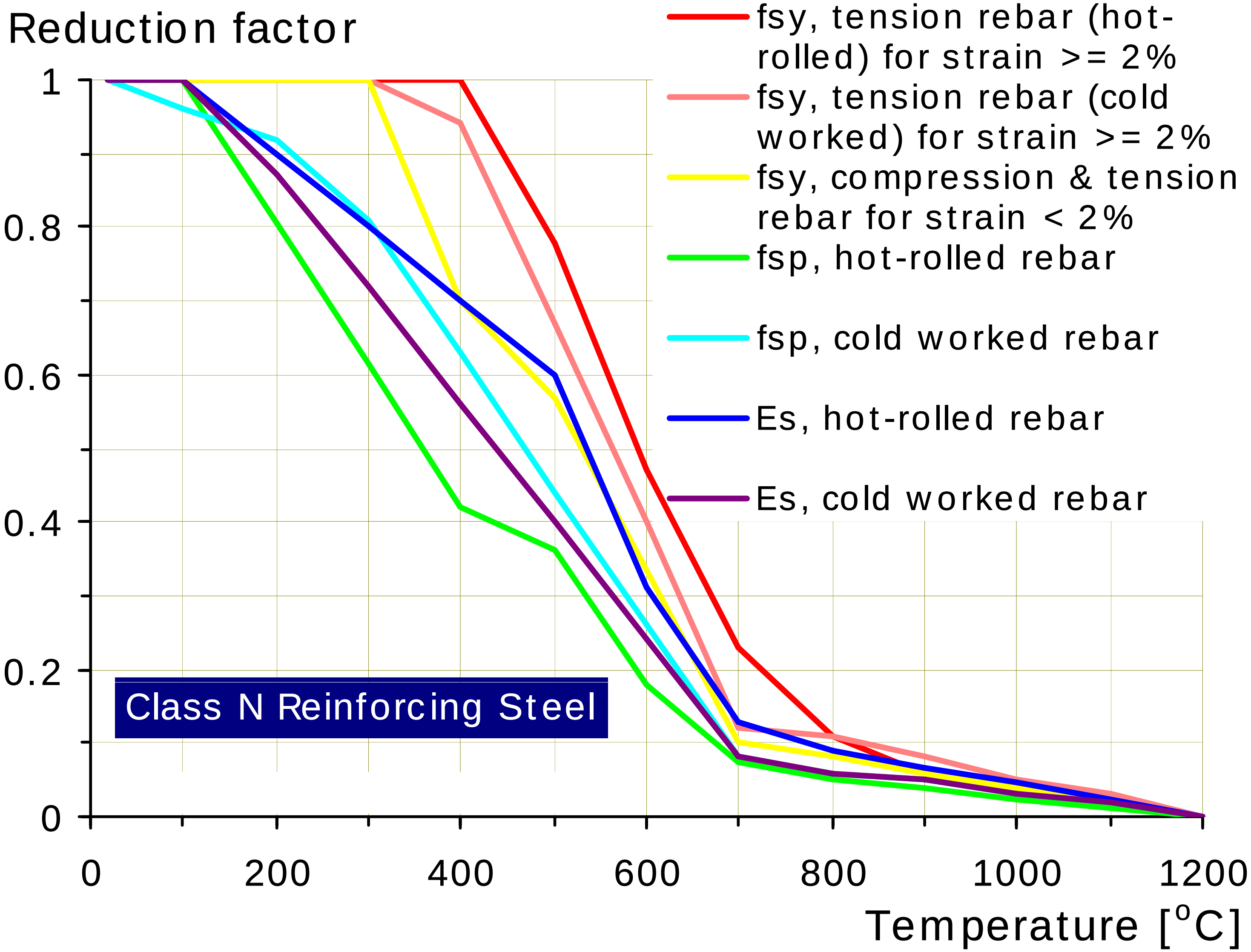
Class A reinforcement:
$\varepsilon_{st,\theta} = 0.05$; $\varepsilon_{su,\theta} = 0.10$

$$\begin{cases}
\text{for } \varepsilon \le \varepsilon_{p,\theta} & E_{t,\theta} = E_{a,\theta} & \sigma = \varepsilon E_{a,\theta} \\
\text{for } \varepsilon_{p,\theta} < \varepsilon < \varepsilon_{y,\theta} & E_{t,\theta} = \dfrac{b(\varepsilon_{y,\theta}-\varepsilon)}{a\sqrt{a^2-(\varepsilon_{y,\theta}-\varepsilon)^2}} & \sigma = f_{p,\theta} - c + \dfrac{b}{a}\sqrt{a^2-(\varepsilon_{y,\theta}-\varepsilon)^2} \\
\text{for } \varepsilon_{y,\theta} \le \varepsilon \le \varepsilon_{t,\theta} & E_{t,\theta} = 0 & \sigma = f_{y,\theta} \\
\text{for } \varepsilon_{t,\theta} < \varepsilon < \varepsilon_{u,\theta} & - & \sigma = f_{y,\theta}\left[1-(\varepsilon-\varepsilon_{t,\theta})/(\varepsilon_{u,\theta}-\varepsilon_{t,\theta})\right] \\
\text{for } \varepsilon \ge \varepsilon_{u,\theta} & - & \sigma = 0.0
\end{cases}$$

