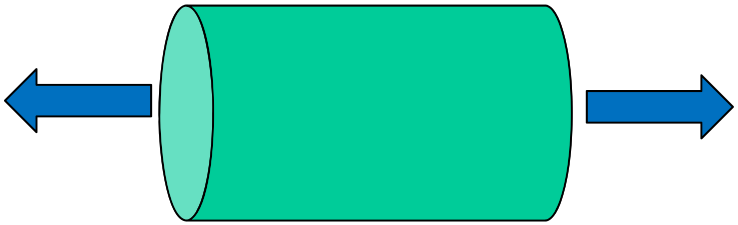
Engineering Materials MECH 390
Tutorial 2

Chapter 6
Mechanical Properties

6.14:A cylindrical specimen of steel having a diameter of 15.2 mm and length of 250 mm is deformed elastically in tension with force of 48,900 N. Using the data contained in Table 6.1, determine the following:

a) The amount by which this specimen will elongate in the direction of the applied stress?
b) The change in diameter of the specimen.Will the diameter increase or decrease?
c) What would be the shear modulus (G)?

D_o=15.2 mm
L_o=250 mm
F=48,900 N deformed elastically
Table 6.1:E=207 GPa, ν=0.3



Compute elongation(ΔL), diameter change (Δd), shear modulus (G)?

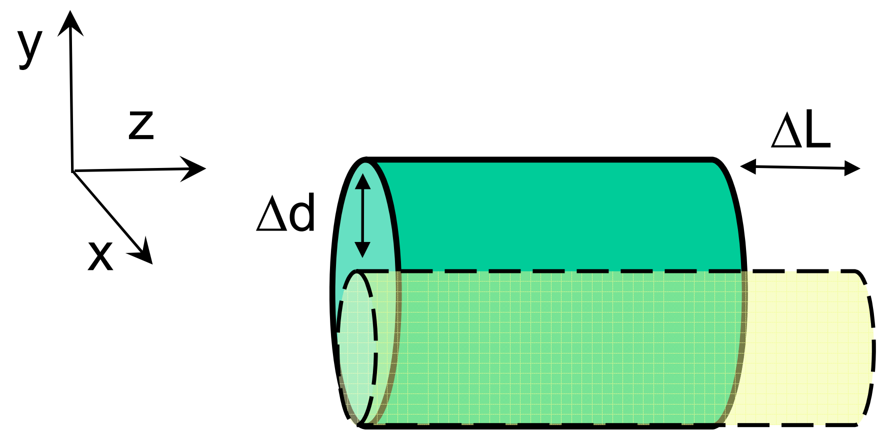
a)

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A_o}{\Delta L/L_o} \Rightarrow \text{knowing that } A_o = \frac{\pi}{4}\mathrm{d}^2$$

$$\therefore \Delta L = \frac{4F.L_o}{\pi.d^2.E} = \frac{(4)(48{,}900\ \mathrm{N})(250\ \mathrm{x}\ 10^{-3}\ \mathrm{m})}{(\pi)(15.2\ \mathrm{x}\ 10^{-3}\ \mathrm{m})^2(207\ \mathrm{x}\ 10^{9}\ \mathrm{N/m^2})}$$

$$= 3.25\ \mathrm{x}\ 10^{-4}\ \mathrm{m} = 0.325\ \mathrm{mm}$$

b)



$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\Delta d/d_0}{\Delta l/l_0}$$

$$\Delta d = -\frac{\nu\,\Delta l\,d_0}{l_0} = -\frac{(0.30)(0.325\ \mathrm{mm})(15.2\ \mathrm{mm})}{250\ \mathrm{mm}}$$

$$= -5.9\ \mathrm{x}\ 10^{-3}\ \mathrm{mm}$$

The diameter will……?

c) Relation between Elastic constants is:

$E=2G(1+\nu)$

$$\therefore G=\frac{E}{2(1+\nu)}=.......?$$

Note: Poisson’s ration is always positive and less than 0.5

6.19:A brass alloy is known to have a yield strength 0f 249MPa, a tensile strength of 310 MPa, and an elastic modulus of 110 GPa. A cylindrical specimen of this alloy 15.2mm in diameter and 380mm long is stressed in tension and found to elongate 1.9mm.

- On the basis of the information given, is it possible to compute the magnitude of the load that is necessary to produce this change in length? If so, calculate the load. If not, explain why?

