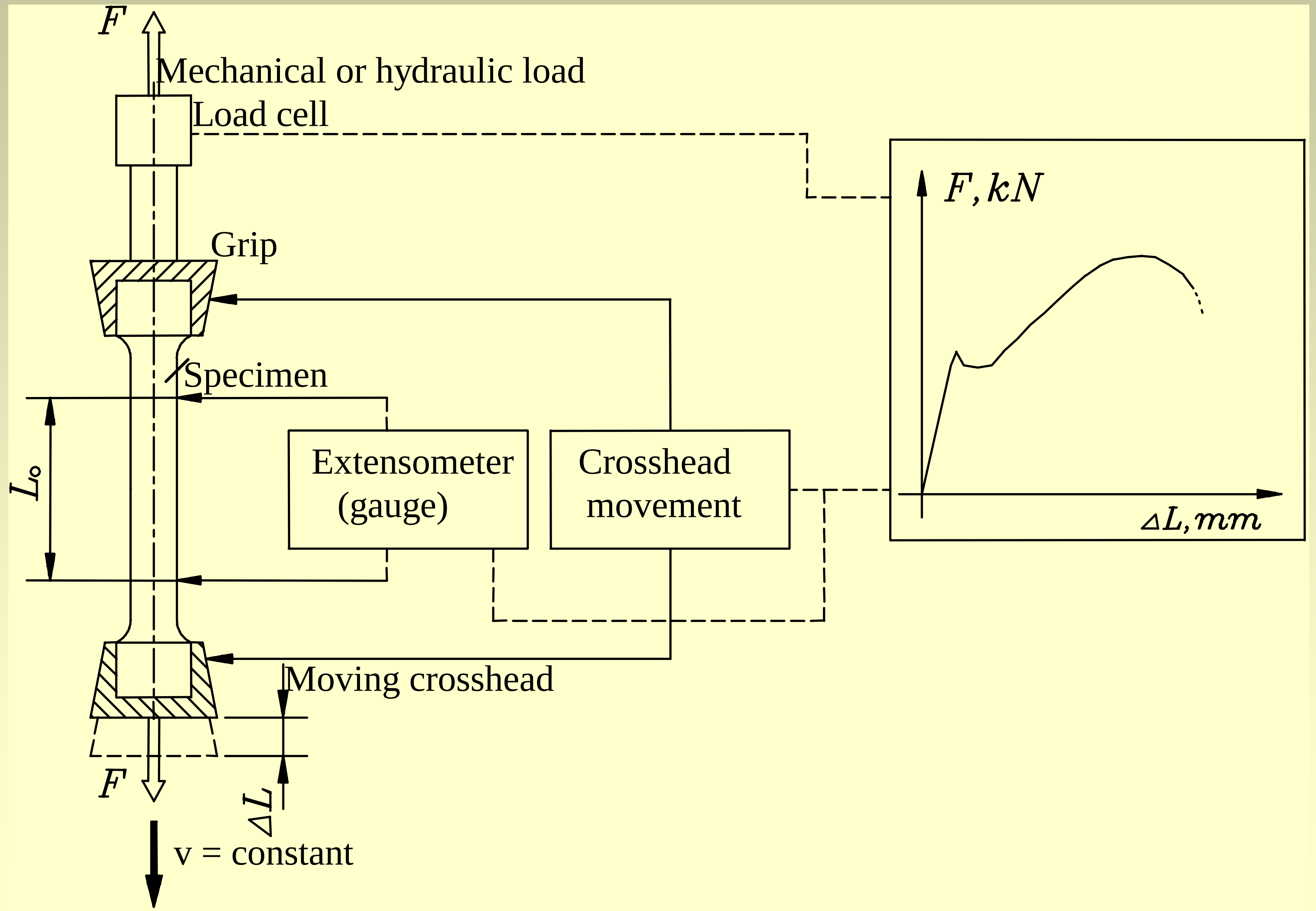
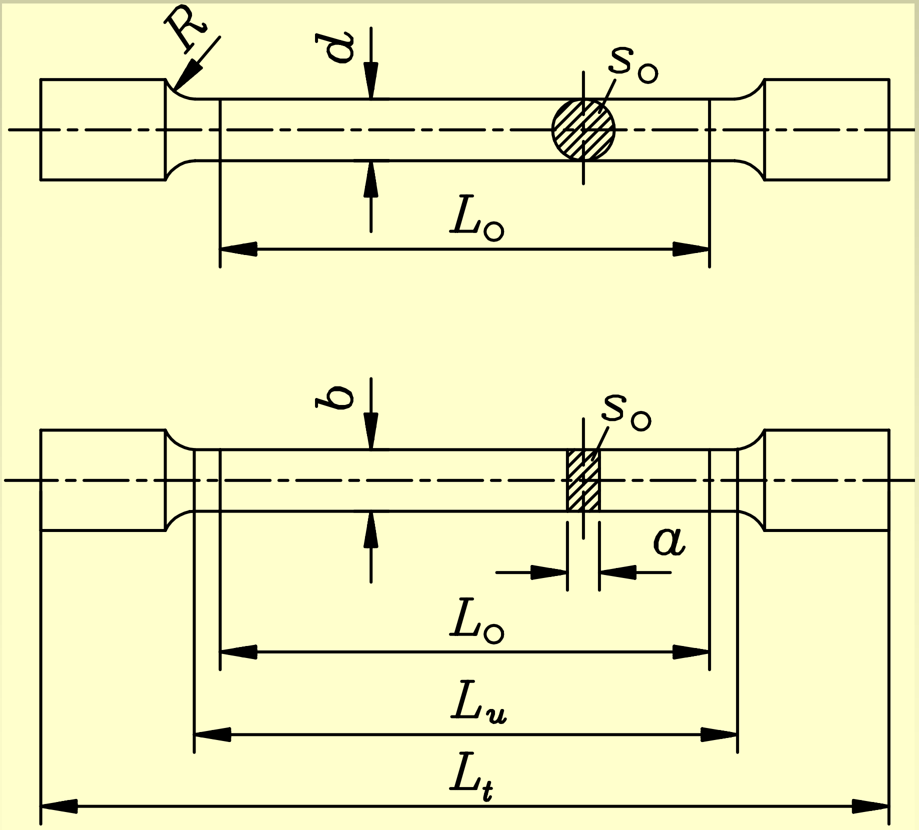
Mechanical Testing 1

