

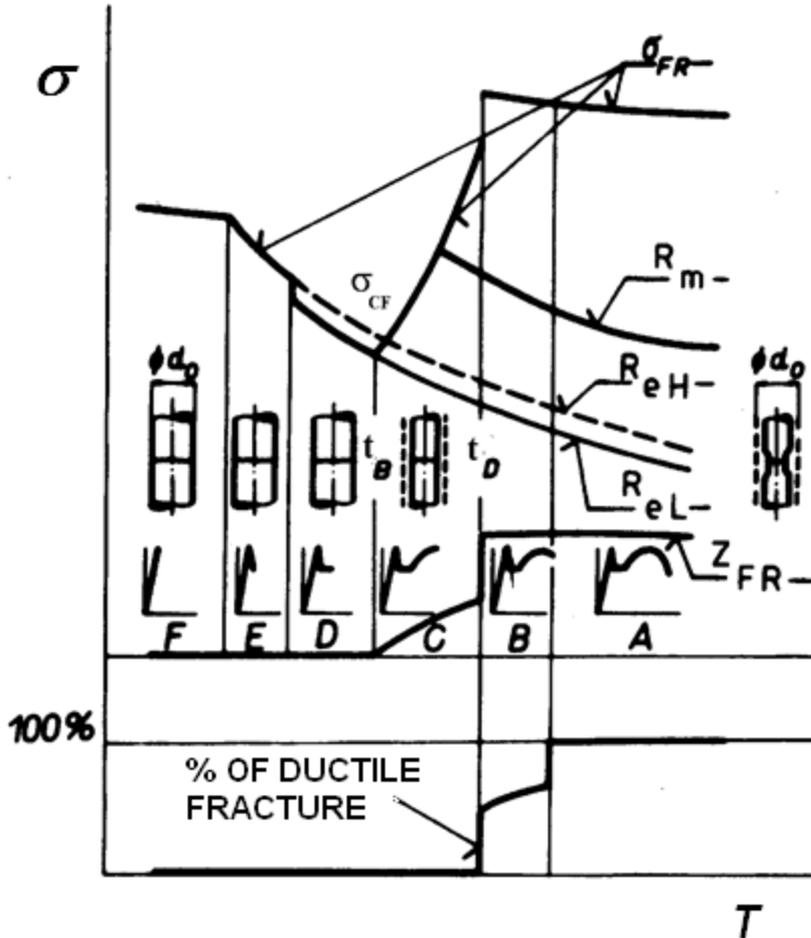


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INSTITUTE OF MATERIALS SCIENCE
AND ENGINEERING

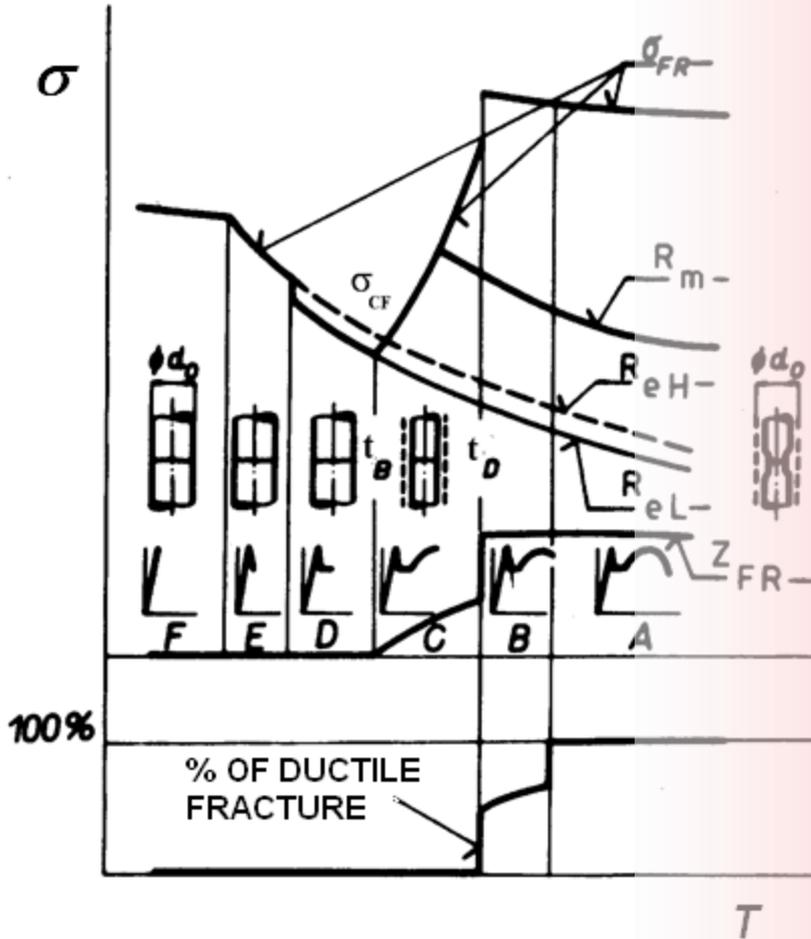
CREEP

Low carbon steel

The changes of tensile test diagram in temperature range $(20 \div -269)^\circ\text{C}$



- A. Ductile fracture
- B. Mixed fracture
- C. Cleavage fracture
- D. Brittle fracture
- E. Brittle fracture
- F. Brittle fracture



CREEP

TEMPERATURE



Creep

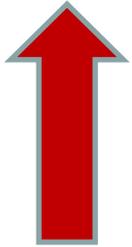
- I. Effect of elevated temperatures on the steel properties
- II. Creep tests
- III. Creep resistance characteristics of the material
- IV. Deformation and fracture during creep
- V. Time-temperature parameters

Creep

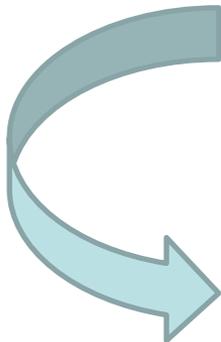
Effect of elevated temperatures on the steel properties

High temperature materials problems

Temperature



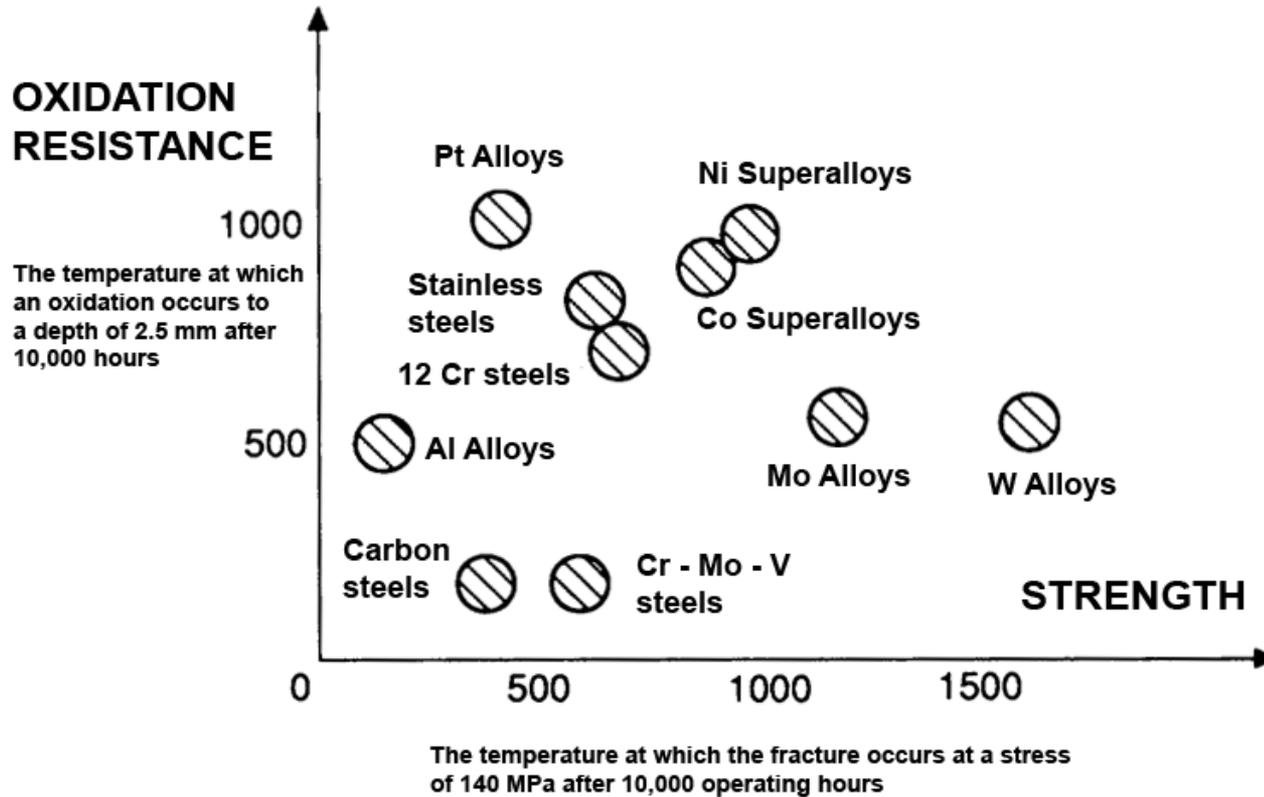
- atoms move faster → diffusion-controlled processes; this affects mechanical properties of materials
- greater mobility of dislocations (climb)
- increased amount of vacancies
- deformation at grain boundaries
- metallurgical changes, i.e., phase transformation, precipitation, oxidation, recrystallization



