Material and Creep Behaviour of S460 in Case of Fire

Experimental Investigation and Analytical Modelling

TECHNISCHE UNIVERSITÄT DARMSTADT

1. Starting Situation

EC3-1-2

Uniform stress-strain-relationships for steel grades S235, S355, S460

S460

- Only very few test results
- Wide scatter range
- Deviations from EC3-1-2

2. Research Objectives

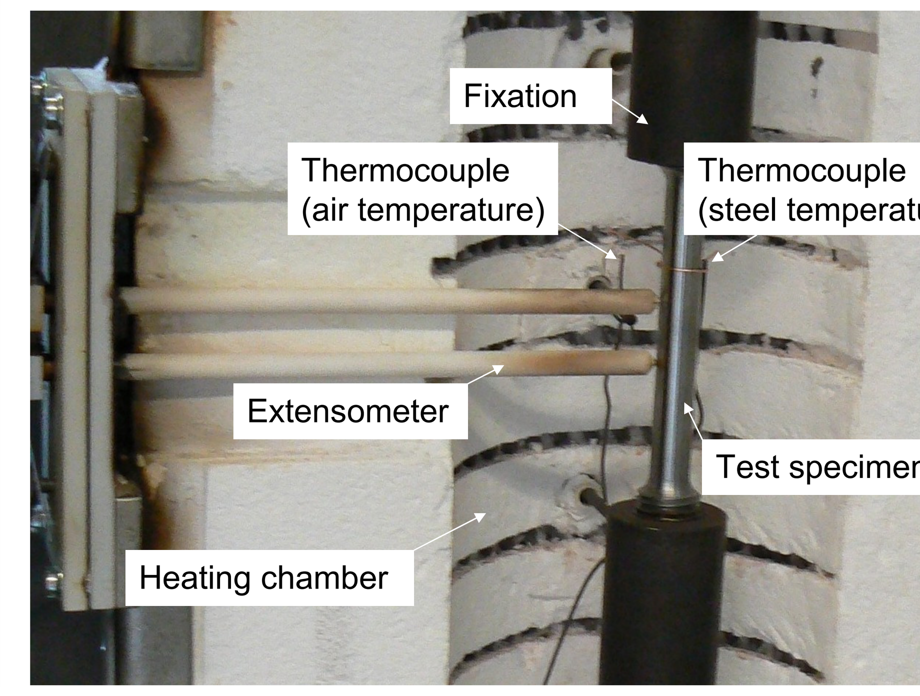
- Stress-strain relationships at high temperatures for S460N and S460M
  N – normalized rolled, M – thermo-mechanically rolled
  - Testing of numerous commercial S460 steels
- Creep behaviour of S460
  - Empirical creep law for structural steel in case of fire
  - Only transient state tests with different heating rates
- Comparison to stress-strain relationships in EC3-1-2
  - Bearing capacity, safety aspects
- Influences on high temperature performance of S460
  - Delivery condition, chemical composition (V, Ti, Nb)

3. Tested Materials

Material			Strength	
Steel grade	Shortcut	Form of manufacture	R_{eH} [N/mm²]	R_m [N/mm²]
S460N	N1	Plate 60 mm	507	640
	N2	Plate 35 mm	489	644
	N3	IPE 550	479	584
S460M	M1	Plate 25 mm	525	598
	M2	Plate 25 mm	558	666
	M3	Plate 58 mm	521	589
	M4	HEA 320	509	584
P420M	P420M	Plate 60 mm	444	529