- to determine if the material meets specification
- to establish design parameters
- to evaluate the effects of processing variables

Tensile (tension) test



Tensile specimen



General geometry

$$L_O = 5 \cdot d_O$$

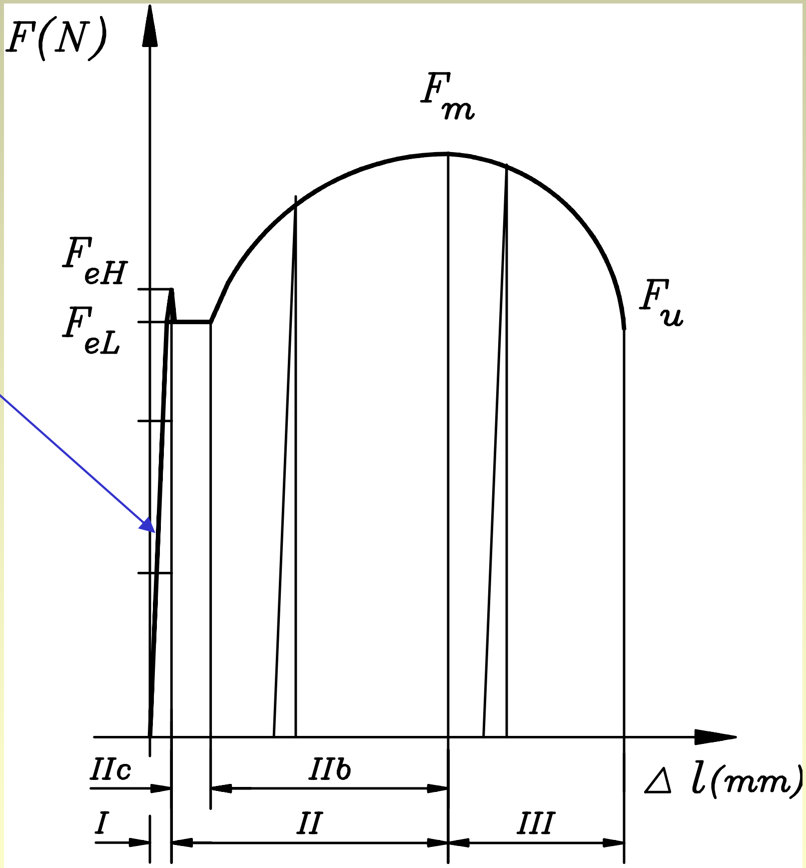
$$L_O = 10 \cdot d_O$$

Tensile specimens


Tensile diagram (1)

I. stage

Elastic deformation



σ = E * ε (Hook's law), where

σ - stress,

E - elastic (Young's) modulus

ε - strain.