High temperature materials/alloys

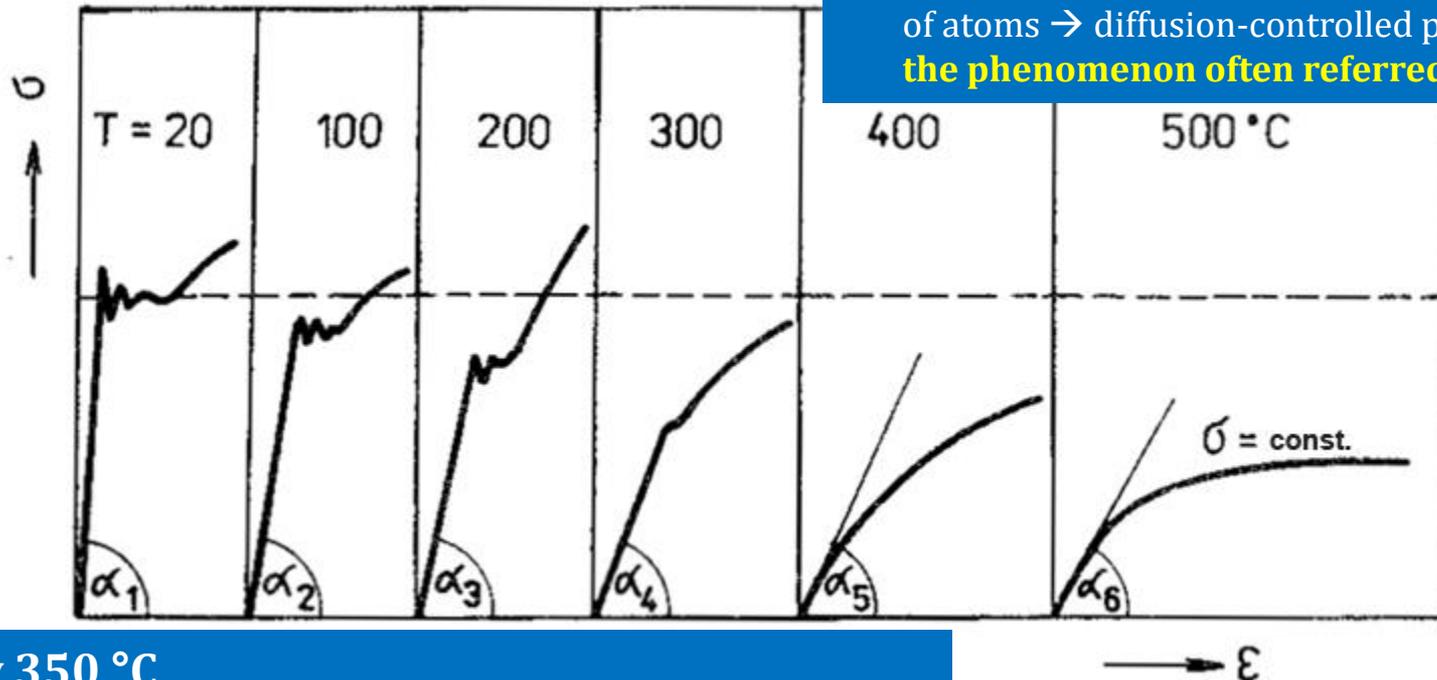
- Improved high temperature strength.
- Good oxidation resistance.

High temperature materials problems



High temperature materials problems

Effect of the temperature on tensile characteristics



Above 350 °C

- sharp yield strength disappeared
- shape of the tensile diagram (stress-strain diagram) is significantly affected by the temperature
- the deformation occurs by diffusion of atoms → diffusion-controlled process → **the phenomenon often referred to as CREEP**

Below 350 °C

- sharp (apparent) yield strength is subsequently disappearing
- the value of R_e decreases
- the deformation occurs by motion of dislocations

What is the CREEP?

Deformation

$$\varepsilon_t = \varepsilon_{el} + \varepsilon_{pl} = f(\sigma)$$

Creep

$$\varepsilon_{pl} = f(\sigma, T, t)$$

We can say

- Creep is slow plastic deformation caused by long term temperature exposition

or

- Creep occurs when a metal is subjected to a constant tensile load at an elevated temperature

What is the CREEP?

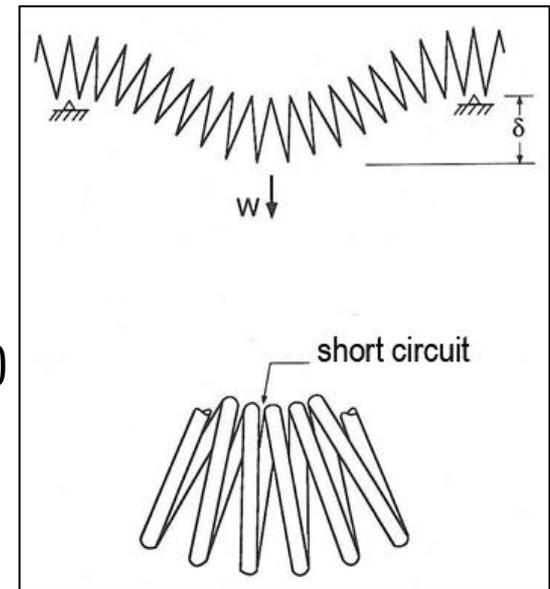
At which temperature the material will creep?

Although the materials have different melting point, they will creep when the **homologous temperature** $> 0.3 \div 0.5$ (exception - Ni superalloys ≈ 0.75)

$$\text{Homologous temperature} = \frac{\text{Test temperature}}{\text{Melting temperature}}$$

Low carbon steels (HT ≈ 0.3 , i.e. approx. 350 °C)

Steam turbine: ≈ 550 °C
 Turbocharger: ≈ 850 °C
 Bulb filament: ≈ 2000 °C



What is the CREEP?

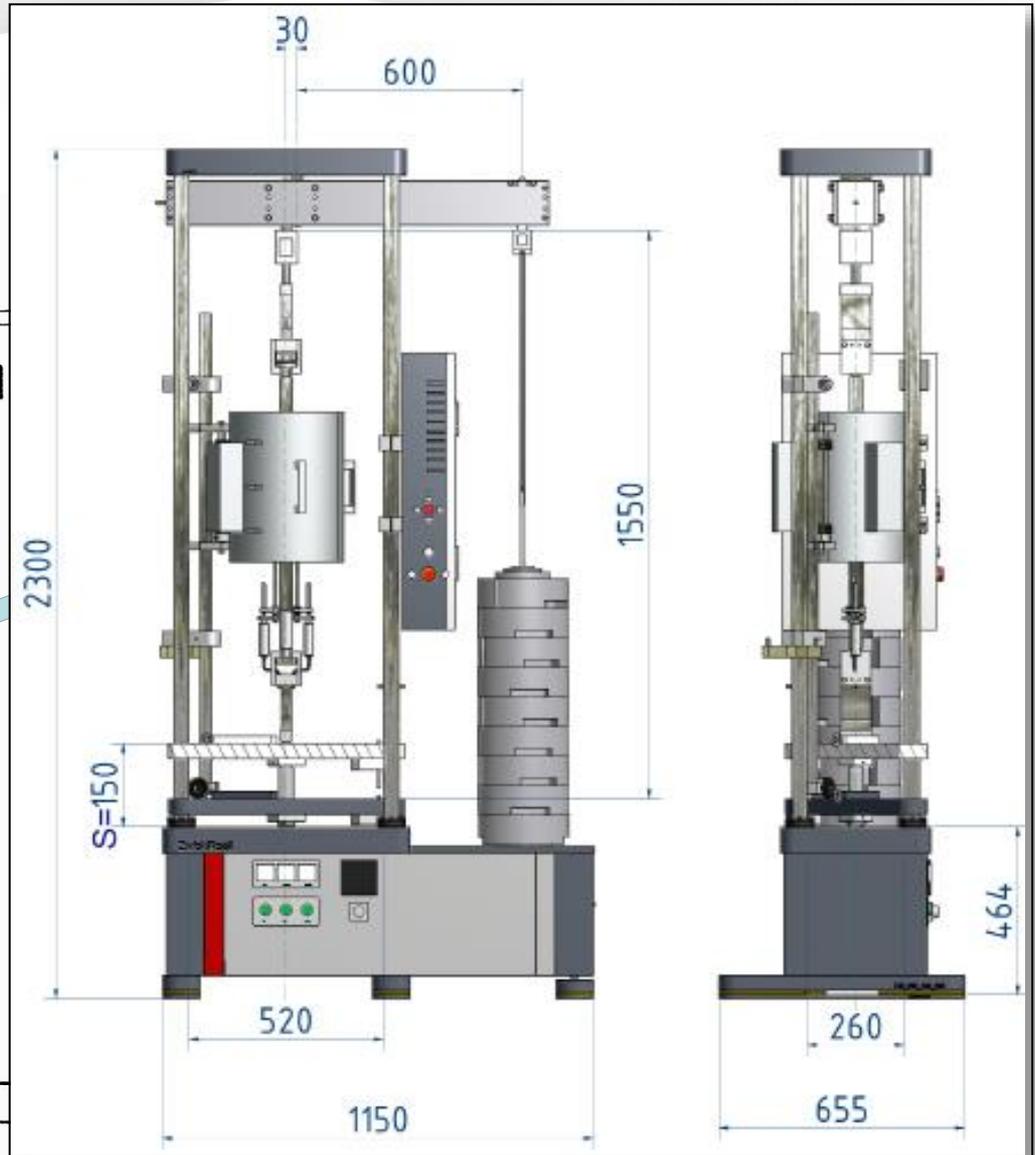
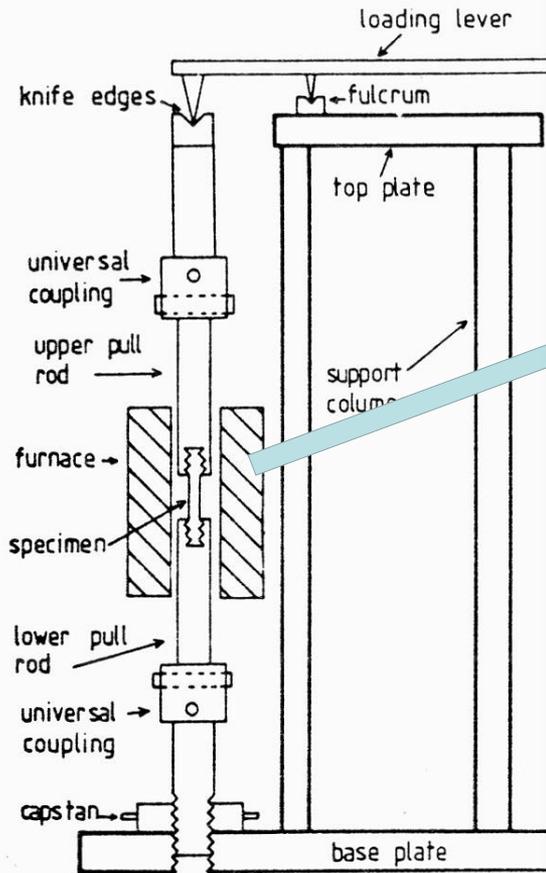
TABLE 17.1
MELTING OR SOFTENING^(S) TEMPERATURE