σ_y=249 Mpa

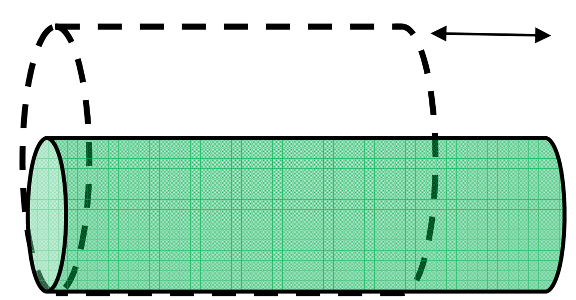
σ_{ult}=310 Mpa

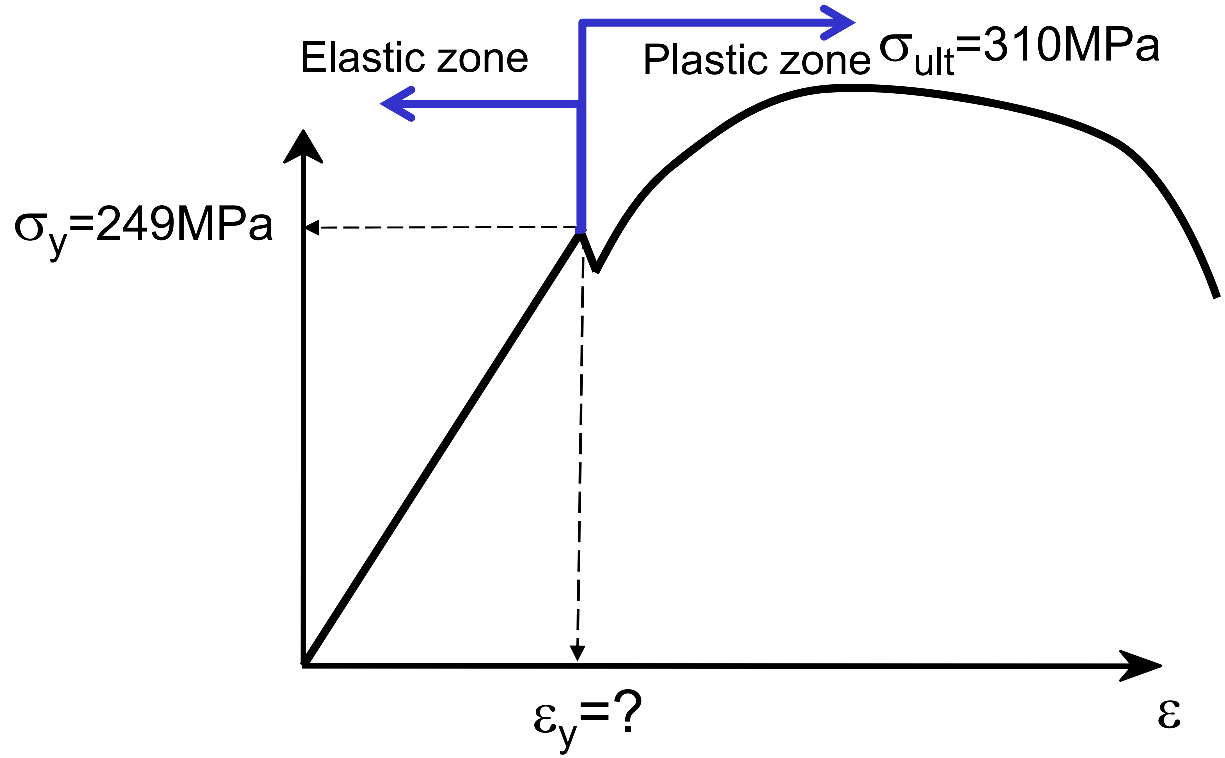
E=110 GPa

D_o=15.2 mm

L_o=380 mm

ΔL=1.9 mm





$$\varepsilon < \varepsilon_y \Rightarrow Elastic$$

$$\varepsilon > \varepsilon_y \Rightarrow Plastic$$

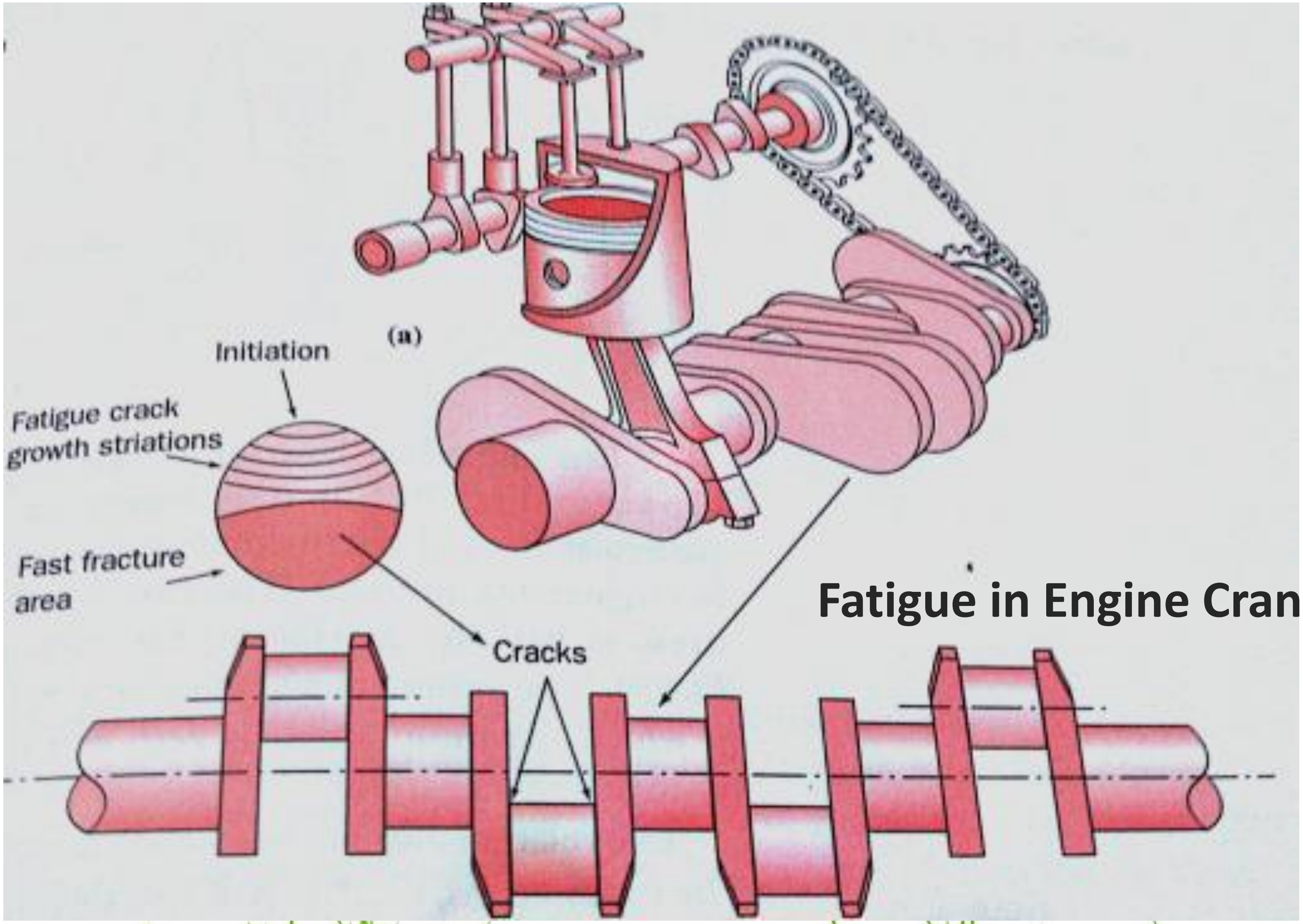
$$\varepsilon = \frac{\Delta l}{l_0} = \frac{1.9 \text{ mm}}{380 \text{ mm}} = 0.005$$

$$\varepsilon_y = \frac{\sigma_y}{E} = \frac{240 \text{ MPa}}{110 \times 10^3 \text{ MPa}} = 0.0022$$

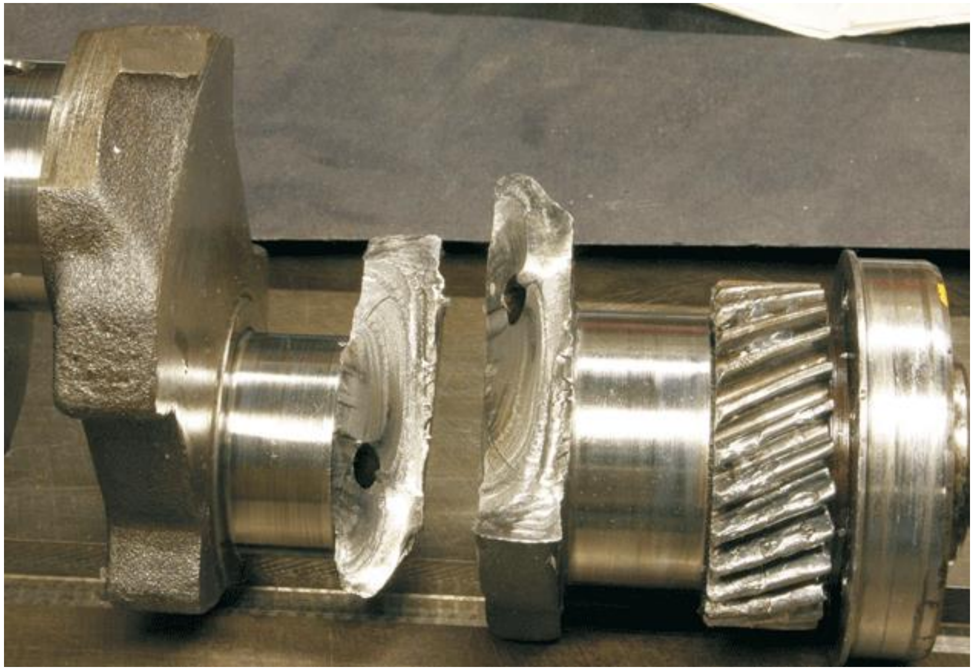
Therefore, computation of the load is not possible since $\varepsilon > \varepsilon_y$