3.2.3 Reinforcing steel
Table 3.2a

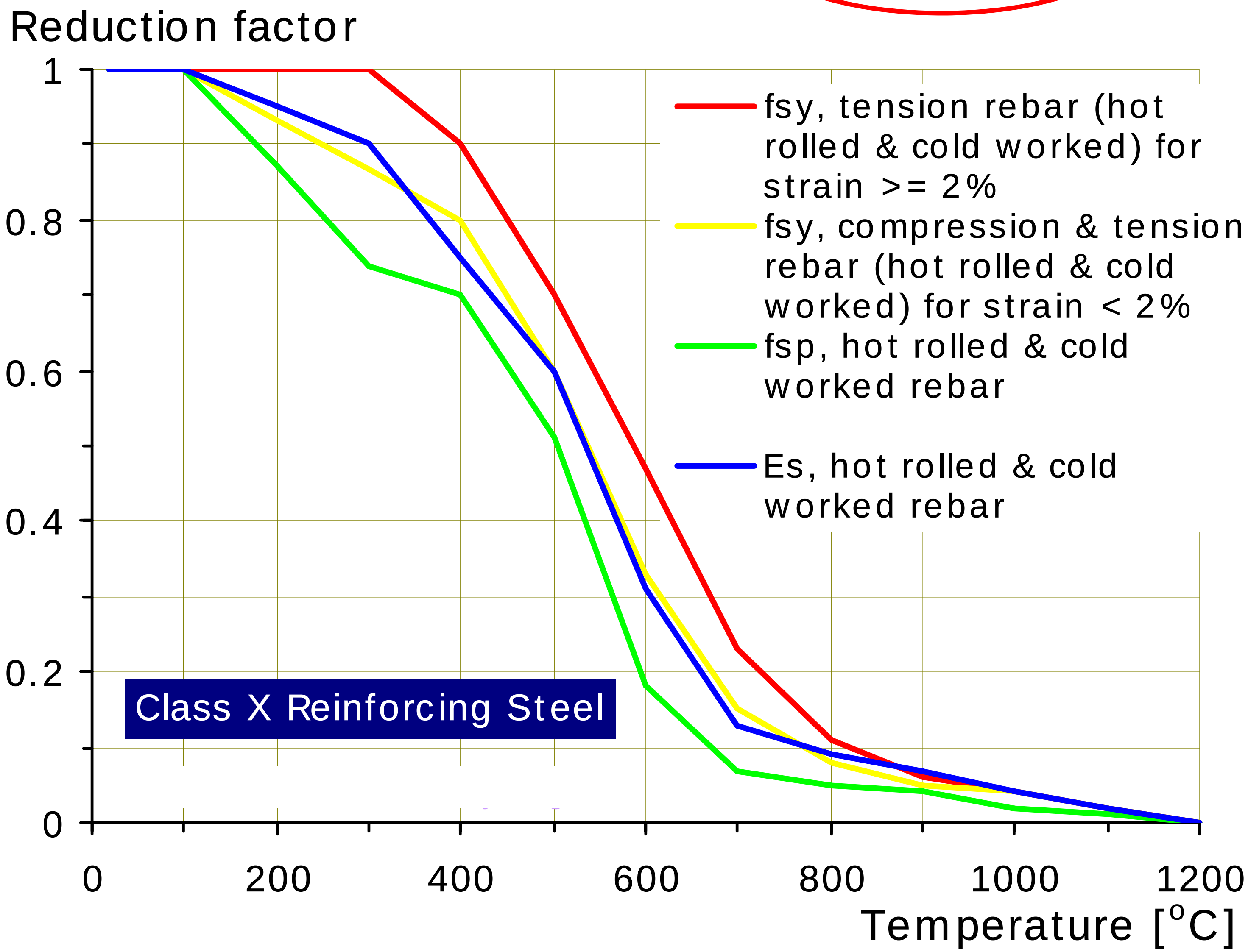
Reduction factors – Class N steel

Without material tests in fire



Reduction factors – Class X steel

strength tested in fire

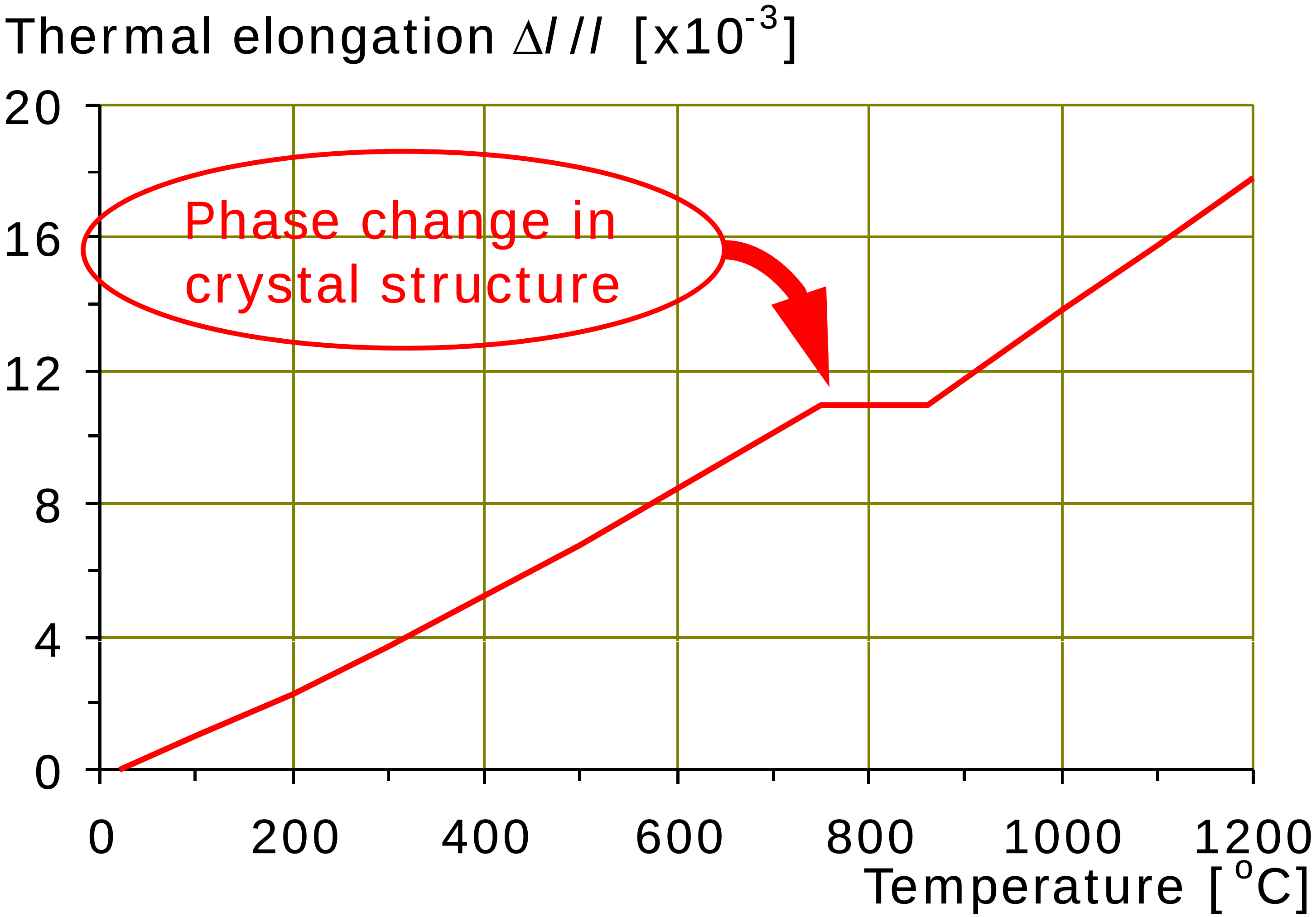