Material	/K	Material	/K
Diamond, graphite	4000	Silica glass	1100
Tungsten	3680	Aluminium	933
Tantalum	3250	Magnesium	923
Silicon carbide, SiC	3110	Soda glass	700–900
Magnesia, MgO	3073	Zinc	692
Molybdenum	2880	Polyimides	580–630 ^(S)
Niobium	2740	Lead	600
Beryllia, BeO	2700	Tin	505
Alumina, Al ₂ O ₃	2323	Melamines	400–480 ^(S)
Silicon nitride, Si ₃ N ₄	2173	Polyesters	450–480 ^(S)
Chromium	2148	Polycarbonates	400 ^(S)
Zirconium	2125	Polyethylene, high-density	300 ^(S)
Platinum	2042	Polyethylene, low-density	360 ^(S)
Titanium	1943	Foamed plastics, rigid	300–380 ^(S)
Iron	1809	Epoxy, general purpose	340–380 ^(S)
Cobalt	1768	Polystyrenes	370–380 ^(S)
Nickel	1726	Nylons	340–380 ^(S)
Cermets	1700	Polyurethane	365 ^(S)
Silicon	1683	Acrylic	350 ^(S)
Alkali halides	800–1600	GFRP	340 ^(S)
Uranium	1405	CFRP	340 ^(S)
Copper	1356	Polypropylene	330 ^(S)
Gold	1336	Ice	273
Silver	1234	Mercury	235

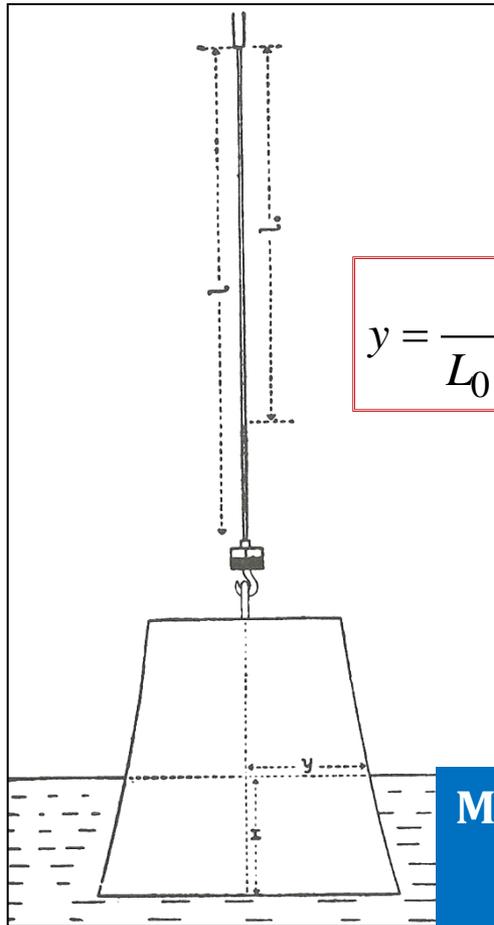
Creep

Creep tests

Creep test



Creep test



$$y = \frac{1}{L_0 + x} \sqrt{\frac{M \cdot L_0}{\pi \cdot \rho}}$$

History
Andrade
during u
(lead)

Measured variables:

- strain versus time
- time to fracture

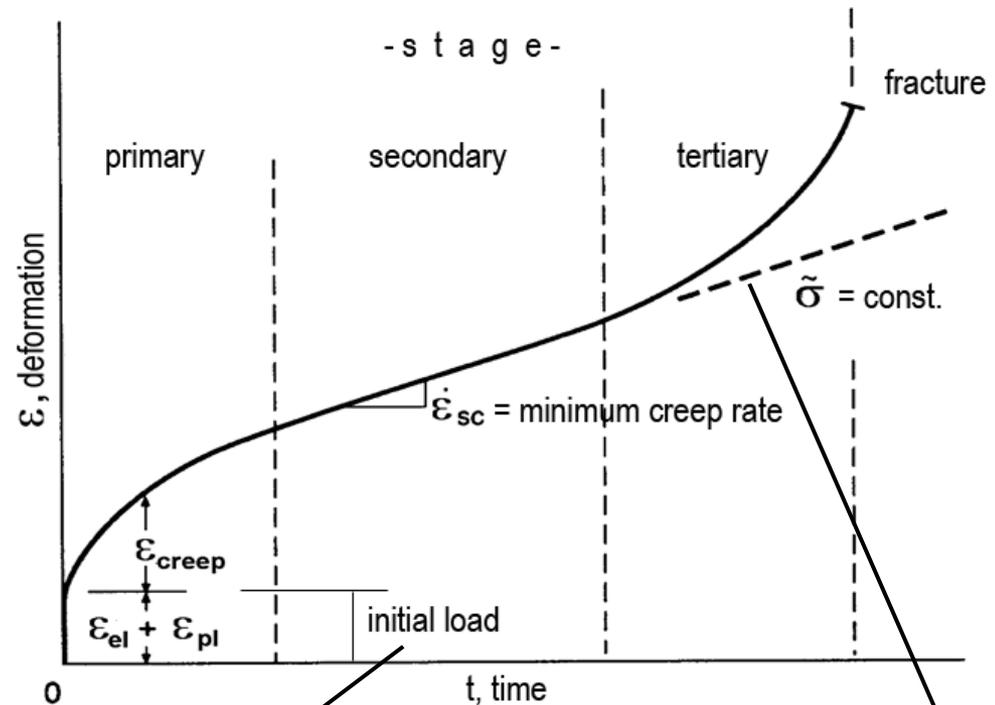


Creep test

The creep test is carried out by applying a constant load to a tensile specimen maintained at a constant temperature