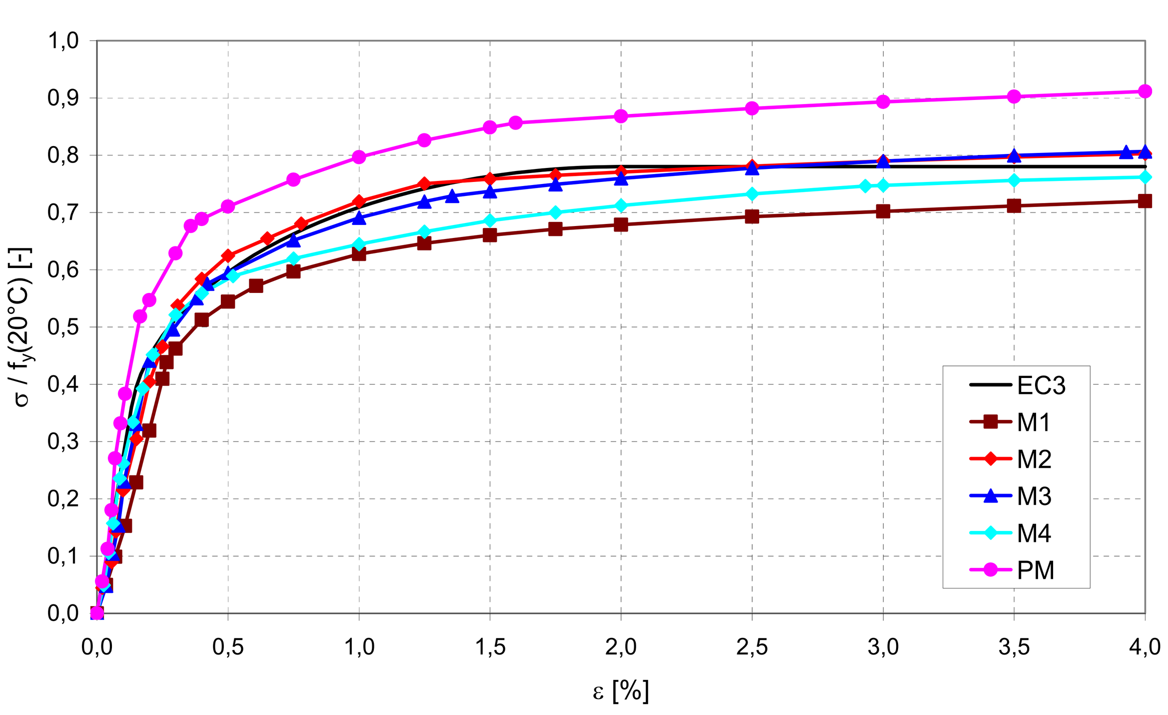
4. Experimental Set-up

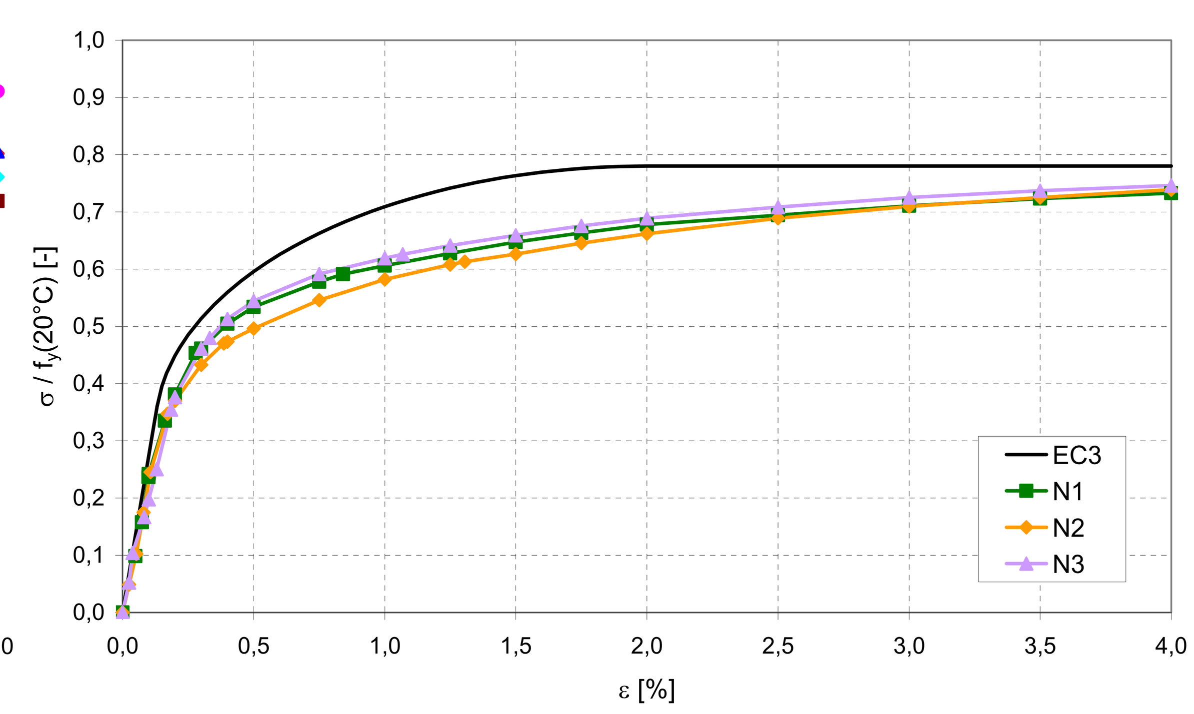
(Transient state tests)