Thermal Properties

STEEL

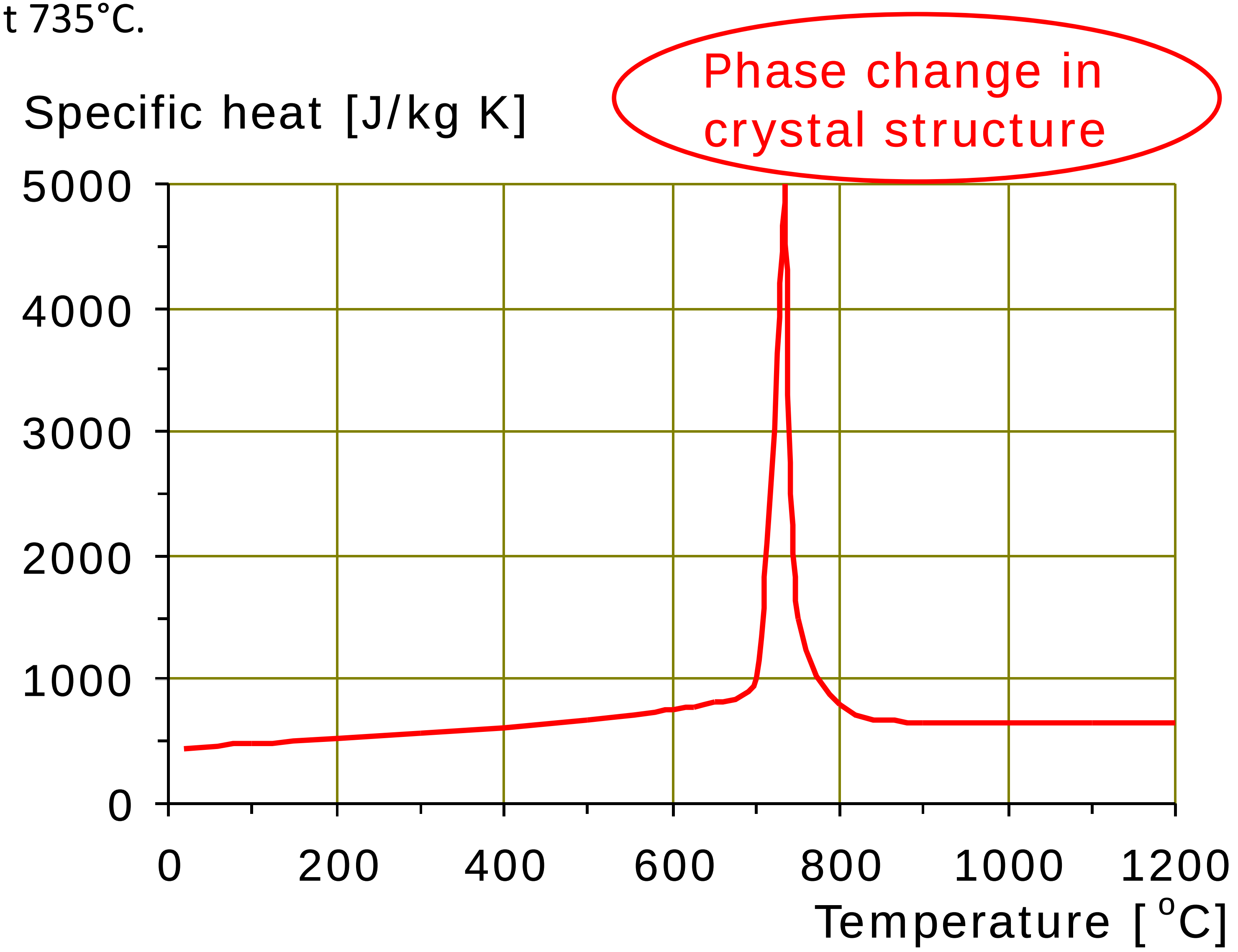
3.4.1.1 Thermal elongation Steel

- The nonlinear model incorporating the effect of phase change in steel crystal structure between 750°C & 860°C.