$$T = \text{const.}, \sigma = \text{const.}$$

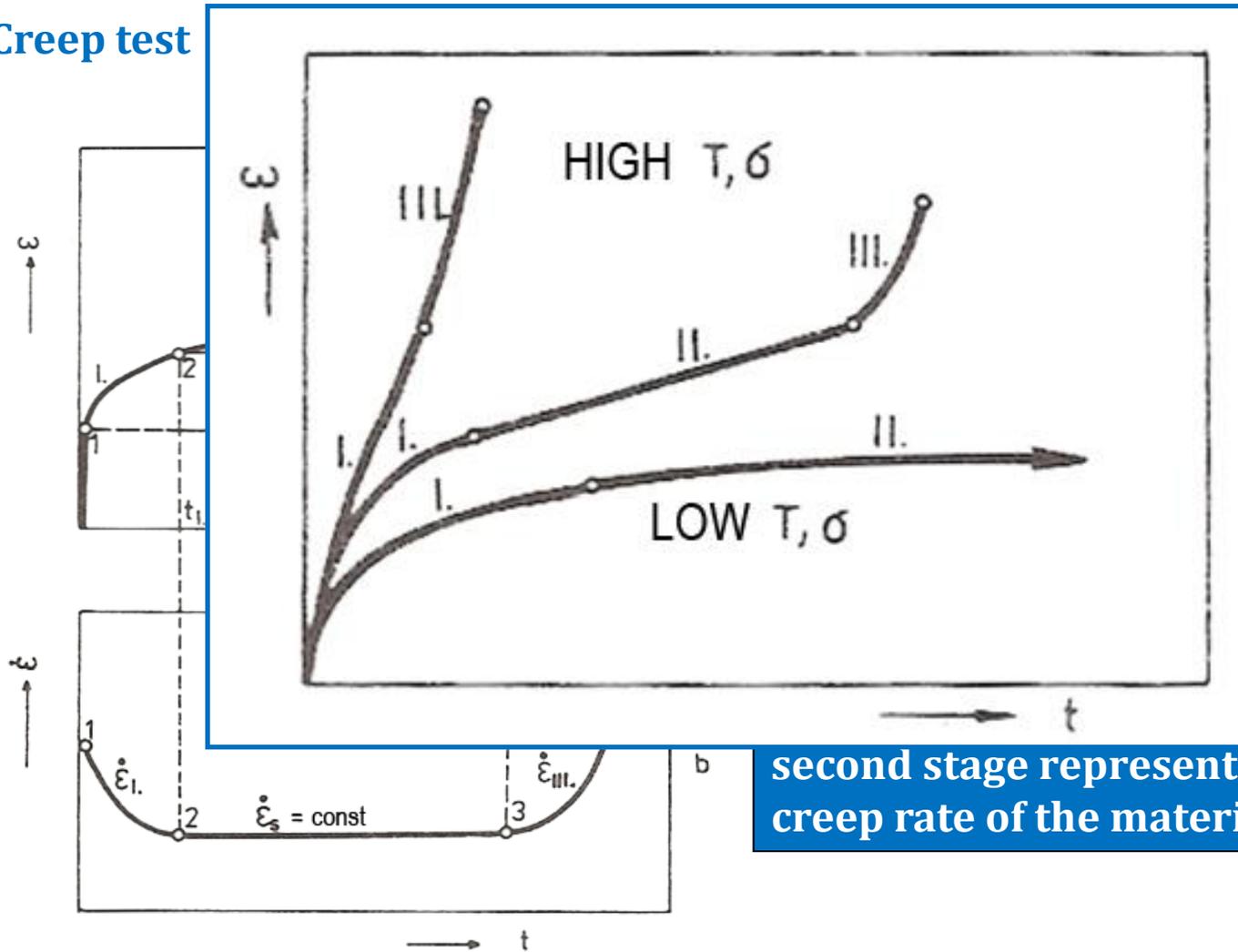
Typical creep curve



Instantaneous strain on loading which is partly recoverable with time (anelastic) and partly nonrecoverable with time (plastic)

This curve is obtained when the stress rather than the load is applied

Creep test



distinct
After an initial
decrease
y state.
creasing creep
representing
creep rate till

in the second stage represents the creep rate of the material

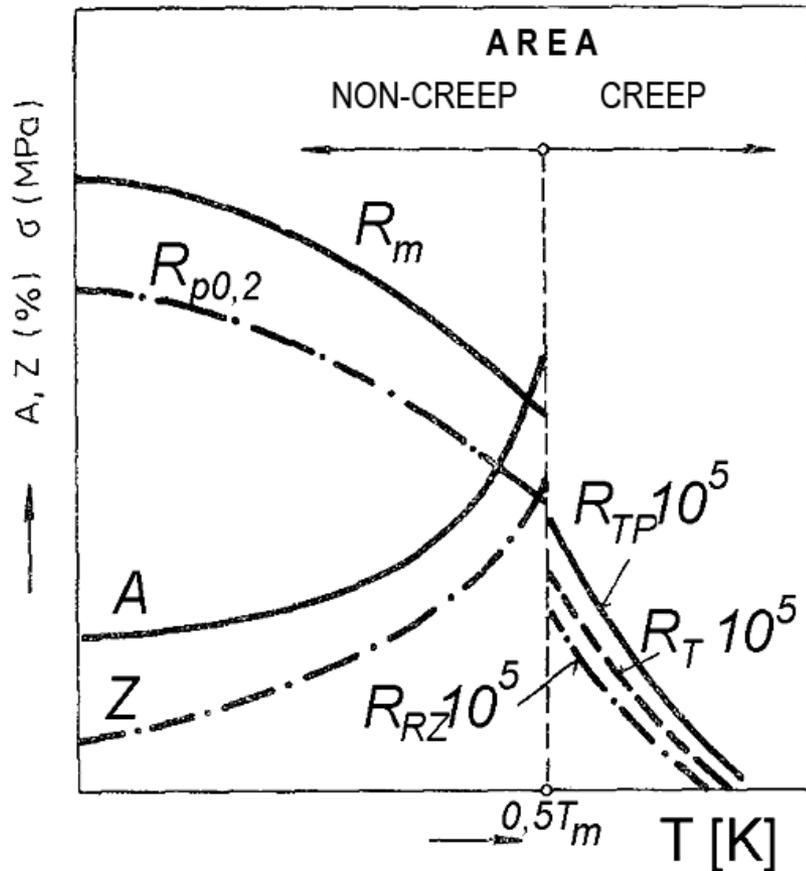
Creep test

1. **Primary creep** is a period of transient (logarithmic) creep. The creep resistance of the material increases due to material deformation. It predominates at low temperature test such as in the creep of lead at RT.
2. **Secondary creep** provides a nearly constant creep rate. The average value of the creep rate during this period is called the minimum creep rate.
3. **Tertiary creep** shows a rapid increase in the creep rate due to effectively reduced cross-sectional area of the specimen.

Creep

Creep resistance characteristics of the material

Creep characteristics



Introduced characteristics:

- ✓ Time to rupture
(for particular conditions of loading)
- ✓ Steady-state rate
- ✓ Creep limit
- ✓ Creep strength
- ✓ Time-temperature parameters

Creep characteristics

Creep limit

R_T [MPa]; (σ_{A1})
temp / deformation / time

the maximum stress that will cause a specified quantity of creep (pl. deformation) at constant temperature under given time

Ex.: P265H steel; $R_e=265$ MPa, $R_m=450$ MPa
 $R_T = 132/380/1/10^5 \sim \langle \text{MPa}/^\circ\text{C}/\%/ \text{hour} \rangle$

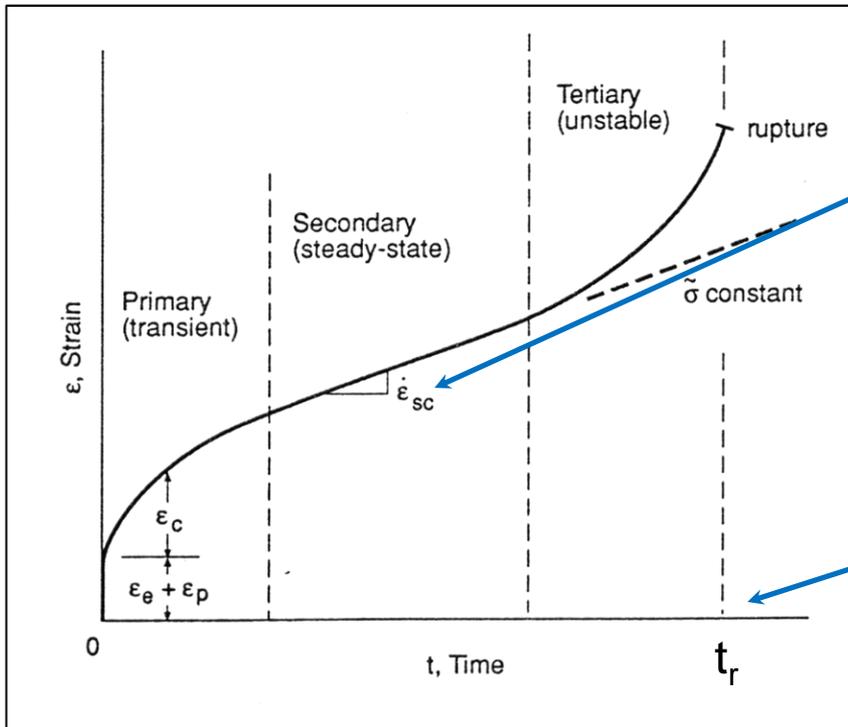
Creep strength

R_{TP} [MPa]; (σ_r)
temp / time to rupture

the constant nominal stress that will cause a rupture at constant temperature under given time

Ex.: P265H steel; $R_e=265$ MPa, $R_m=450$ MPa
 $R_{TP} = 165/380/10^5 \sim \langle \text{MPa}/^\circ\text{C}/ \text{hour} \rangle$

Creep characteristics



Steady-state rate

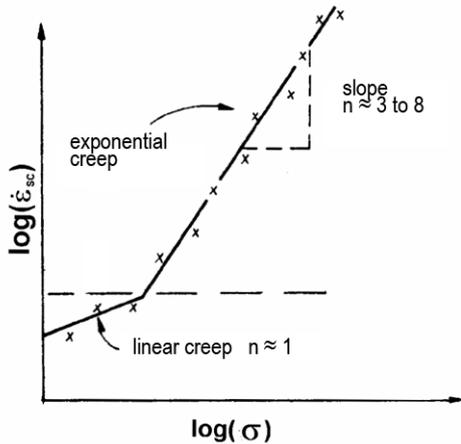
slope of the ϵ vs. t in the secondary creep stage (steady-state)

$$\dot{\epsilon}_{sc} = \frac{d\epsilon}{dt}$$

Time to rupture

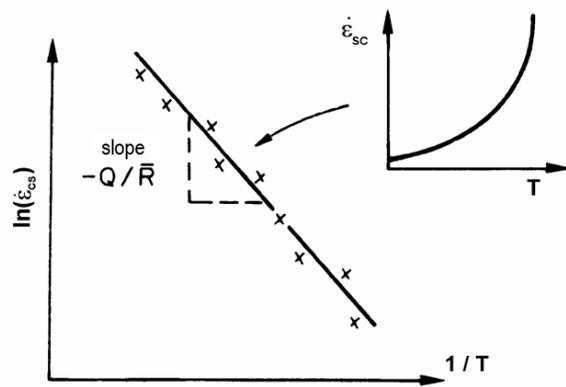
for particular conditions of loading

Creep characteristics



Dependence $\log(\dot{\epsilon}_{sc})$ vs. $\log(\sigma)$; $T = \text{const.}$

$$\dot{\epsilon}_{sc} = B\sigma^n$$



Dependence $\ln(\dot{\epsilon}_{sc})$ vs. $1/T$

$$\dot{\epsilon}_{sc} = C \exp\left(-\frac{Q}{RT}\right)$$

Arrhenius equation

$$\dot{\epsilon}_{sc} = A\sigma^n e^{-\frac{Q}{RT}}$$

where

n – creep exponent

R – universal gas constant: 2 cal/kmol
(8,31 J.mol⁻¹K⁻¹)