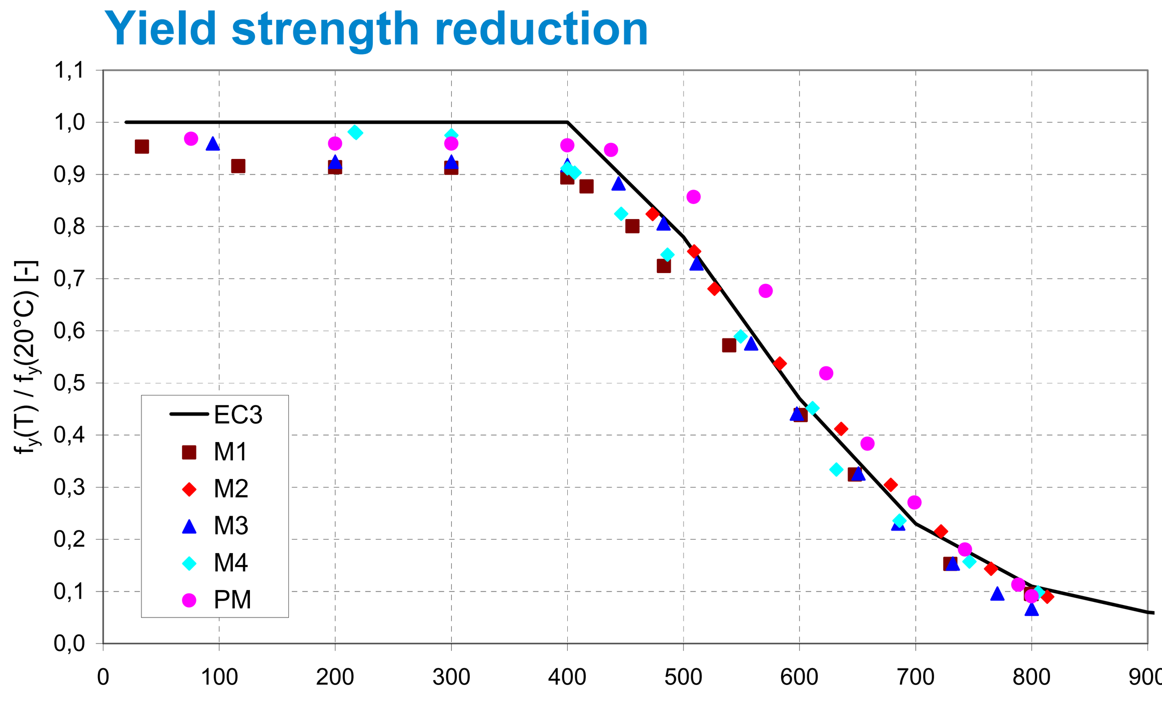
5. Experimental Results: σ-ε-relationships