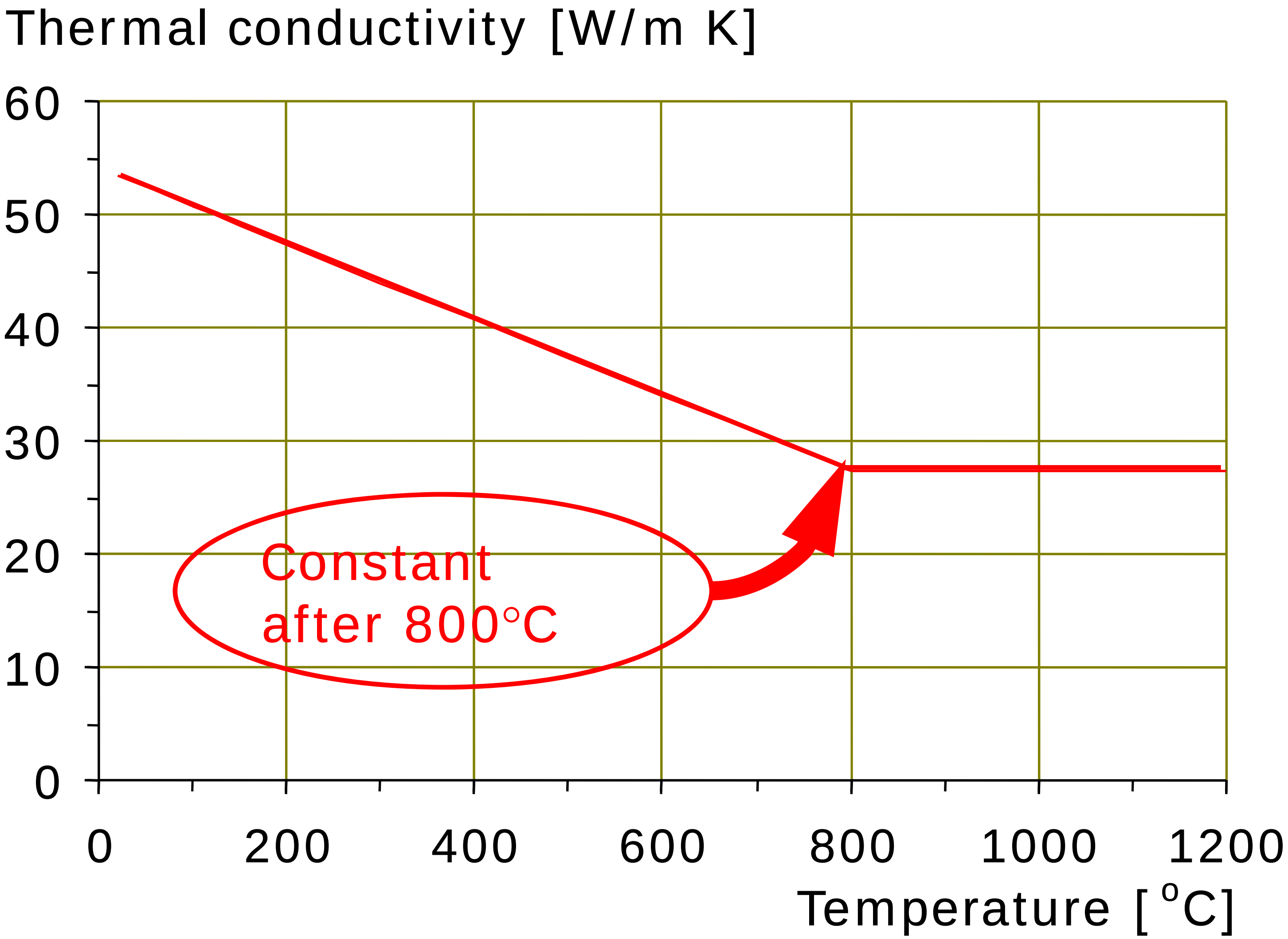


3.4.1.2 Specific heat Steel

- The model incorporates the effect of phase change in steel crystal structure at 735°C.