T – temperature in Kelvins [K]

Q – activation energy [J/mol]

A – material constant

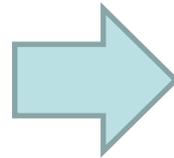
Creep

Deformation and fracture during creep

Creep deformation and fracture

Creep is caused by diffusion of atoms under the effect of the stress and elevated temperature

$$\dot{\epsilon}_{SC} = A \sigma^n e^{-\frac{Q}{RT}}$$



$n \approx 1$ creep of polymers
 $n \approx 1$ diffusion creep
 $n = 3 \div 8$ dislocation creep

In case of metallic materials



DIFFUSION CREEP

Involves the flow of vacancies and interstitials through a crystal under the influence of applied stress

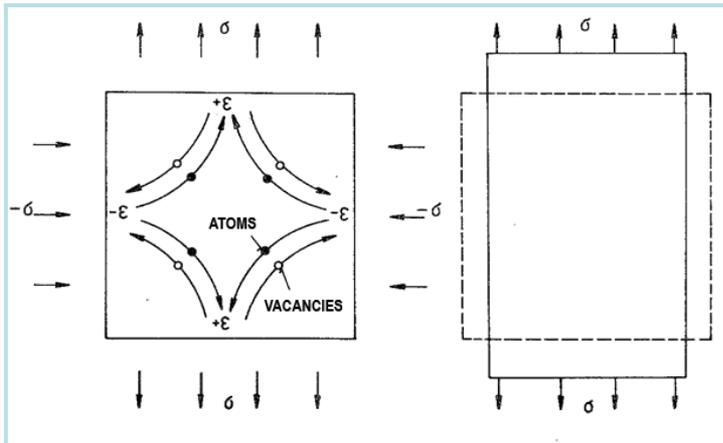


DISLOCATION CREEP

Involves dislocation movement to overcome barriers by diffusion of vacancies or interstitials

Creep deformation and fracture

DIFFUSION CREEP

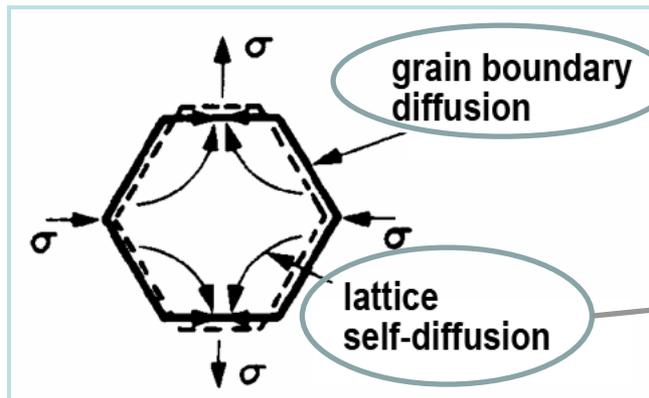


Vacancies are moving from tensile stress areas into pressure areas and interstitials migrate in the opposite direction. The result of diffusion is a permanent change of the element shape, i.e. plastic deformation.

Coble creep

$$\dot{\epsilon}_{SC} = \frac{\sigma A_2}{d^3} D_B$$

lower stress,
lower temperature



Herring-Nabarro creep

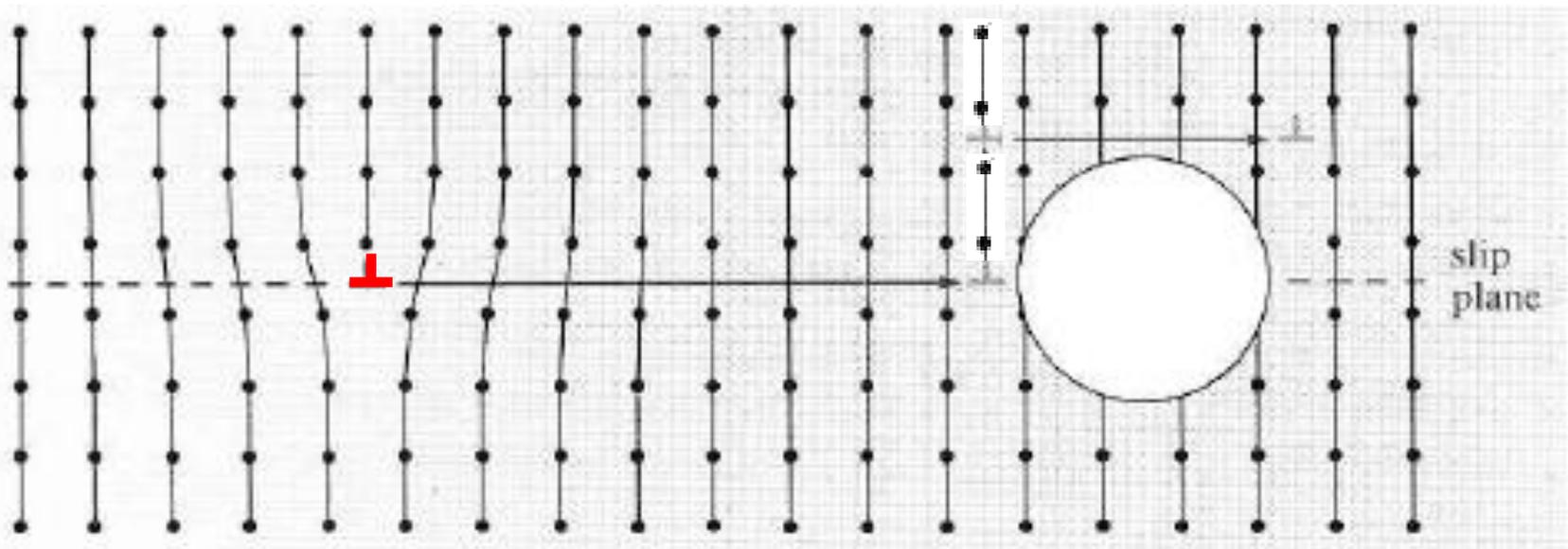
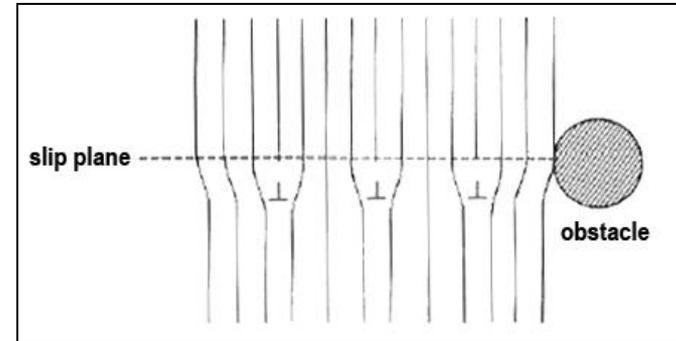
$$\dot{\epsilon}_{SC} = \frac{\sigma A_1}{d^2} D_G$$

lower stress,
high temperature

Creep deformation and fracture

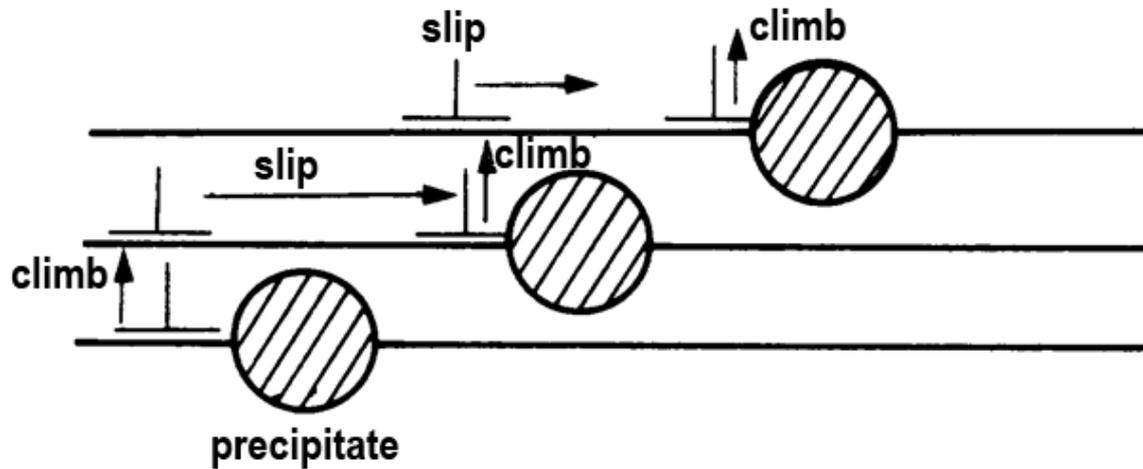
DISLOCATION CREEP

Involves dislocation movement to overcome barriers by diffusion of vacancies or interstitials