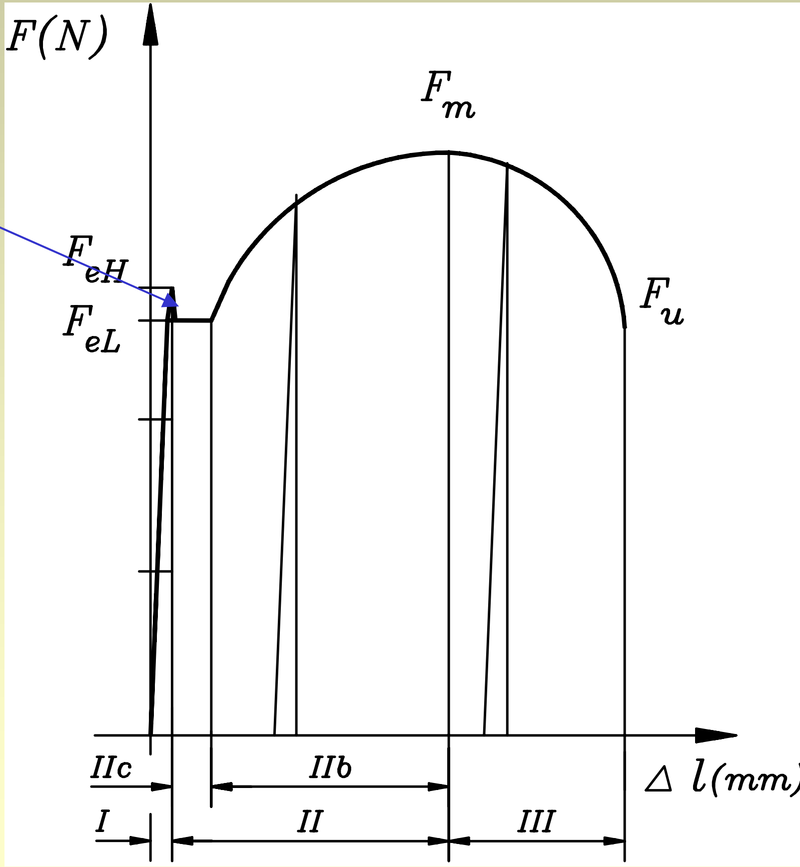
Tensile diagram (2)