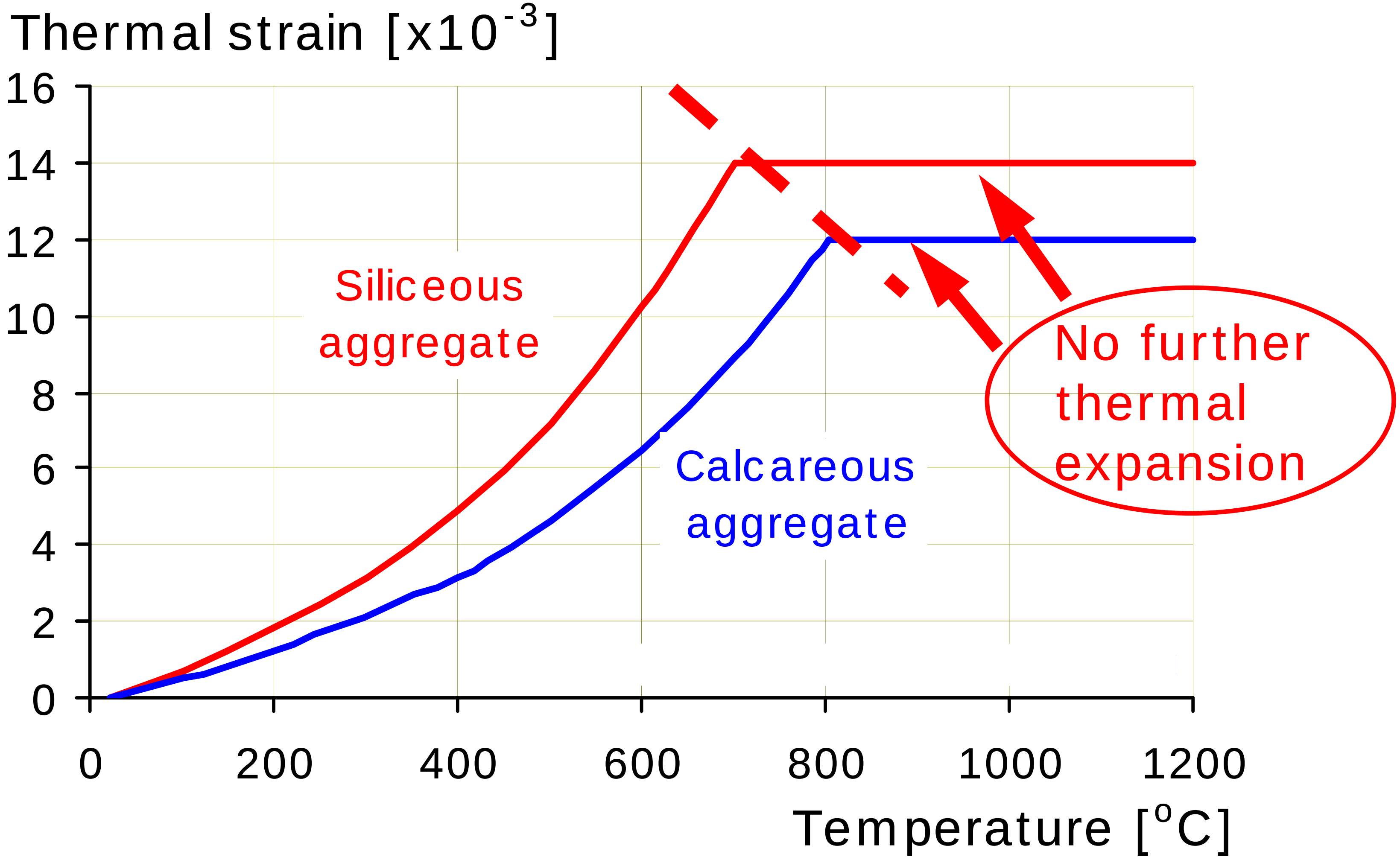
3.4.1.3 Thermal conductivity Steel



CONCRETE

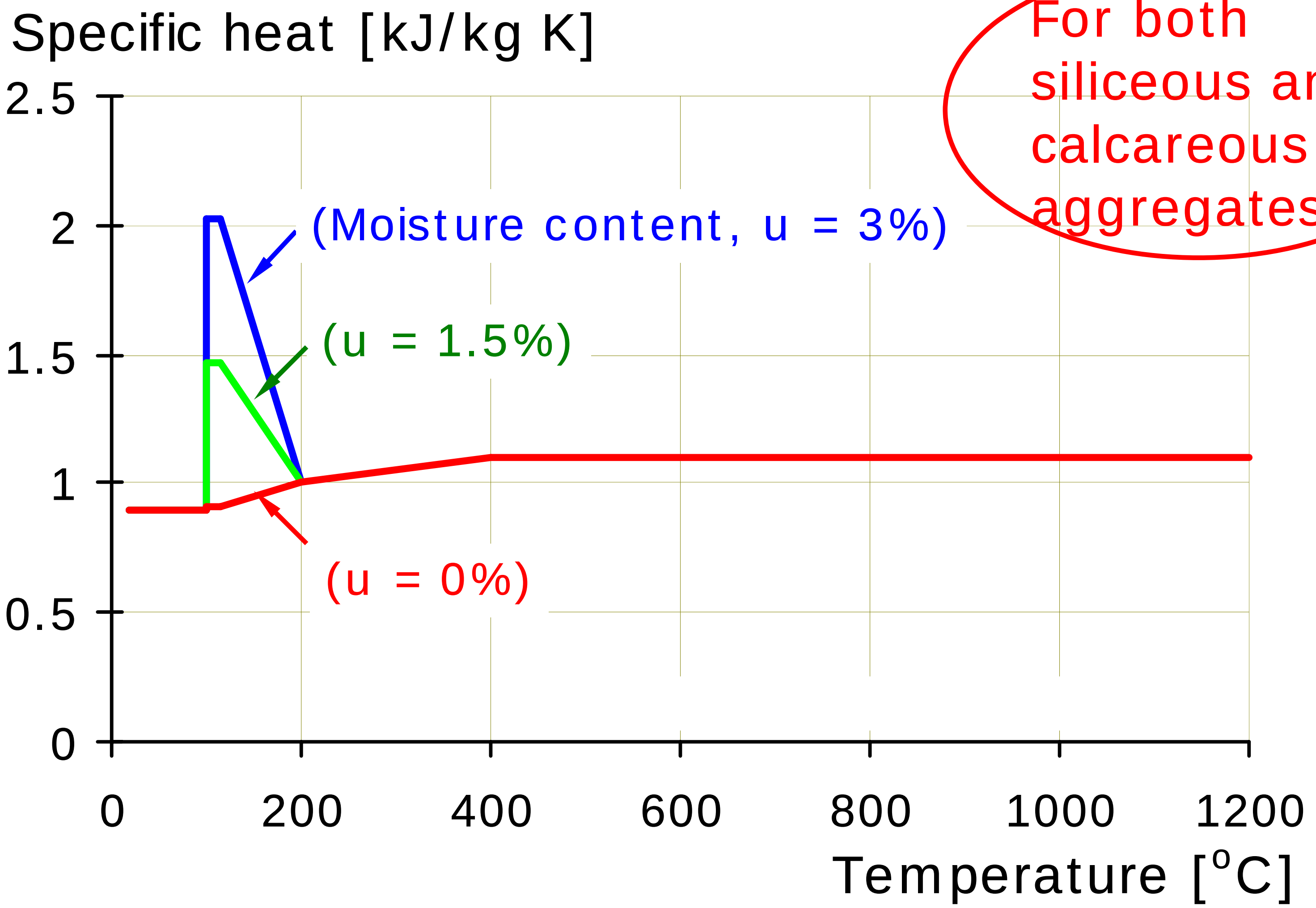