Creep deformation and fracture

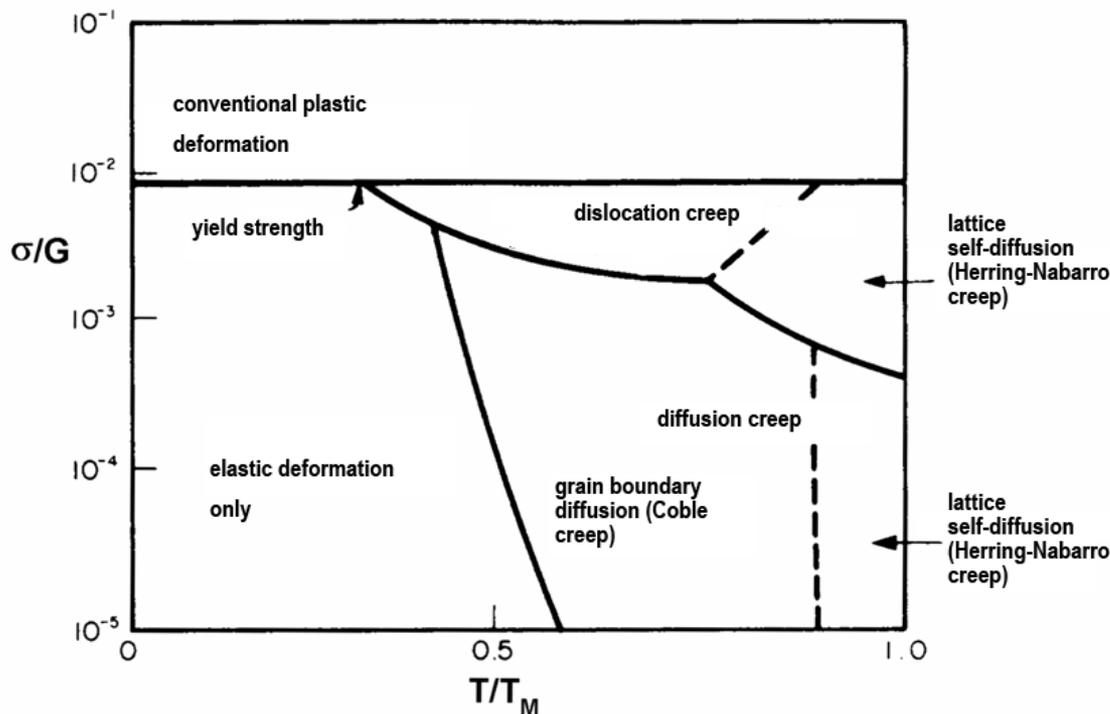
DISLOCATION CREEP



$$\dot{\epsilon}_{SC} = A_3 \sigma^n D_G; (n \approx 3 \div 8)$$

Creep deformation and fracture

DEFORMATION MECHANISM MAPS

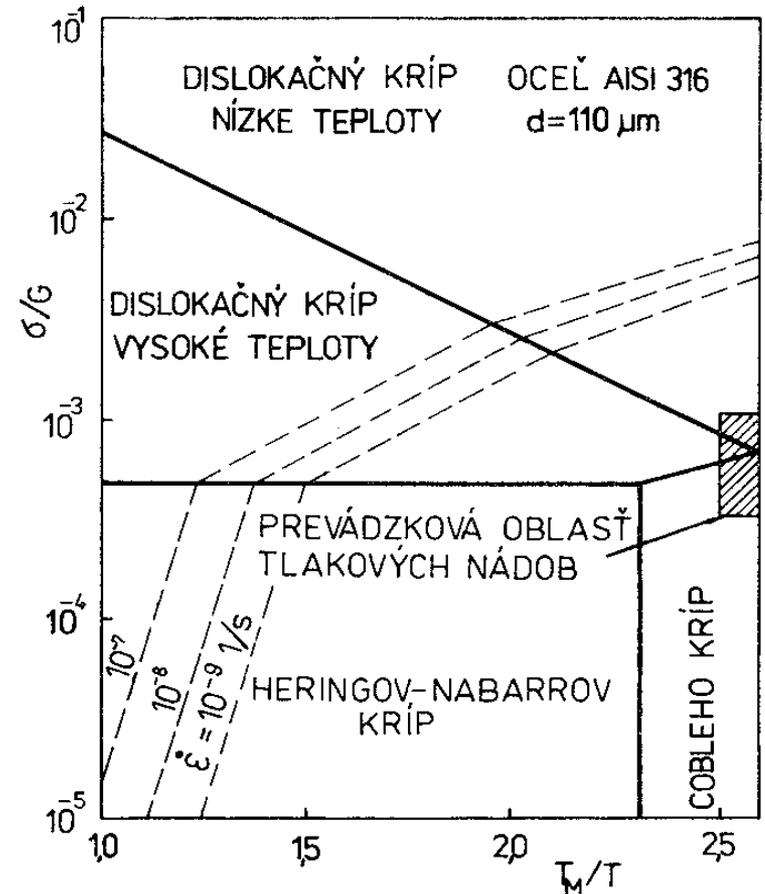
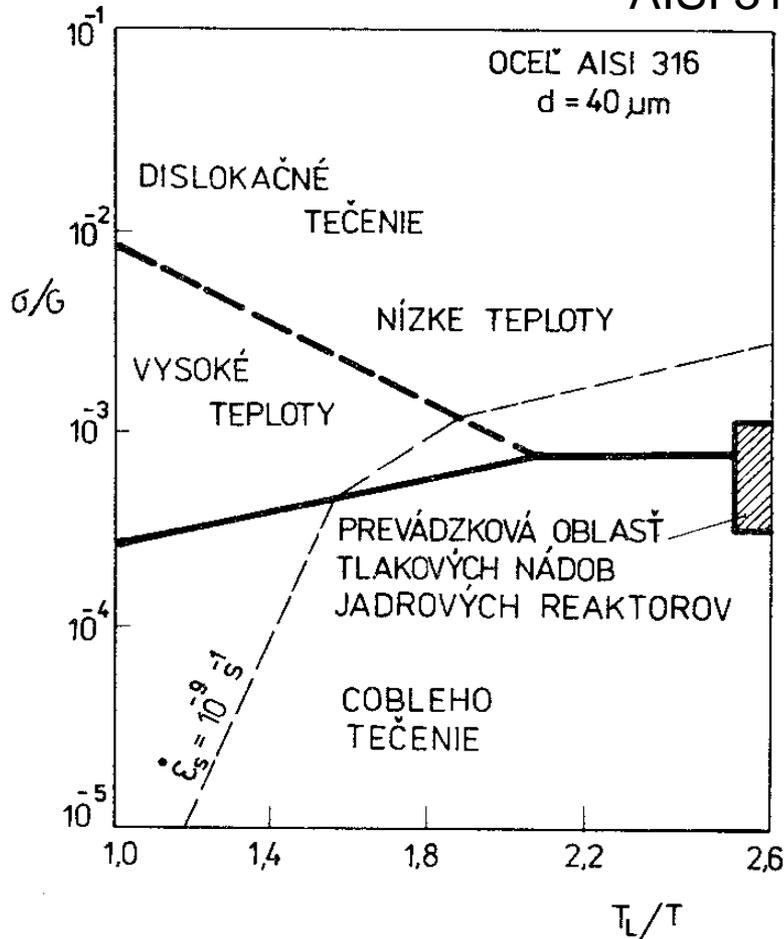


Simplified deformation mechanism map

The various regions of the map indicate the dominant deformation mechanism for the combination of stress and temperature.

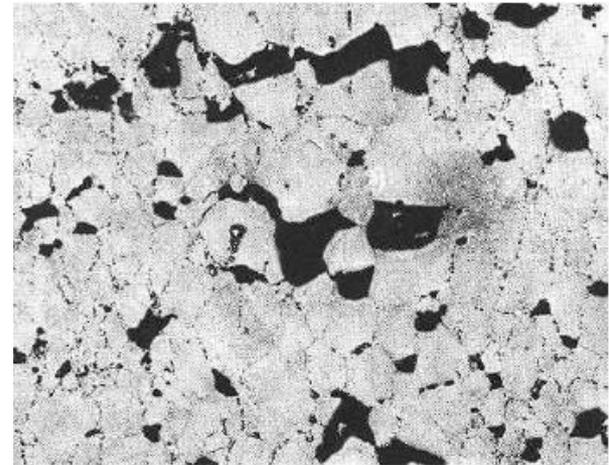
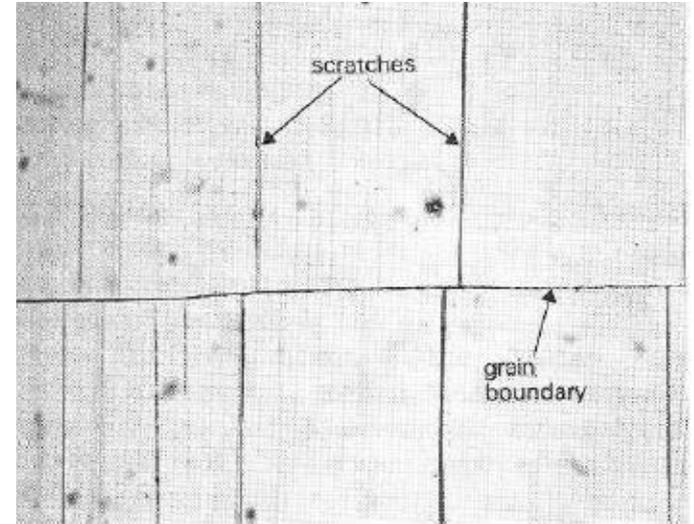
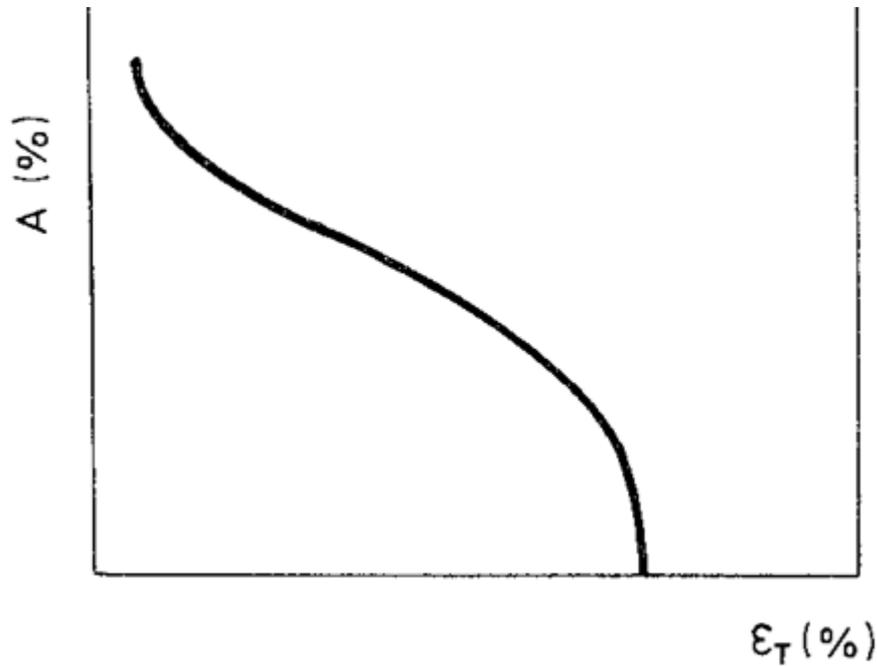
Creep deformation and fracture