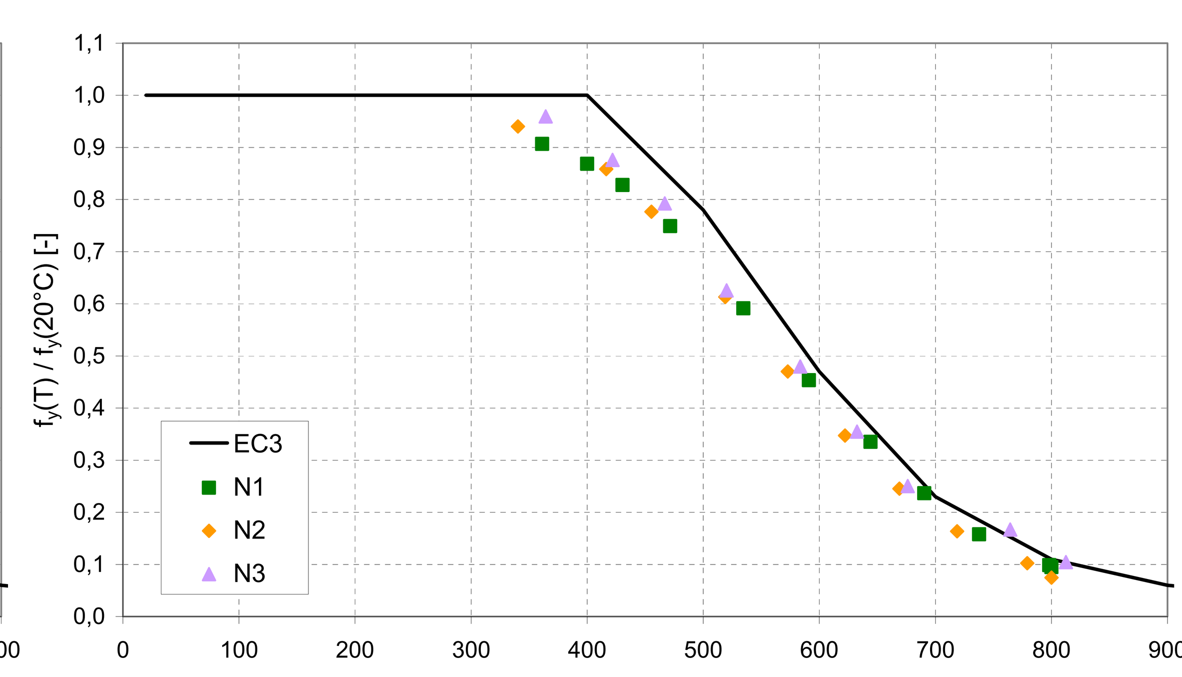
σ–ε-relationships at 500 °C



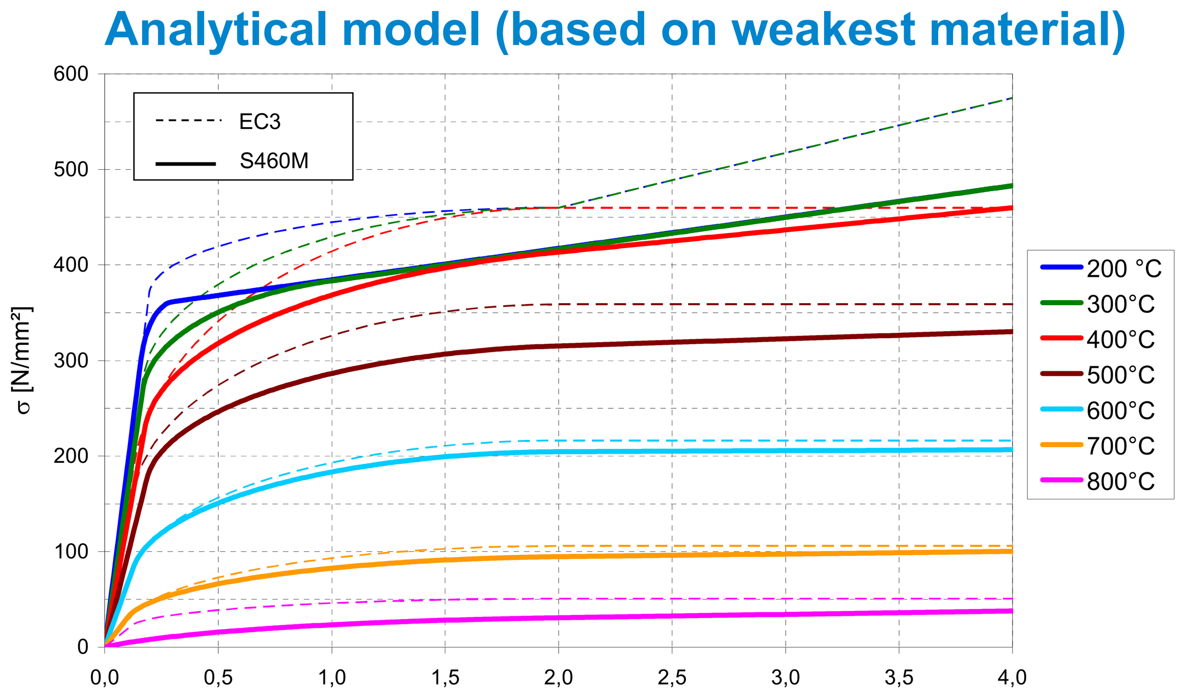


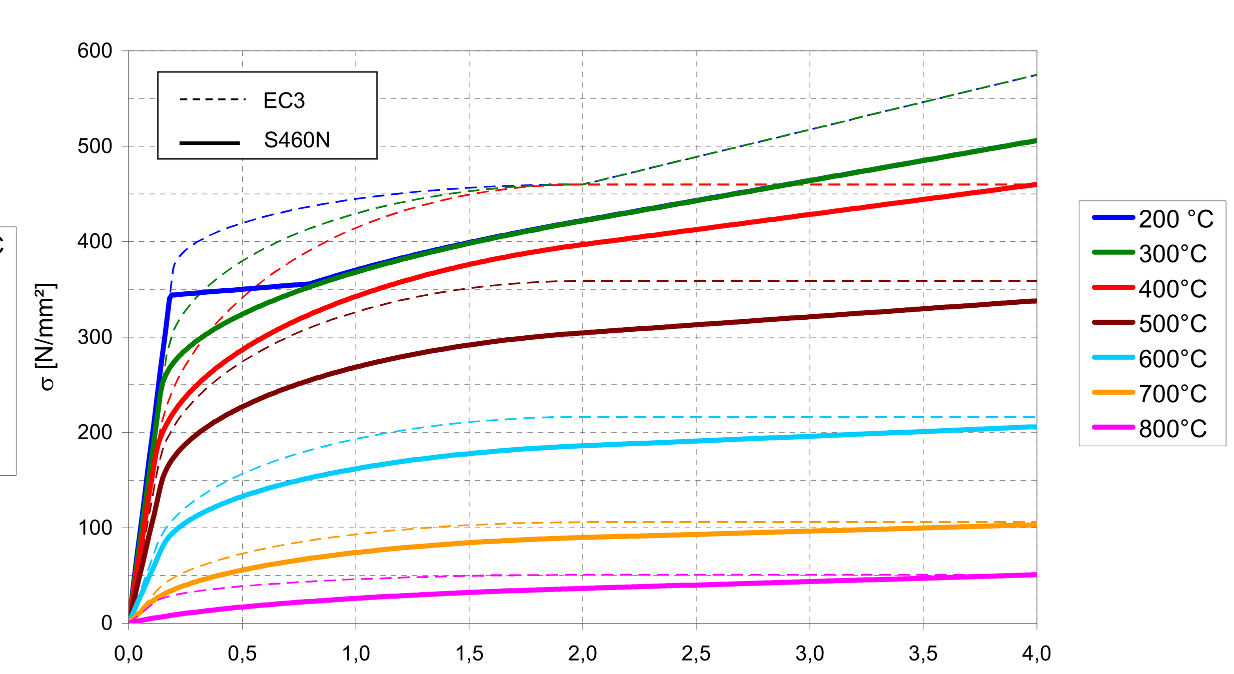