II.a. stage

yielding

starts at $\mathbf{F_{eH}}$ force

start of plastic deformation

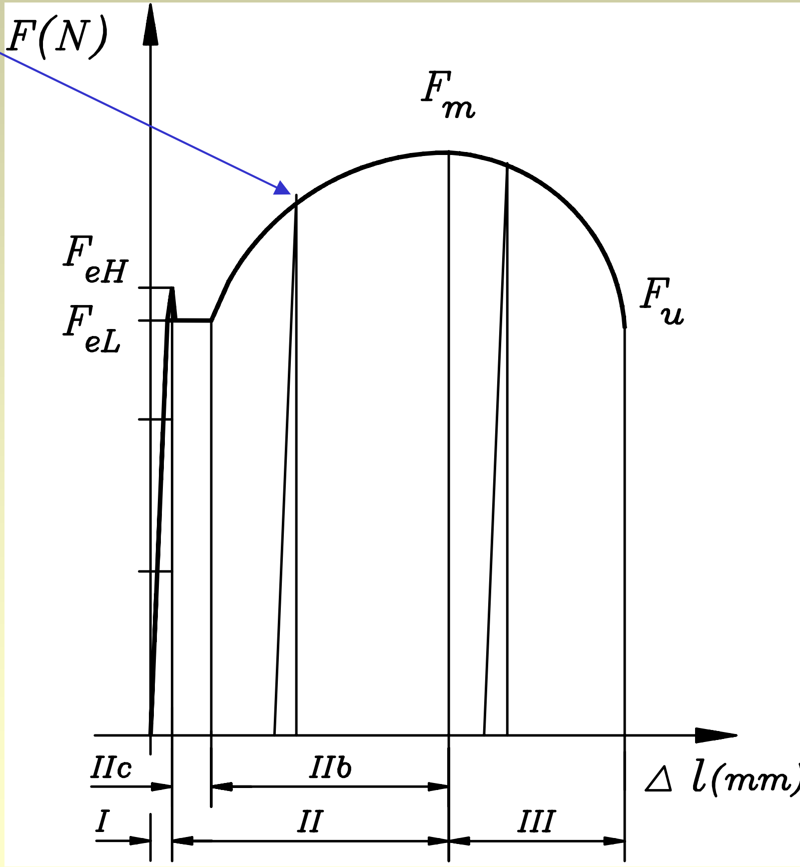


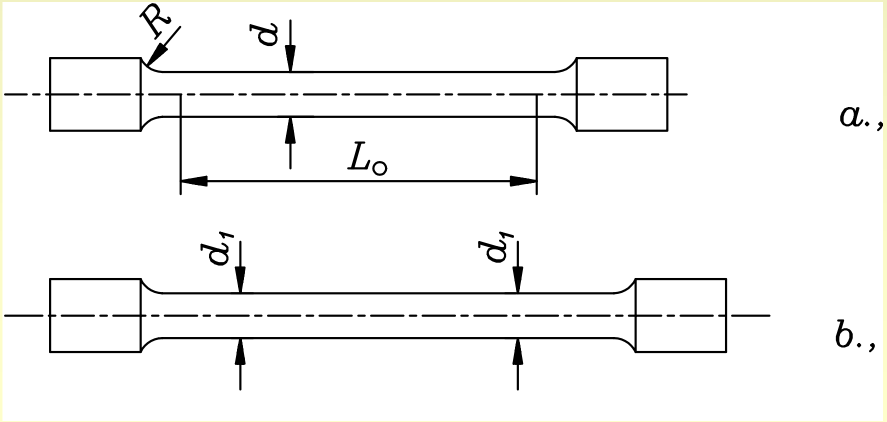
Tensile diagram (3)

II.b. stage

uniform plastic deformation

strain hardening(!)