AISI 316 (16Cr-13Ni-2,5Mo)



Creep deformation and fracture

CREEP FRACTURE



Creep deformation and fracture

CREEP FRACTURE



(equicohesive temperature)

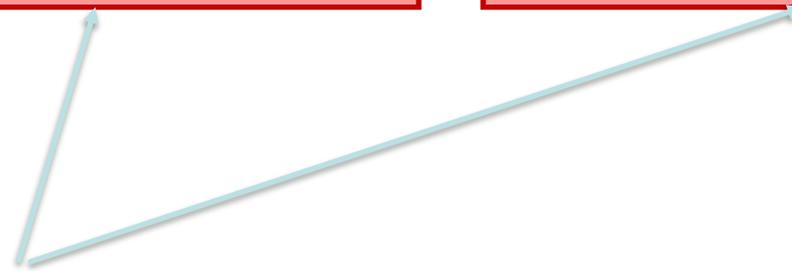
Transgranular fracture

Slip planes are weaker than grain boundaries

Intergranular fracture

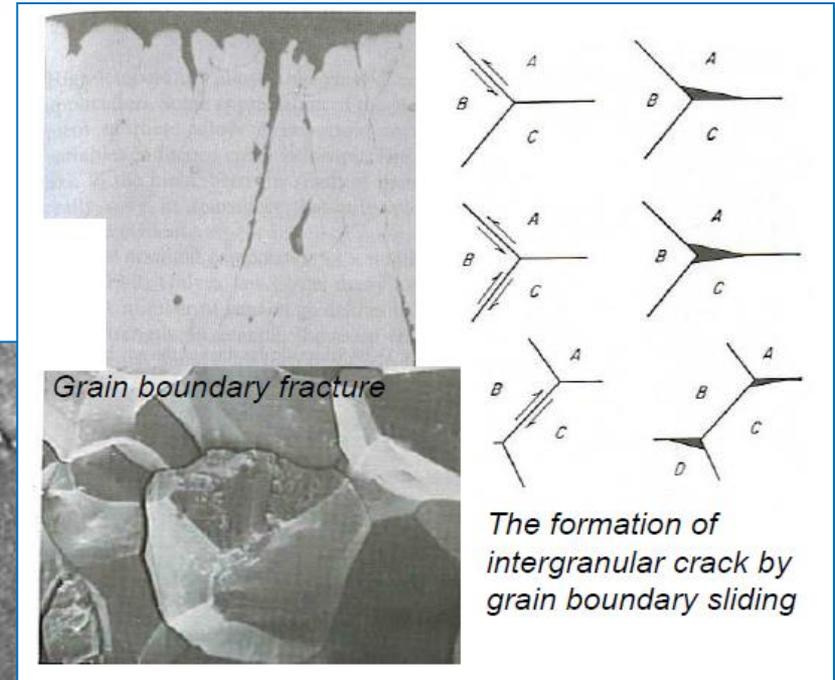
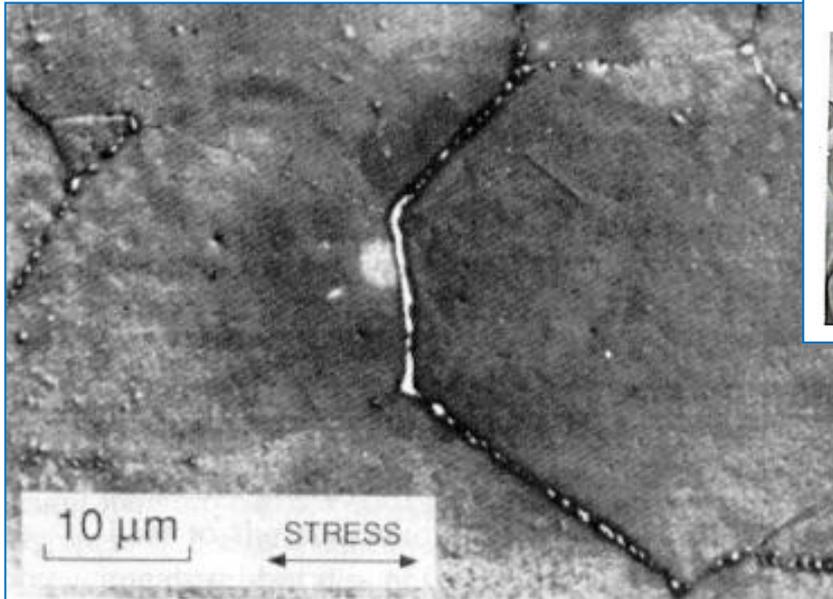
Grain boundaries are weaker than slip planes

Fracture line through the structure



Creep deformation and fracture

CREEP FRACTURE



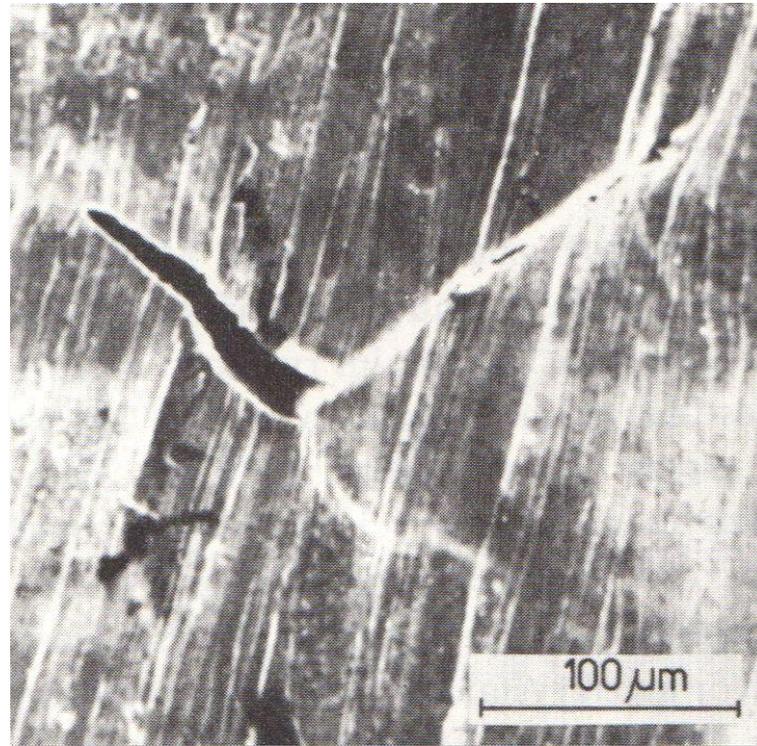
grain boundary sliding



wedge cracks / formation of cavities

Creep deformation and fracture

CREEP FRACTURE



Wedge crack
steel 18Cr – 10Ni (773 K, 300 MPa)

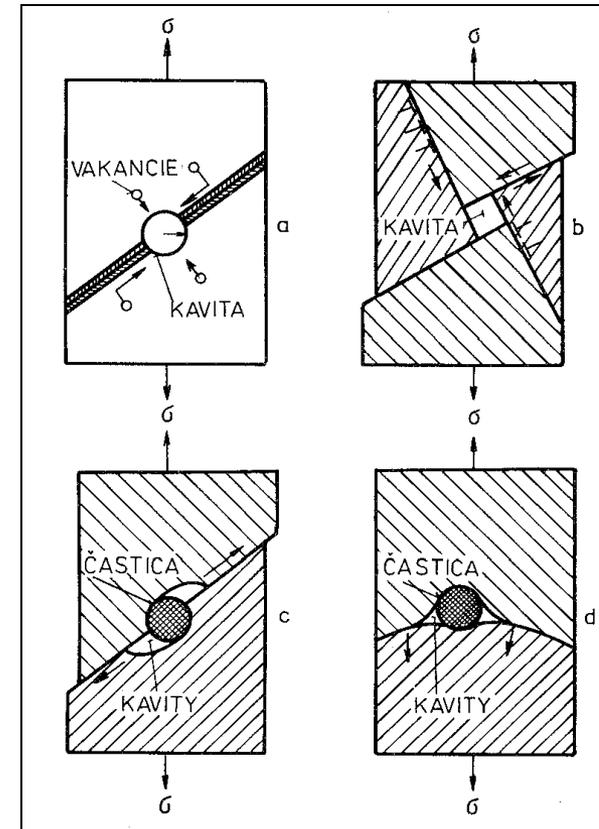
Creep deformation and fracture

CREEP FRACTURE

Vacancy migration, grain boundary sliding,
foreign phase particles (slip, migration of grain
borders)