Yield strength reduction





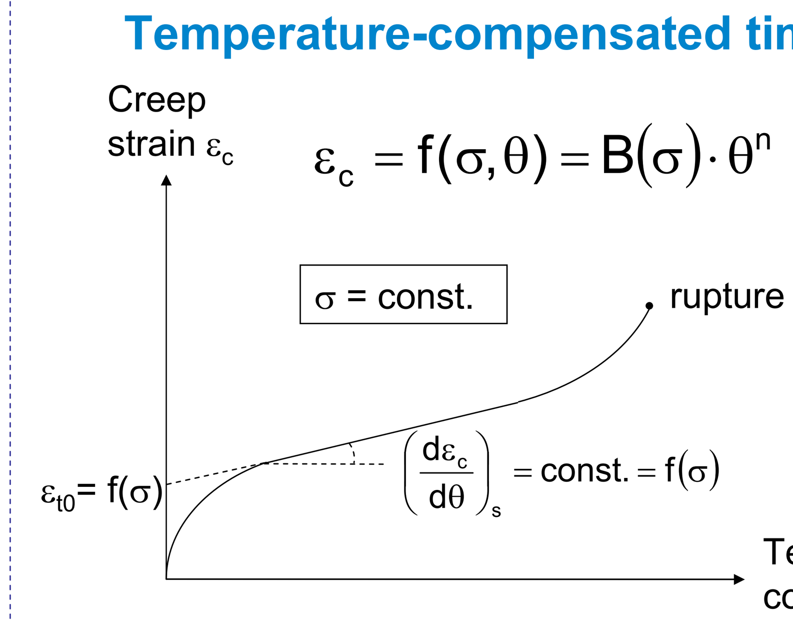
Analytical model (based on weakest material)