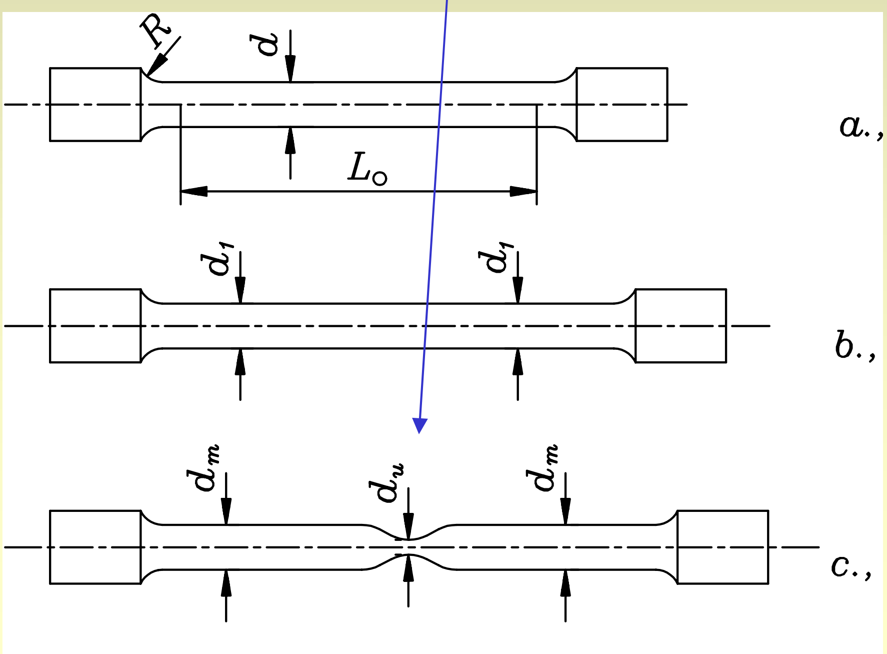


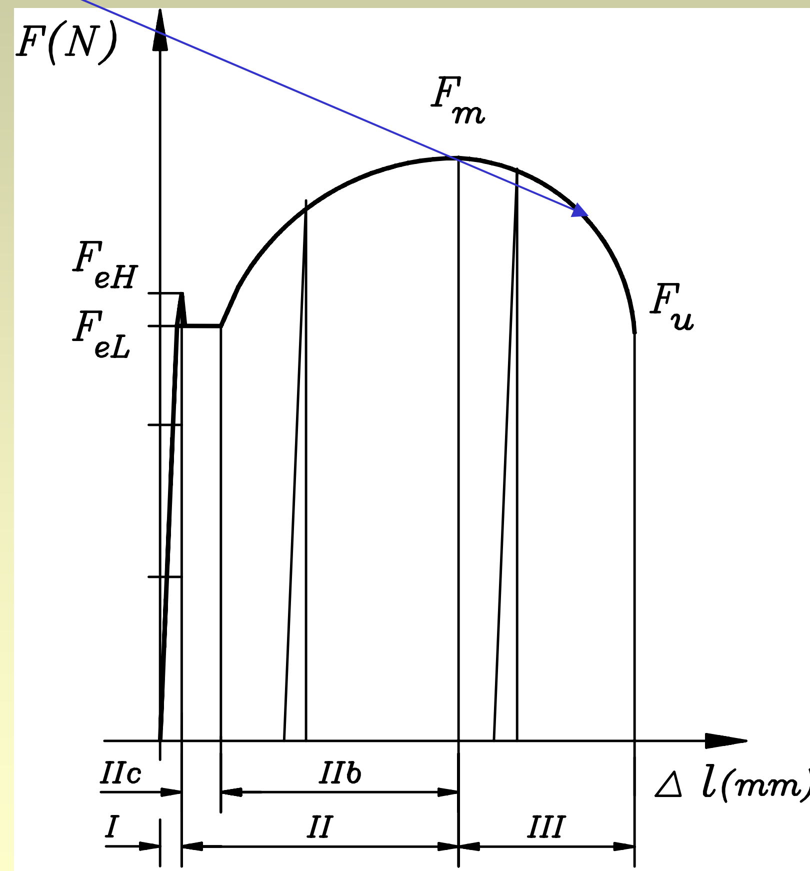
Tensile diagram (4)