FATIGUE FAILURE

Fracture Surface in a Fatigue failure:

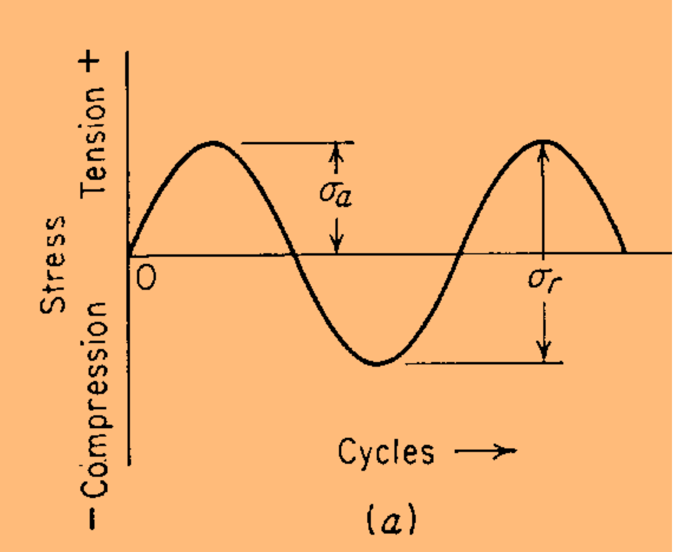


Fatigue in Engine Crankshaft

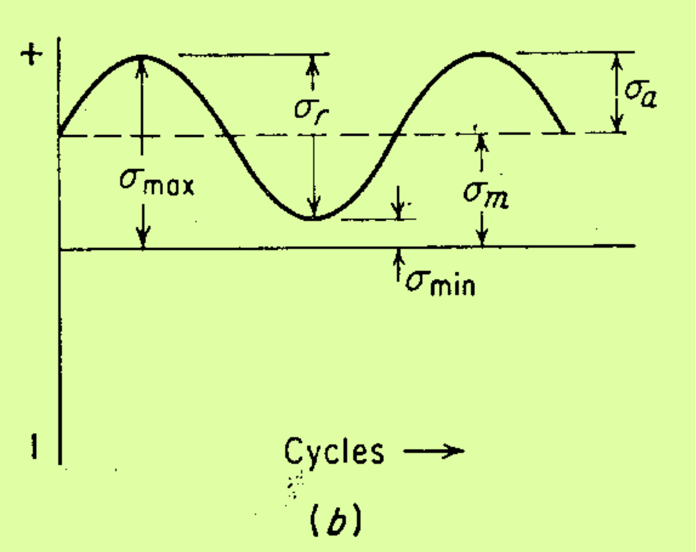


Types Of Fluctuating Stresses

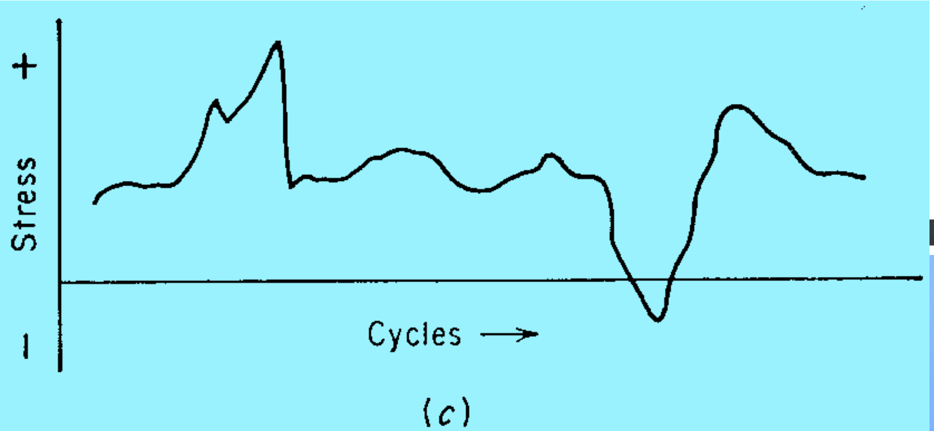
Reversed Stress cycle



Repeated Stress cycle



Random/irregular stress cycles



Stress Cycles in Fatigue

Mean Stress:

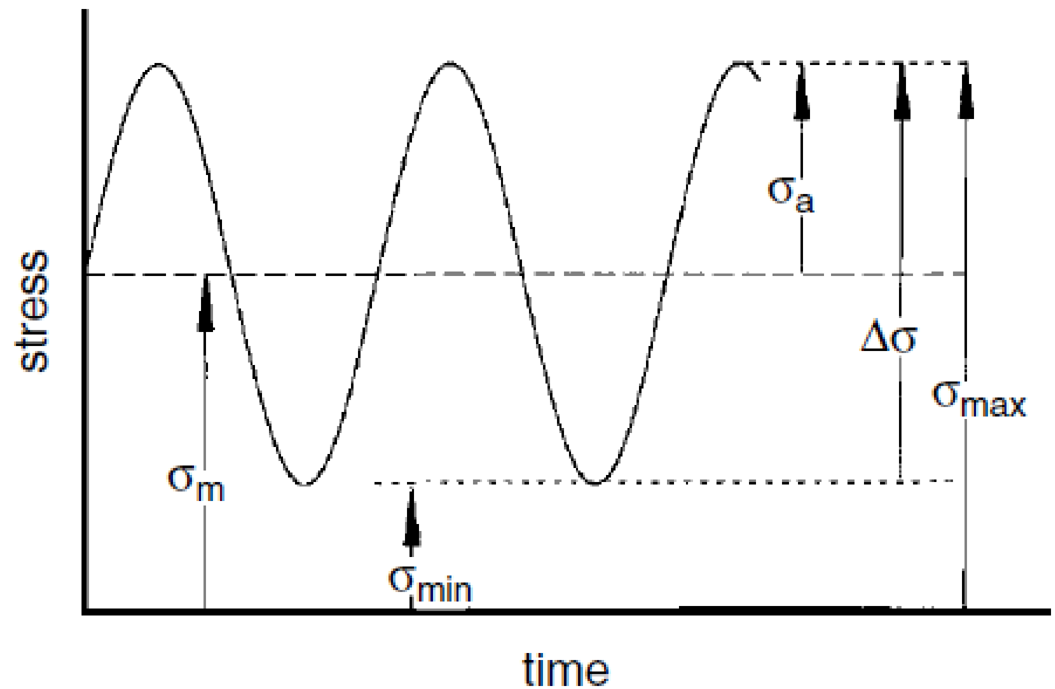
$$\sigma_m = (\sigma_{max} + \sigma_{min})/2$$

Amplitude Stress:

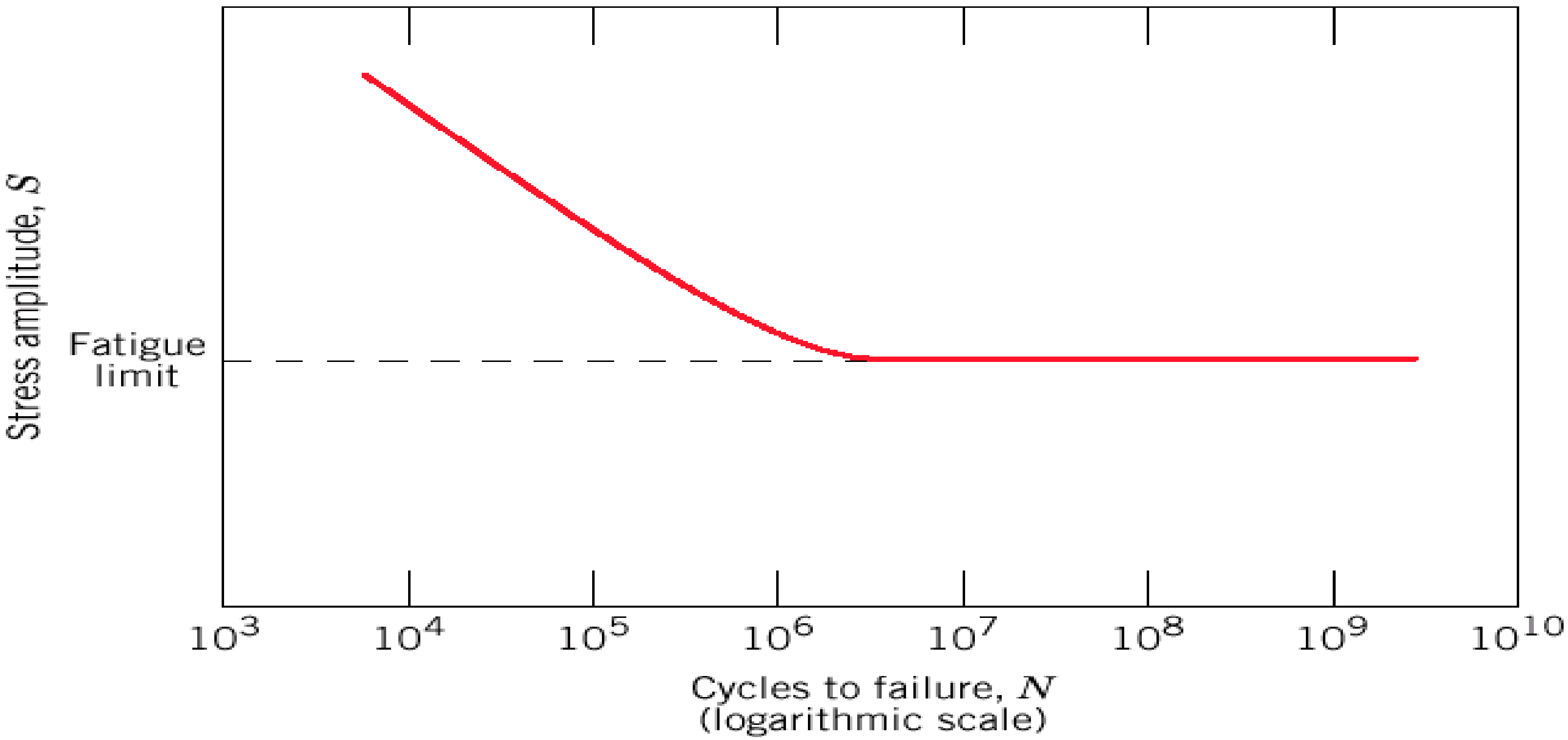
$$\sigma_a = (\sigma_{max} - \sigma_{min})/2$$

Ratio:

$$R = \sigma_{min}/\sigma_{max}$$



Fatigue: S—N curves (II)

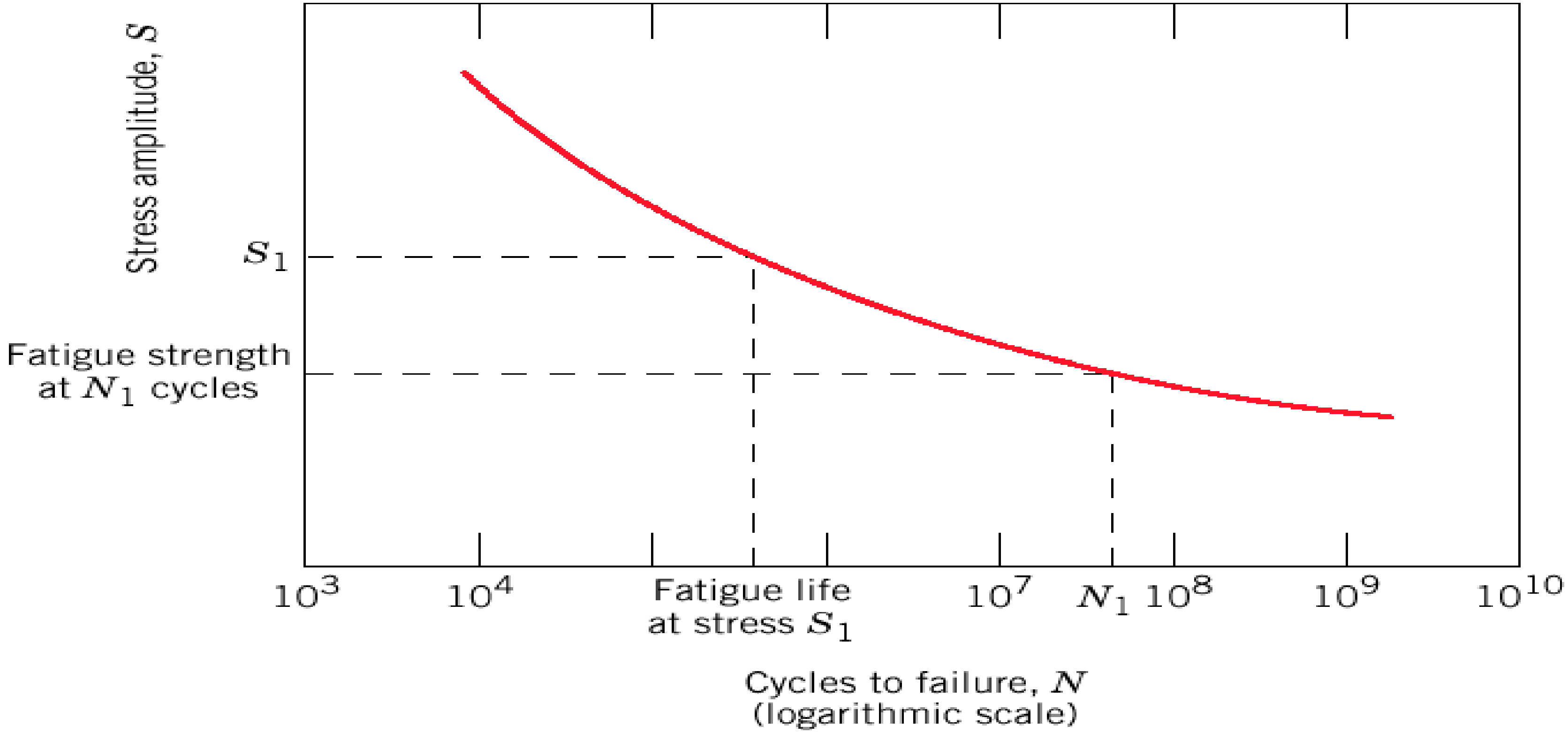


Fatigue limit (some Fe and Ti alloys)

S—N curve becomes horizontal at large N

Stress amplitude below which the material never fails, no matter how large the number of cycles is

Fatigue: S—N curves (III)



Most alloys: S decreases with N.