6. Empirical Creep Law for S460 in Case of Fire

Temperature-compensated time θ (J. E. Dorn 1954)

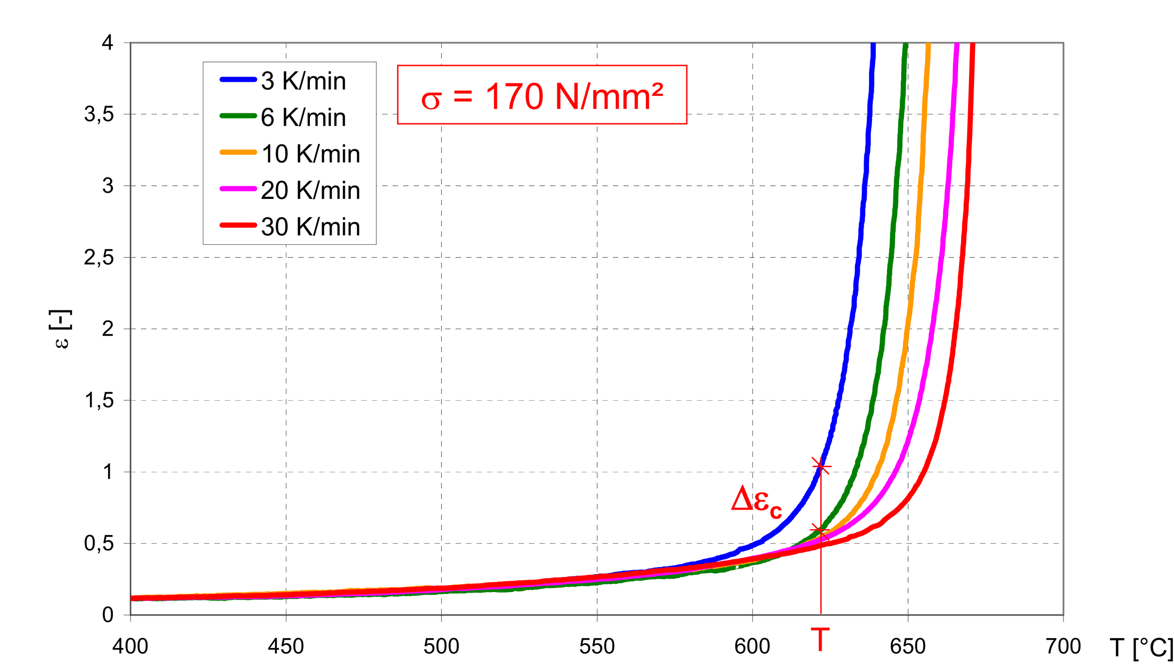


$$\theta = \int e^{\frac{-\Delta H}{R T(t)}} dt$$

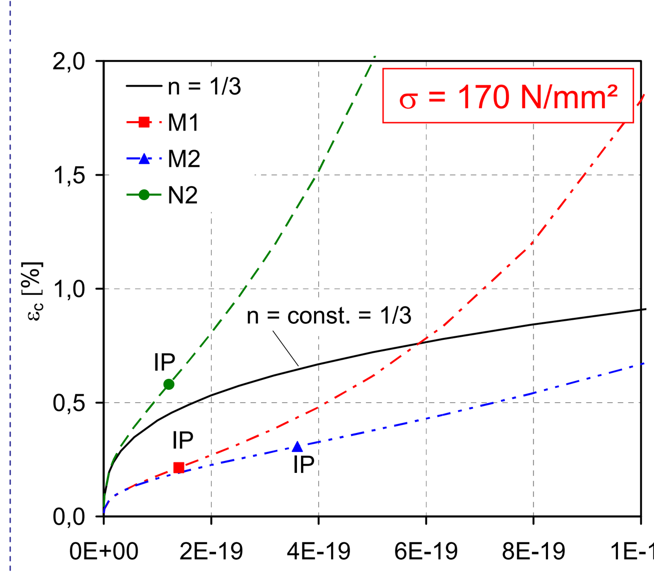
ΔH	Activation energy of creep [J/mol]
R	Gas constant [J/mol K]
T	Temperature [K]
t	Time [h]

Any variable temperature profile can be treated without superposition rules!