III. stage

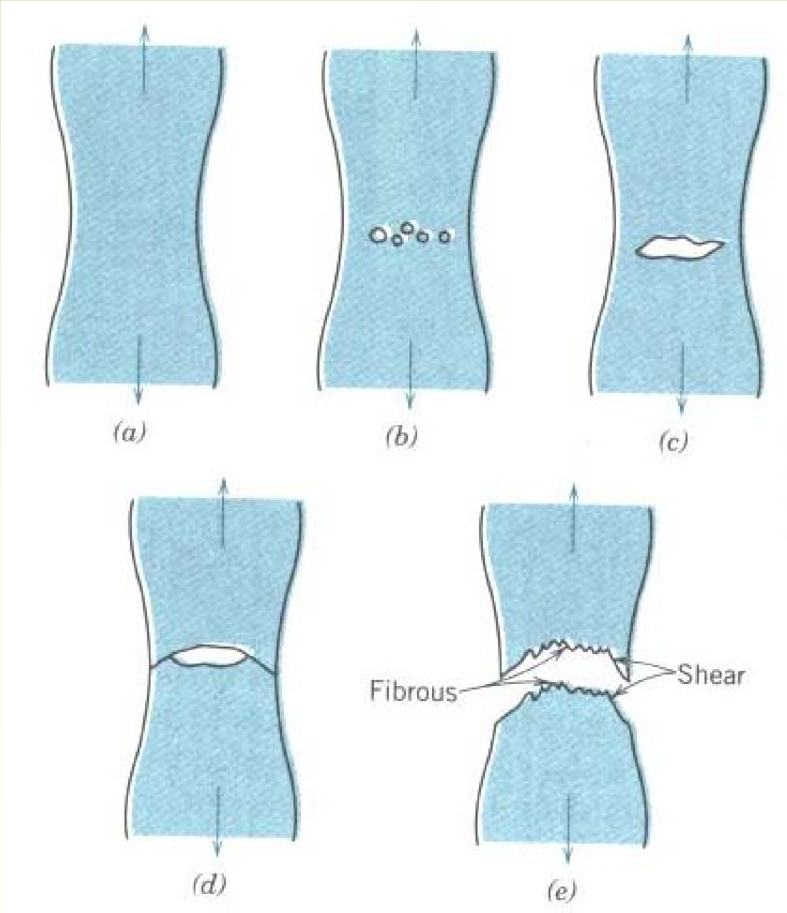
Necking

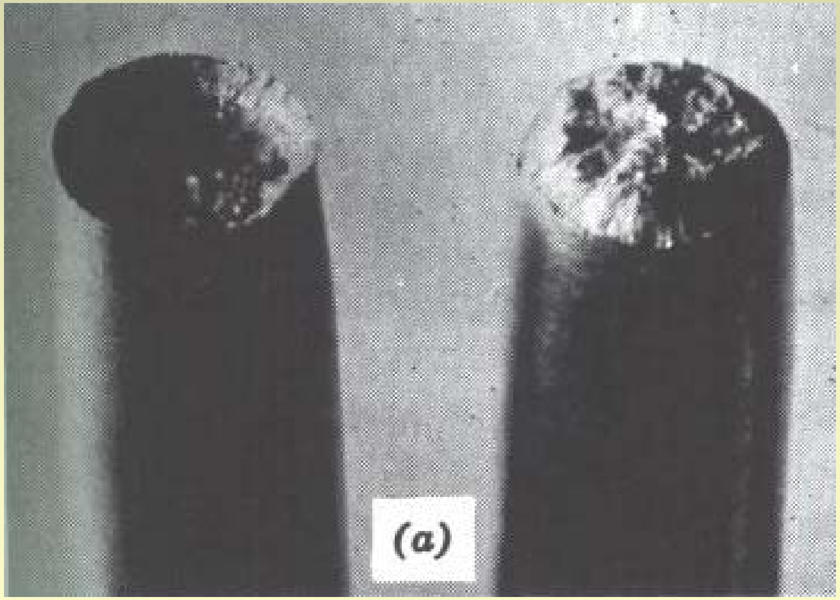
the strain becomes localised to a small volume only





The process of rupture





Calculation of material properties:

Engineering system

Force and elongation is divided with the **original** cross section and gauge length

stress : $\sigma = F/ S_o$

strain, specific elongation : $\varepsilon = \Delta L/L_o$

where

F - force

S_o – **original** cross section

L_o – **original** gauge length

ΔL – length difference

Calculation of material properties:

Real system

Force and elongation is divided with the
actual cross section and gauge length

stress: $$\sigma' = \frac{F}{S}$$

strain: $$d\varphi = \frac{dL}{L}$$

integrating the equation: $$\varphi = 2\ln\frac{L_0}{L}$$

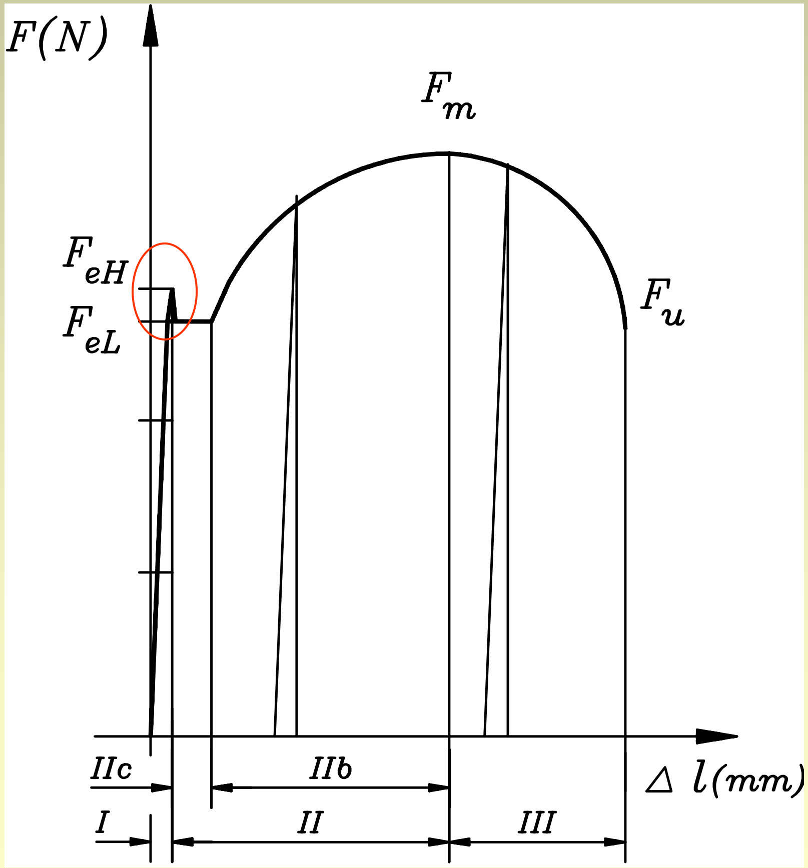
F –	force
S –	actual cross section
dL –	actual length difference
d_o –	original diameter
d –	actual diameter
φ –	logarithmic strain