Fatigue strength: Stress at which fracture occurs after specified number of cycles (e.g. 10^7)

Fatigue life: Number of cycles to fail at specified stress level

8.16:A 6.4 mm diameter cylindrical rod fabricated from a 2014-T6 aluminum alloy is subjected to reversed tension-compression load cycling along its axis. If the maximum tensile and compressive loads are +5340 N and -5340 N respectively,

•determine its fatigue life. Assume that the stress plotted in Figure 8.34 is stress amplitude ?

•If the safety factor is 1.5, what would be the fatigue life ?

D=6.4 mm

F_{max}=+5340 N

F_{min}=-5340 N

Find N_f=?

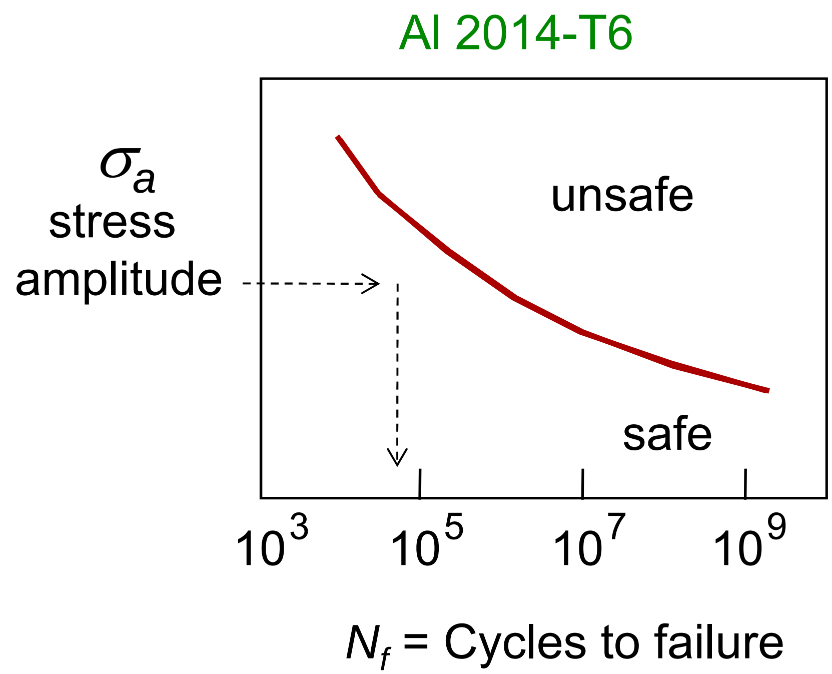
If safety factor is 1.5, Find N_f=?

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$\sigma_{max} = \frac{F_{max}}{A} = \frac{F_{max}}{\pi\left(\frac{d}{2}\right)^2}$$

$$= \frac{5340\ \text{N}}{(\pi)\left(\frac{6.4\ \text{x}\ 10^{-3}\ \text{m}}{2}\right)^2}$$

$$= 166\ \text{x}\ 10^6\ \text{N/m}^2 = 166\ \text{MPa}$$



$$\sigma_{min} = \frac{F_{min}}{A} = \frac{F_{min}}{\pi\left(\frac{d}{2}\right)^2} = \frac{-5340\ \text{N}}{(\pi)\left(\frac{6.4\ \text{x}\ 10^{-3}\ \text{m}}{2}\right)^2} = -166\ \text{x}\ 10^6\ \text{N/m}^2 = -166\ \text{MPa}$$

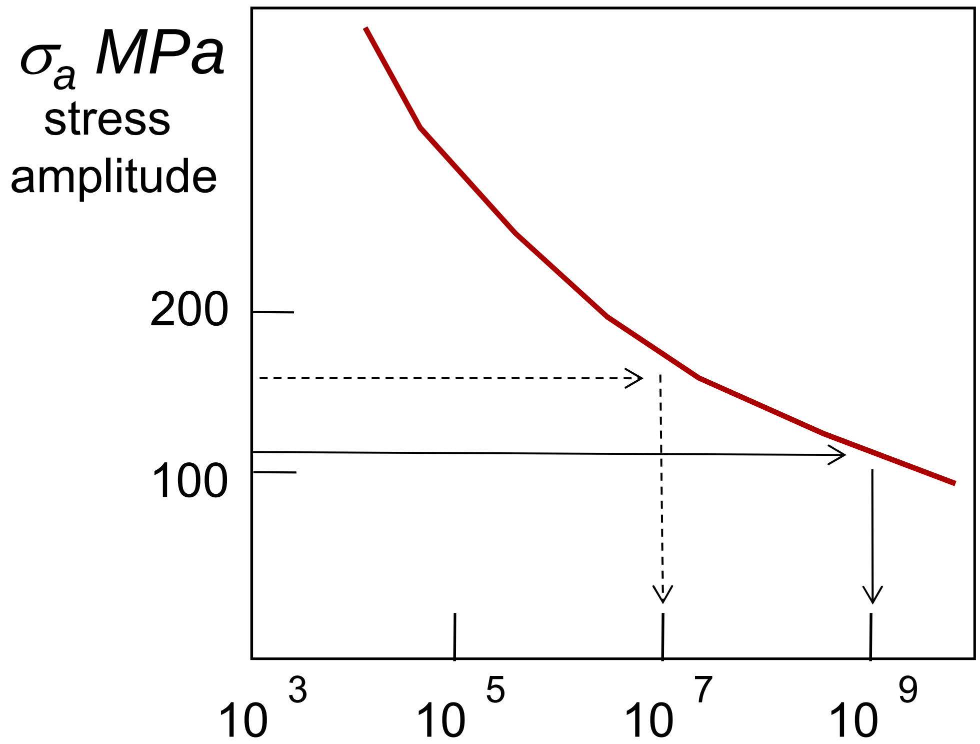
Al 2014-T6

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$= \frac{166 \text{ MPa} - (-166 \text{ MPa})}{2}$$

$$= 166 \text{ MPa}$$

$N_f=10^7$



N_f = Cycles to failure

If safety factor is used:

$$\sigma_w = \frac{\sigma_a}{N} = \frac{166MPa}{1.5} \approx 111MPa$$

$N_f=10^9$

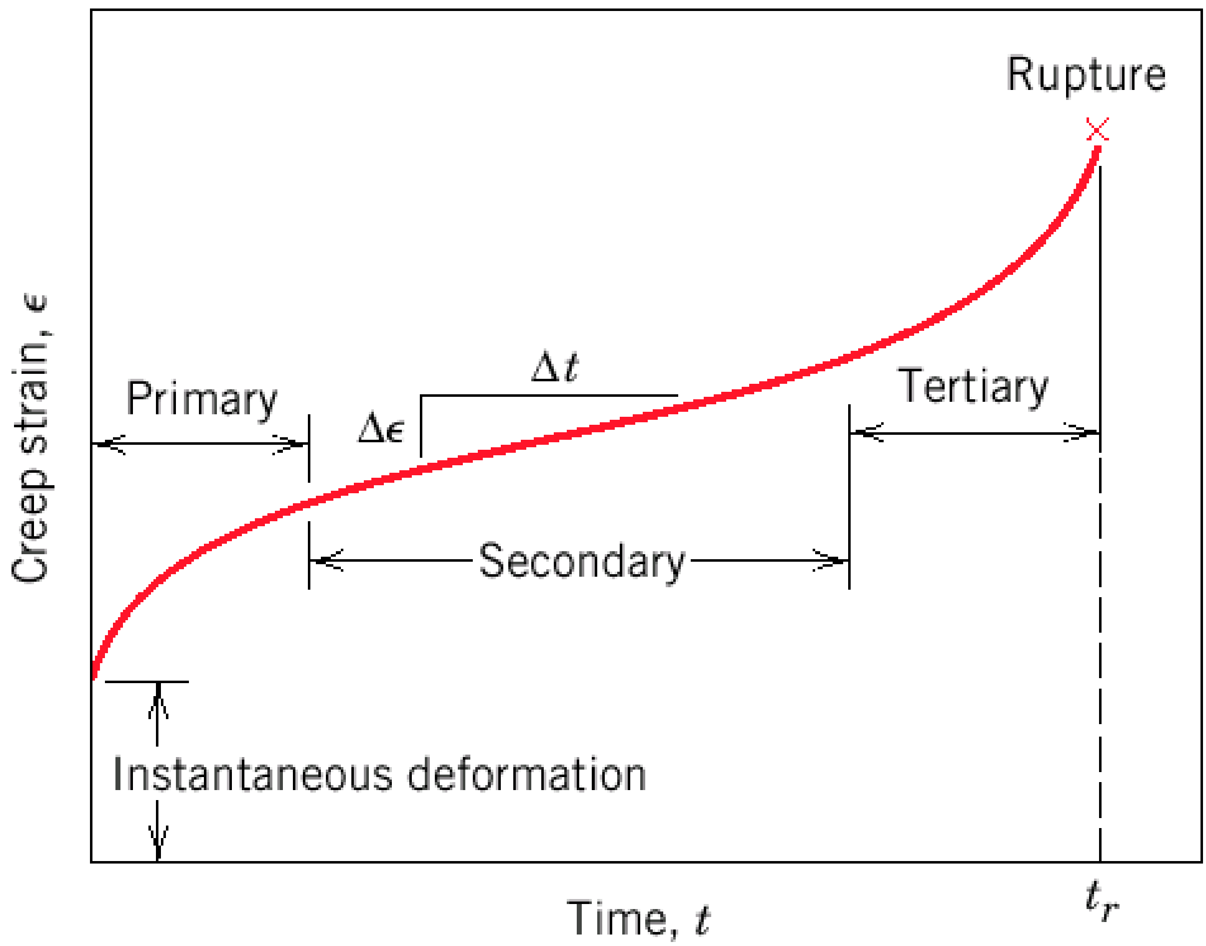
Creep

Time-dependent deformation due to constant load at high temperature

(> 0.4 T_m)

Examples: turbine blades, steam generators.

Stages of creep



1. **Instantaneous deformation, mainly elastic.**
2. **Primary/transient creep. Slope of strain vs. time decreases with time: work-hardening**
3. **Secondary/steady-state creep. Rate of straining constant: work-hardening and recovery.**
4. **Tertiary. Rapidly accelerating strain rate up to failure: formation of internal cracks, voids, grain boundary separation, necking, etc.**

Parameters of creep behavior

Secondary/steady-state creep:

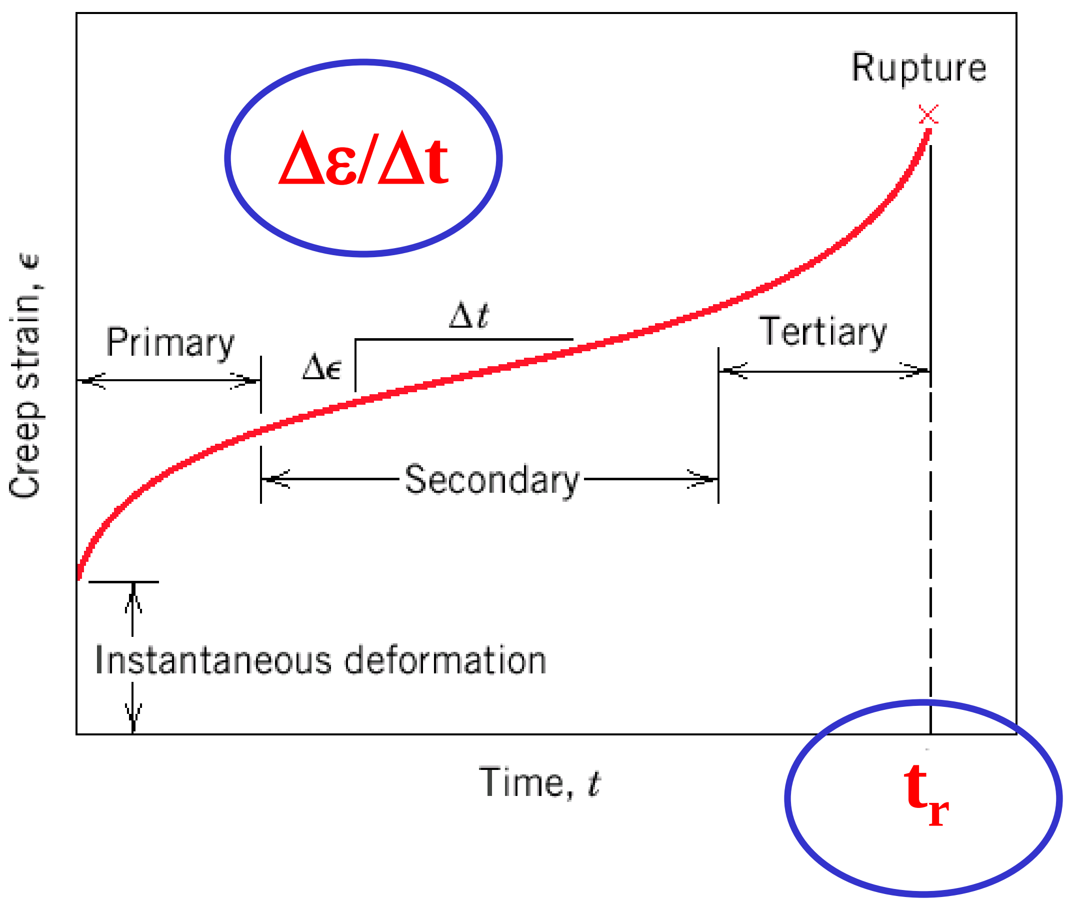
Longest duration

Long-life applications

$$\dot{\varepsilon}_s = \Delta\varepsilon / \Delta t$$

Time to rupture (rupture lifetime, t_r):