Transient tests with different heating rates



Result: Creep law with variable exponent n = f(σ,θ)



$$\varepsilon_c = B(\sigma)\cdot\theta^{a(\sigma)\cdot\theta+\frac{1}{3}} \quad [\%]$$

Material M1:

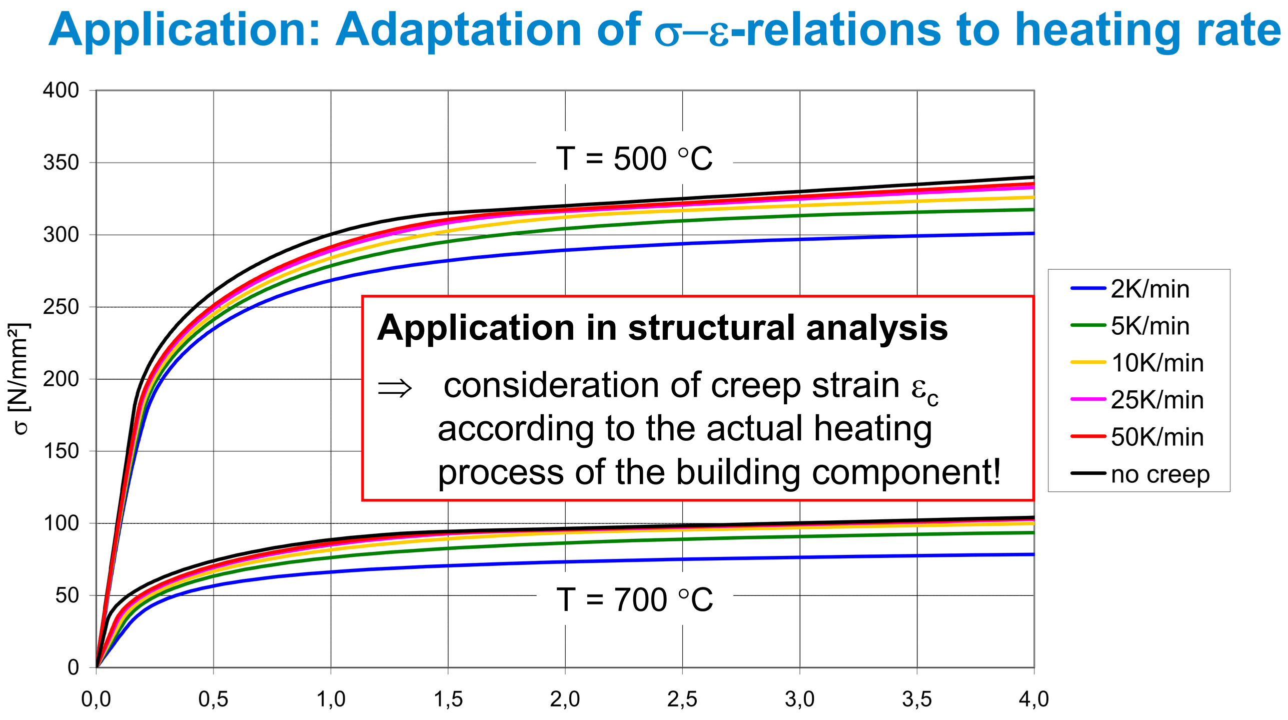
$$B(\sigma) = \begin{cases} 803\cdot\sigma & \text{für } \sigma < 0{,}08\ f_{yk} \\ 15300\cdot e^{0{,}01789\cdot\sigma} & \text{für } \sigma \geq 0{,}08\ f_{yk} \end{cases}$$

$$a(\sigma) = \begin{cases} -2{,}48\cdot 10^{6}\cdot\sigma^{4{,}586} & \text{für } \sigma < 0{,}4\ f_{yk} \\ -1{,}8\cdot 10^{13}\cdot e^{0{,}0442\cdot\sigma} & \text{für } \sigma \geq 0{,}4\ f_{yk} \end{cases}$$