Material properties: Yield strength

$$R_{eH} = \frac{F_{eH}}{S_o}$$

Stress at yielding

N/mm²

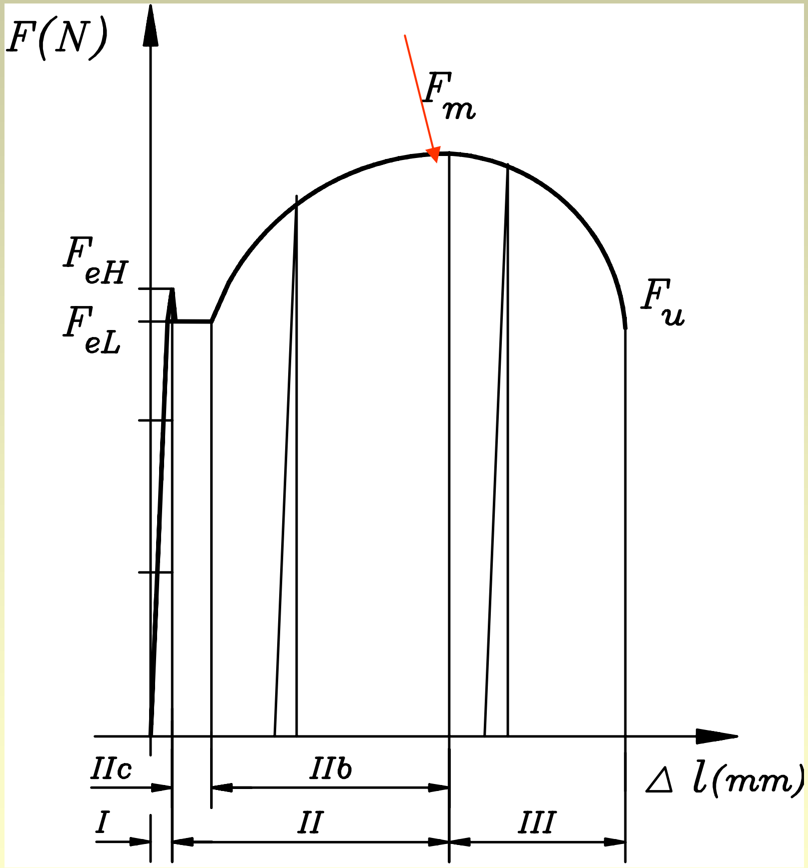


Material properties: Tensile strength

$$R_m = \frac{F_m}{S_o}$$

Ultimate tensile strength (UTS or TS) is a measure of the maximum load that a material can whitstand.