3.3.1 Thermal elongation of concrete

- It is assumed that siliceous concrete expands more at elevated temperatures than calcareous concrete.



3.3.2 Specific heat of concrete

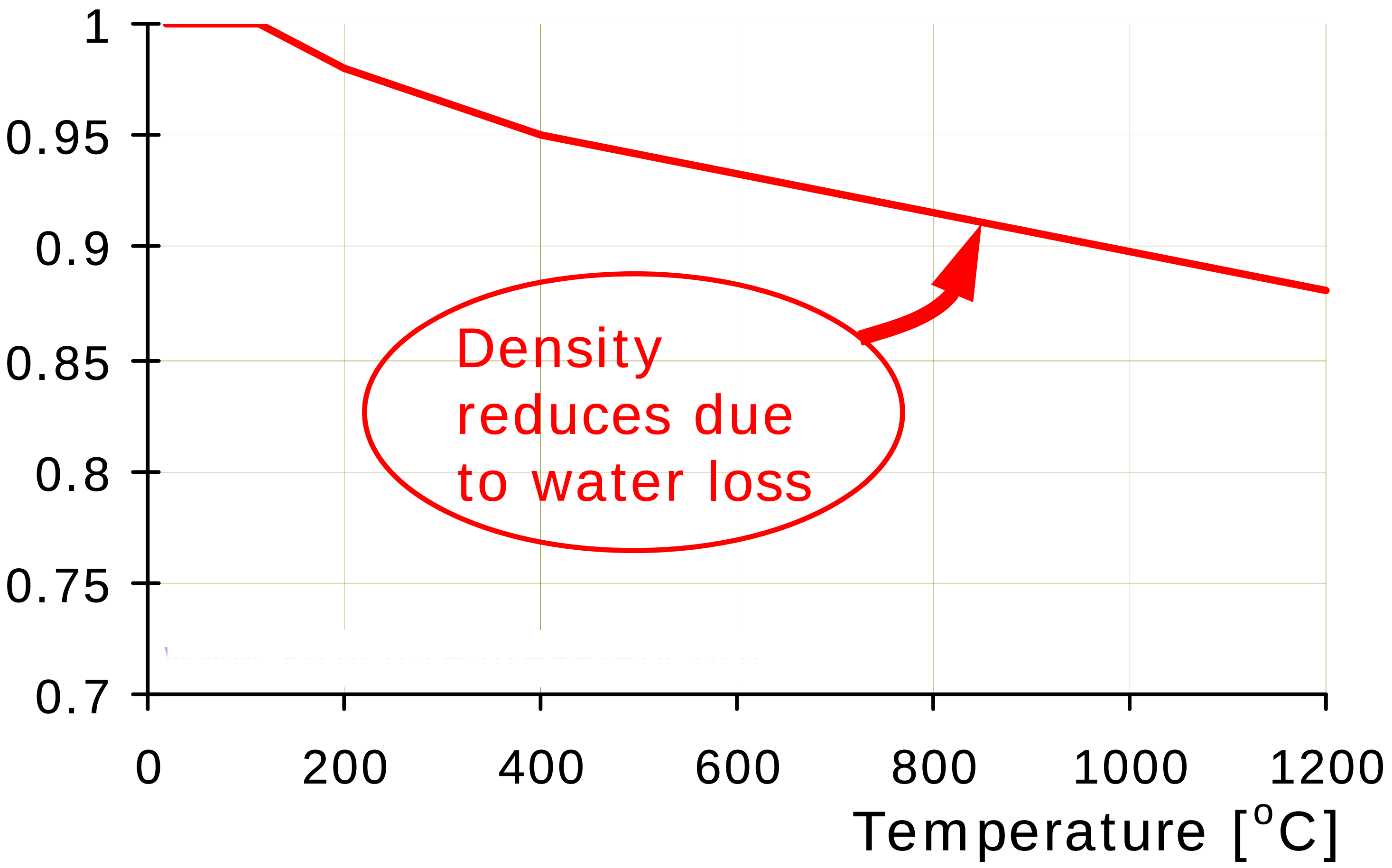
- The moisture content is modelled by the peak values, situated between 100 °C and 115°C.