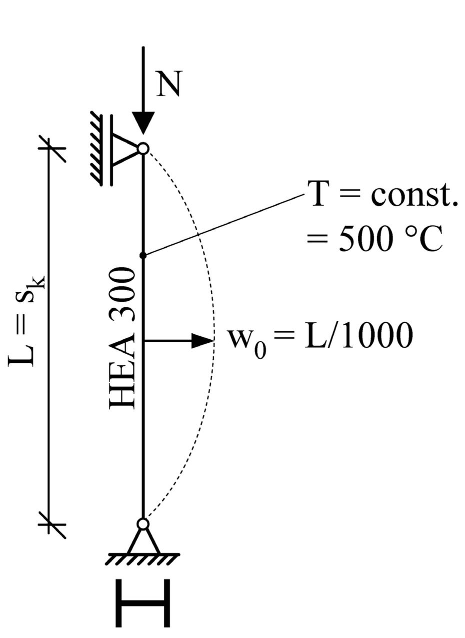
Creep law with n = f(σ,θ): Inflection point!

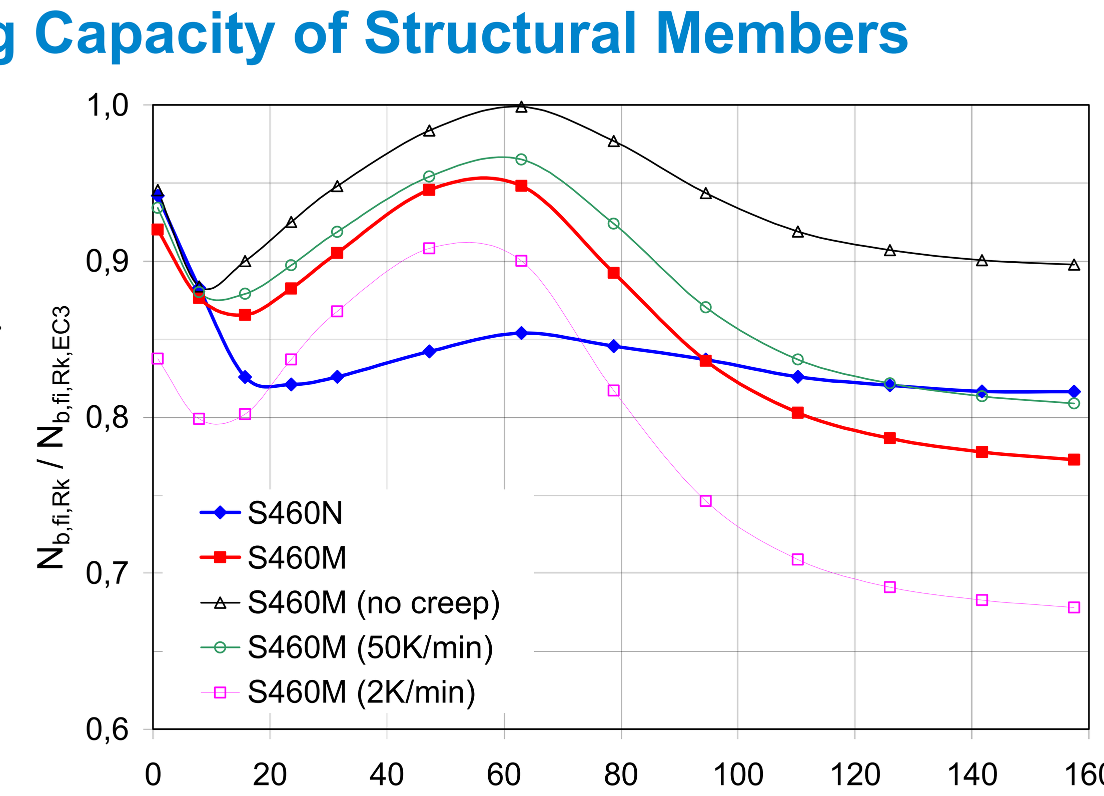
Materials M2, N2: slightly different values of the constants

Application: Adaptation of σ–ε-relations to heating rate



7. Load-Carrying Capacity of Structural Members





Conclusions

- Material model used in nonlinear limit load calculations
- Time-depending effects (creep)

have an enormous influence on

- Calculated bearing capacity
- Fire resistance

of structural steel members

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