Important for short-life creep



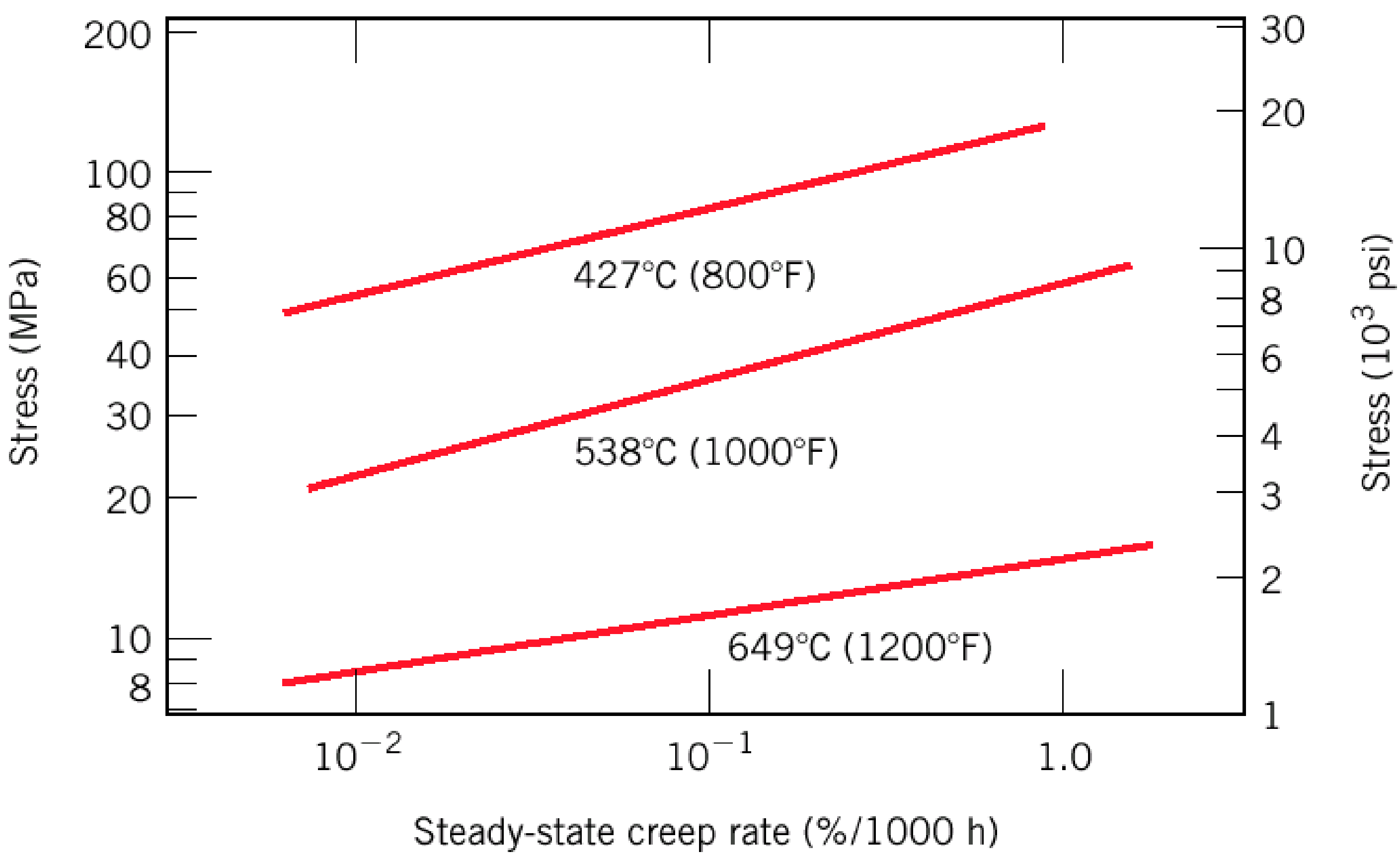
Creep: stress and temperature effects

Stress/temperature dependence of the steady-state creep rate can be described by

$$\dot{\varepsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

Q_c = activation energy for creep

K_2 and n are material constants



8.28: A specimen 1015mm long of a low carbon-nickel alloy is to be exposed to a tensile stress of 70MPa at 427^{o}C.

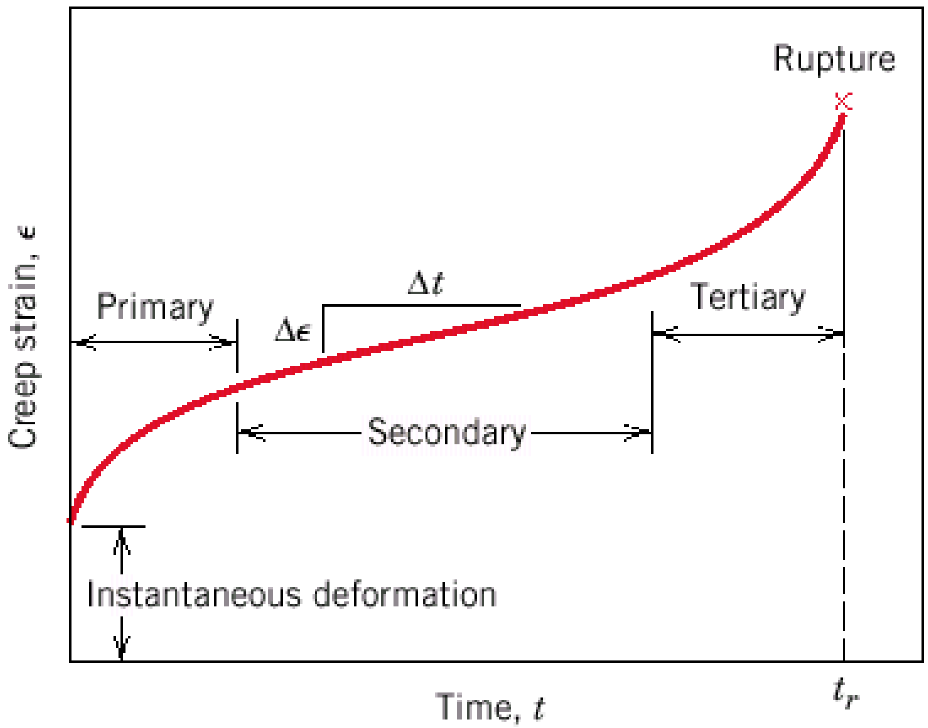
- Determine its elongation after 10,000h. Assume that the total of both instantaneous and primary creep elongation is 1.3mm.

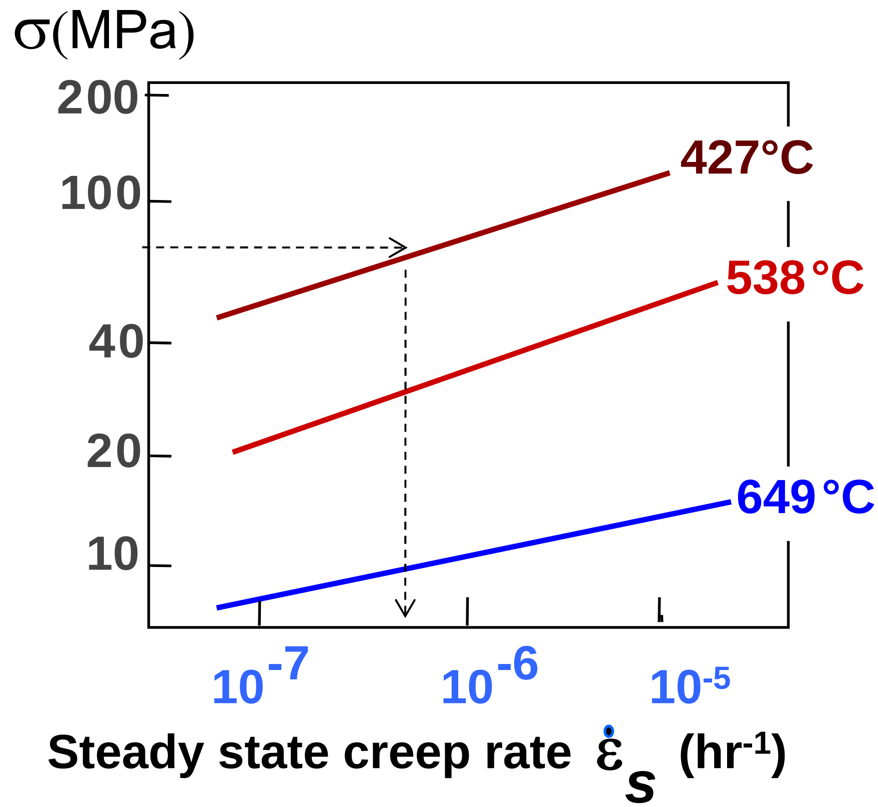
L=1015mm

σ=70 MPa

T=427^{o}C

Find ΔL after 10,000h?