For both siliceous and calcareous aggregates

3.3.2 Density of concrete

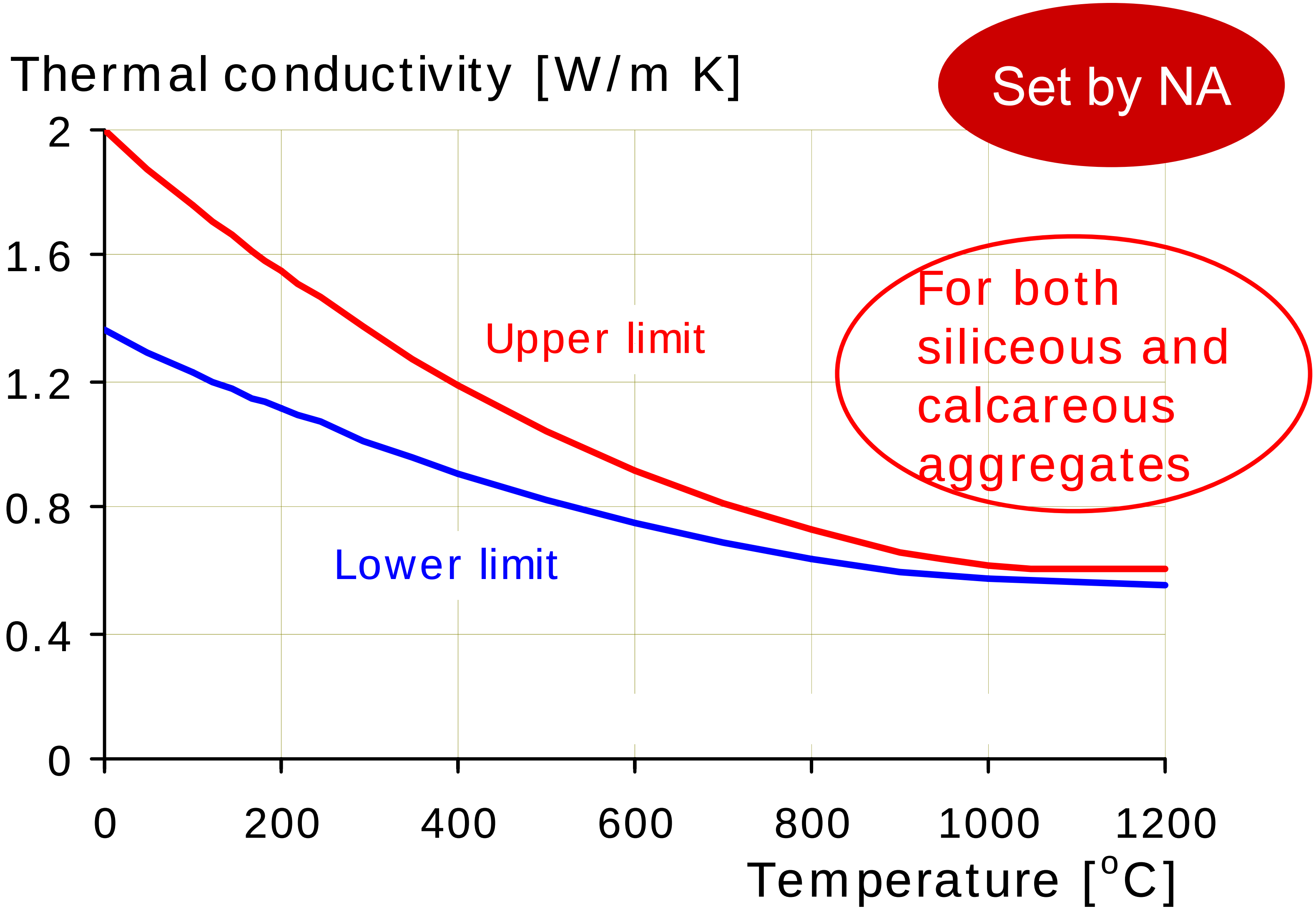
Percentage reduction of densitry



Density reduces due to water loss

3.3.3 Thermal conductivity of concrete

- Determined between the lower and upper limit values:



3.4 Thermal elongation of reinforcing and prestressing steel