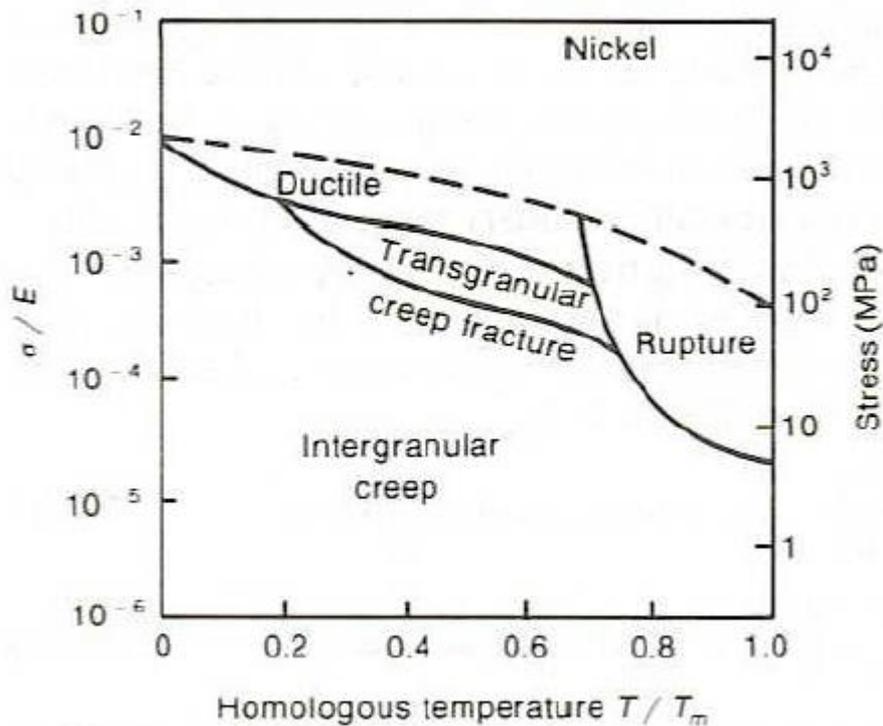


cavities



Creep deformation and fracture

CREEP FRACTURE



Fracture mechanism map for nickel

Temperature 

Transgranular fracture

Slip planes are weaker than grain boundaries

Intergranular fracture

Grain boundaries are weaker than slip planes

The regions of the map indicate the dominant fracture mechanism for the combination of stress and temperature.

Creep

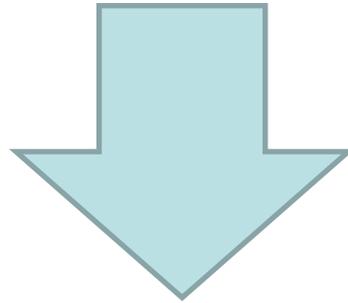
Time-temperature parameters

Time-temperature parameters

the lifetime of machines, various facilities etc. is usually designed for 20 or more years

versus

consumption of the laboratory time



extrapolation of the laboratory results to the real structures

Time-temperature parameters

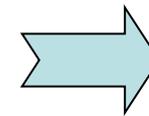
➤ **Sherby-Dorn Parameter**

➤ **Larson-Miller Parameter**

All p
equ

$$\theta_i = t_1 e^{\frac{-Q}{RT_1}} = \dots = t_n e^{\frac{-Q}{RT_n}}$$

after integration



temperature-compensated time



$$\varepsilon_{sc} = A \sigma t e^{-\frac{Q}{RT}}$$

$$\theta = \frac{\varepsilon_{sc}}{A \sigma} = t \cdot e^{-\frac{Q}{RT}}$$

Time-temperature parameters

Sherby-Dorn parameter

$$P_{SD} = \log \theta = \log t - 0,217 \frac{Q}{T}$$

$$\langle R = 2 \text{ cal / kmol}; \log_{10} e = 0,434 \rangle$$

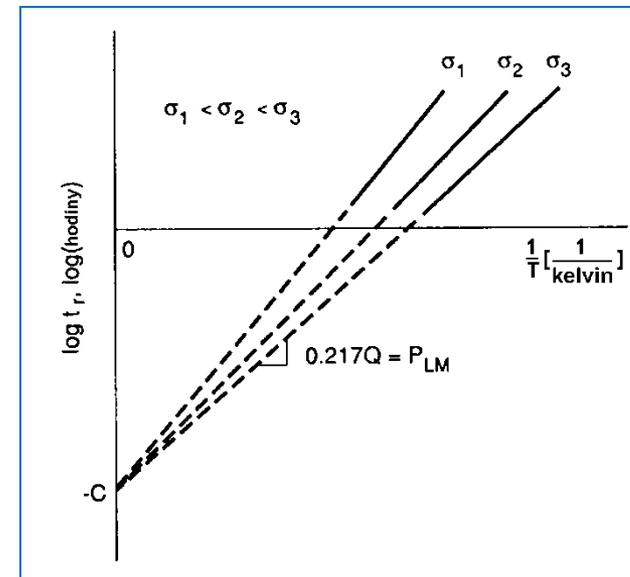
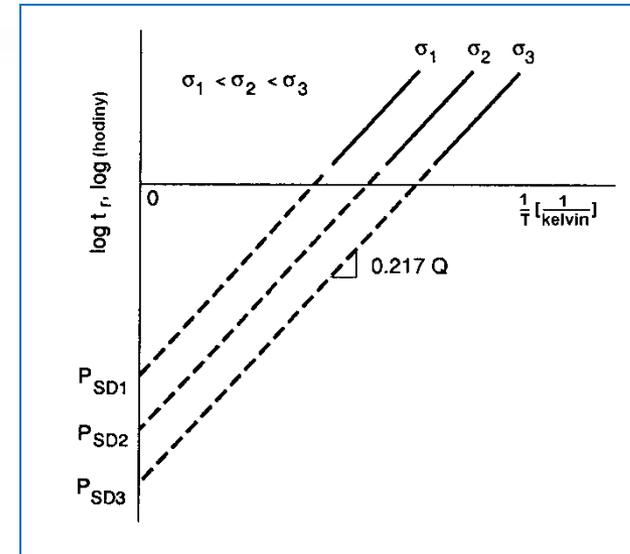
Larson-Miller parameter

$$\log \theta = \log t - 0,217 \frac{Q}{T};$$

substitution : $\log \theta = -C$

$$-C = \log t - \frac{0,217Q}{T}$$

$$P_{LM} = 0,217Q = T[\log t + C]$$

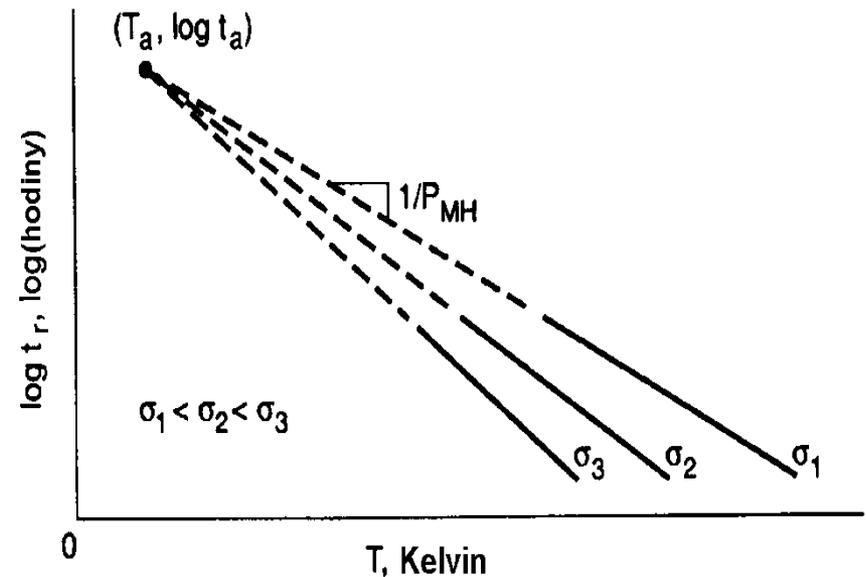


Time-temperature parameters

Manson-Haferd parameter

Based on assumption, that there is for particular material convergent point for various stresses. This point is described by temperature T_a and $\log t_a$, which are considered to be material constants.

$$P_{MH} = \frac{T - T_a}{\log(t_r) - \log(t_a)}$$



Time-temperature parameters

Material	Sherby-Dorn Q , cal/mole	Larson-Miller C	Manson-Haferd	
			T_a , K	$\log t_a$
Various steels and stainless steels	$\approx 90,000$	≈ 20	—	—
Pure aluminum and dilute alloys	$\approx 36,000$	—	—	—
S-590 alloy (Fe base)	85,000 ⁵	17	172	20
A-286 stainless steel	91,000	20	367	16
Nimonic 80A (Ni base)	91,000	18	311	16
1Cr-1Mo-0.25V steel	110,000	22	311	18

THANK YOU FOR YOUR ATTENTION

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