ΔL=(Instaneneous+Primary)+Steady State (secondary)

Steady state strain rate $\varepsilon_s^{\bullet}$ = **4.7 x 10^{-7} /h at 70MPa and 427°C**

$$\varepsilon_s^{\bullet} = \frac{\varepsilon_s}{time} \Rightarrow$$

$$\varepsilon_s = \varepsilon_s^{\bullet}.time$$

$$= 4.7 \text{ x } 10^{-7} \text{ /h} * 10{,}000\text{h}$$

$$\therefore \varepsilon_s = 4.7 \text{ x } 10^{-3}$$

$$\Delta l_s = l_0 \, \varepsilon_s = (1015 \text{ mm})\left(4.7 \text{ x } 10^{-3}\right) = 4.8 \text{ mm}$$

ΔL=(Instaneneous+Primary)+Steady State (secondary)

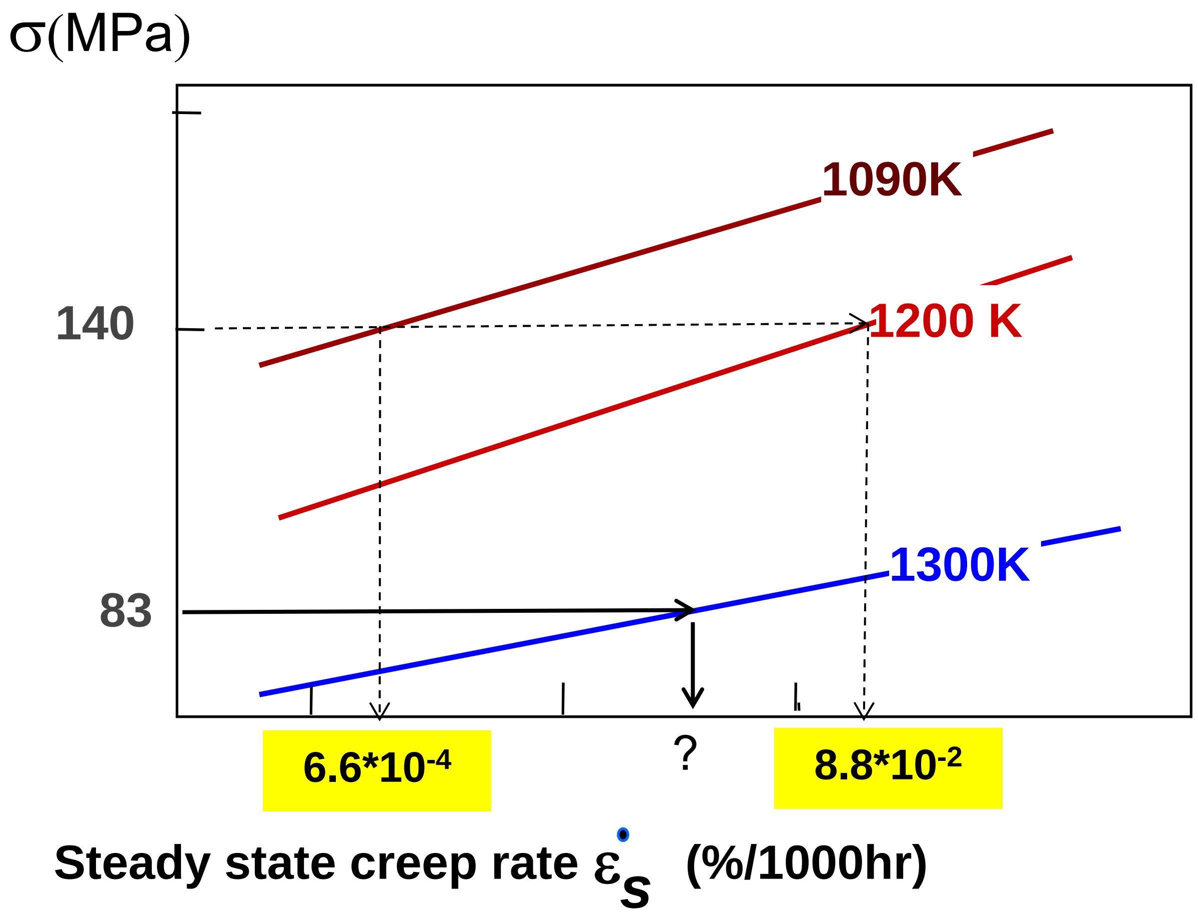
=1.3mm+4.8mm
=6.1mm

8.35: Steady-State creep data taken for an iron at a stress level of 140MPa are given below:

$\dot{\varepsilon}_s$ **(h^{-1})**	**T(K)**
$6.6*10^{-4}$	1090
$8.8*10^{-2}$	1200

•If it is known that the value of the stress component ***n*** for this alloy is 8.5, compute the Steady-State creep rate at 1300K and a stress level of 83MPa.

Find $\dot{\varepsilon}_s$ at 1300K and 83MPa


σ(MPa)
140
83
1090K
1200 K
1300K
6.6*10-4
?
8.8*10-2
Steady state creep rate $\dot{\varepsilon}_s$ (%/1000hr)

applied stress

stress exponent (material parameter)

$$\dot{\varepsilon}_s = K_2 \sigma^n \exp\left(-\frac{Q_c}{RT}\right)$$

strain rate

material const.

Gas constant 8.31J/mol-K

activation energy for creep (material parameter)

Temp.(K)

K_2, Q_c, n are constant for the same material

$$\left.\begin{aligned}\ln\left(6.6 \text{ x } 10^{-4} \text{ h}^{-1}\right) &= \ln K_2 + (8.5)\ln(140 \text{ MPa}) - \frac{Q_c}{(8.31 \text{ J/mol-K})(1090 \text{ K})} \\ \ln\left(8.8 \text{ x } 10^{-2} \text{ h}^{-1}\right) &= \ln K_2 + (8.5)\ln(140 \text{ MPa}) - \frac{Q_c}{(8.31 \text{ J/mol-K})(1200 \text{ K})}\end{aligned}\right\} \quad \begin{aligned} K_2 &= 57.5 \text{ h}^{-1} \\ Q_c &= 483{,}500 \text{ J/mol.}\end{aligned}$$

$$\therefore \dot{\varepsilon}_s = \left(57.5 \text{ h}^{-1}\right)(83 \text{ MPa})^{8.5} \exp\left[-\frac{483{,}500 \text{ J/mol}}{(8.31 \text{ J/mol-K})(1300 \text{ K})}\right]$$

$$\dot{\varepsilon}_s = 4.31 \text{ x } 10^{-2} \text{ h}^{-1}$$