N/mm^2



Material properties:
Measure of ductility

- Elongation, A %

change in length/initial length

$$A = \frac{L_u - L_o}{L_o} 100 \quad \%$$

Material properties: **Measure of ductility**

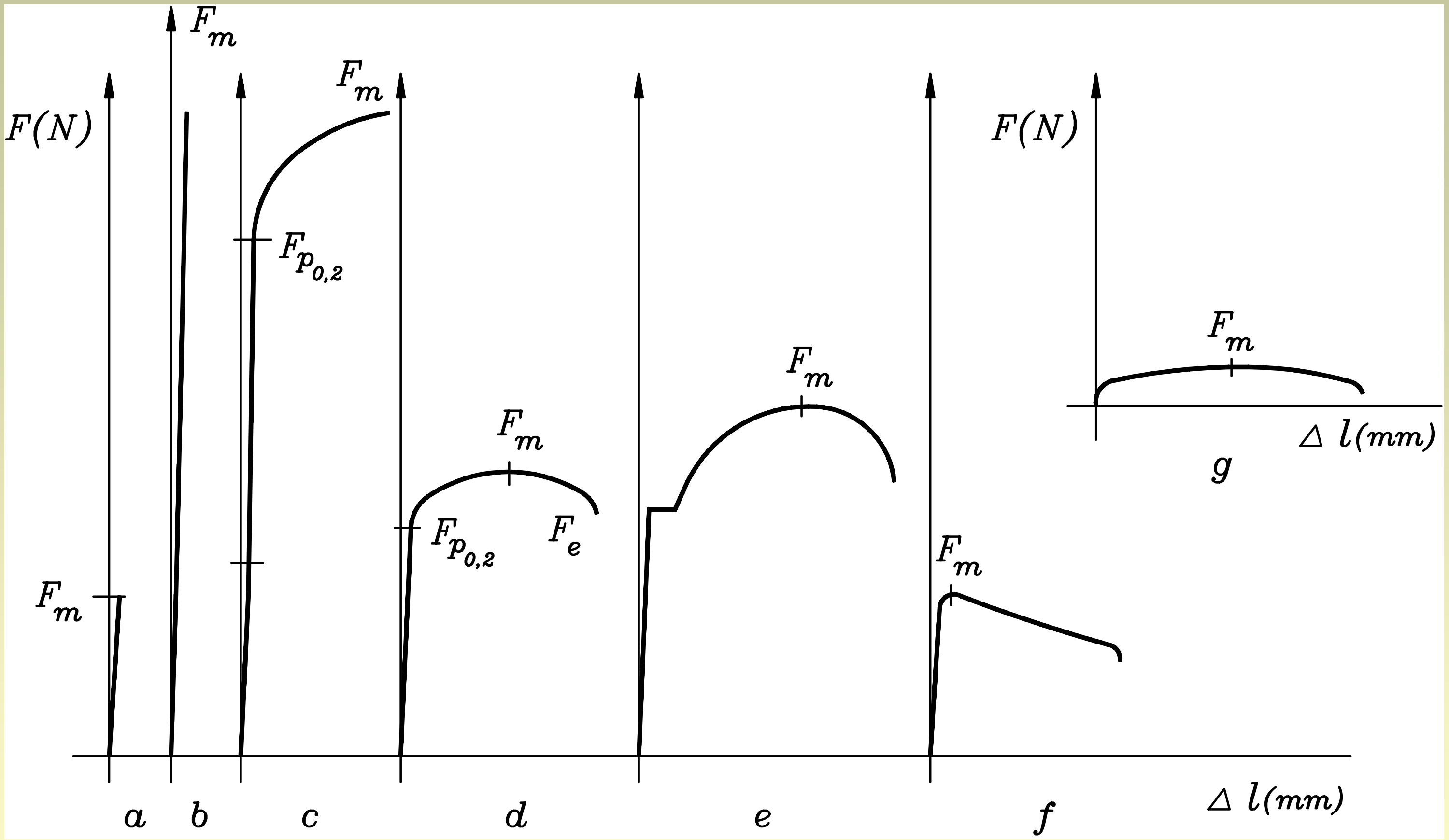
- Reduction in area, Z

  %

change in cross section/initial cross section

$$Z = \frac{S_o - S_u}{S_o} 100\%$$

Yield strength – Proof strength



If characteristic yielding can not be observed, we calculate proof stress as: **stress at a given elongation** (e.g. 0,2%)

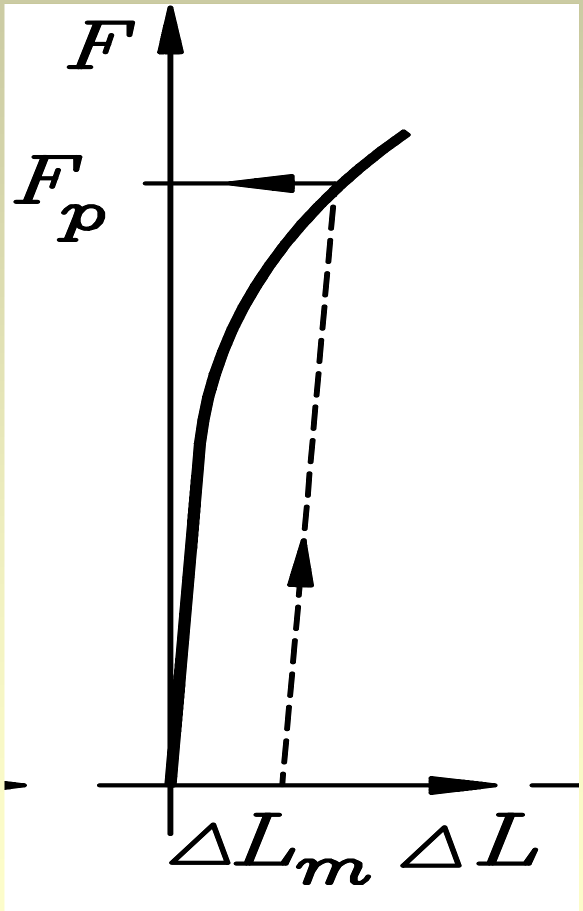
Proof strength

Stress required to produce a small amount of plastic deformation :

$$R_{p0,2} = \frac{F_{p0,2}}{S_o} \quad [N/mm^2]$$

specified value of strain offset:

usually 0,2 % of gauge length



Extensometer for proof strength determination

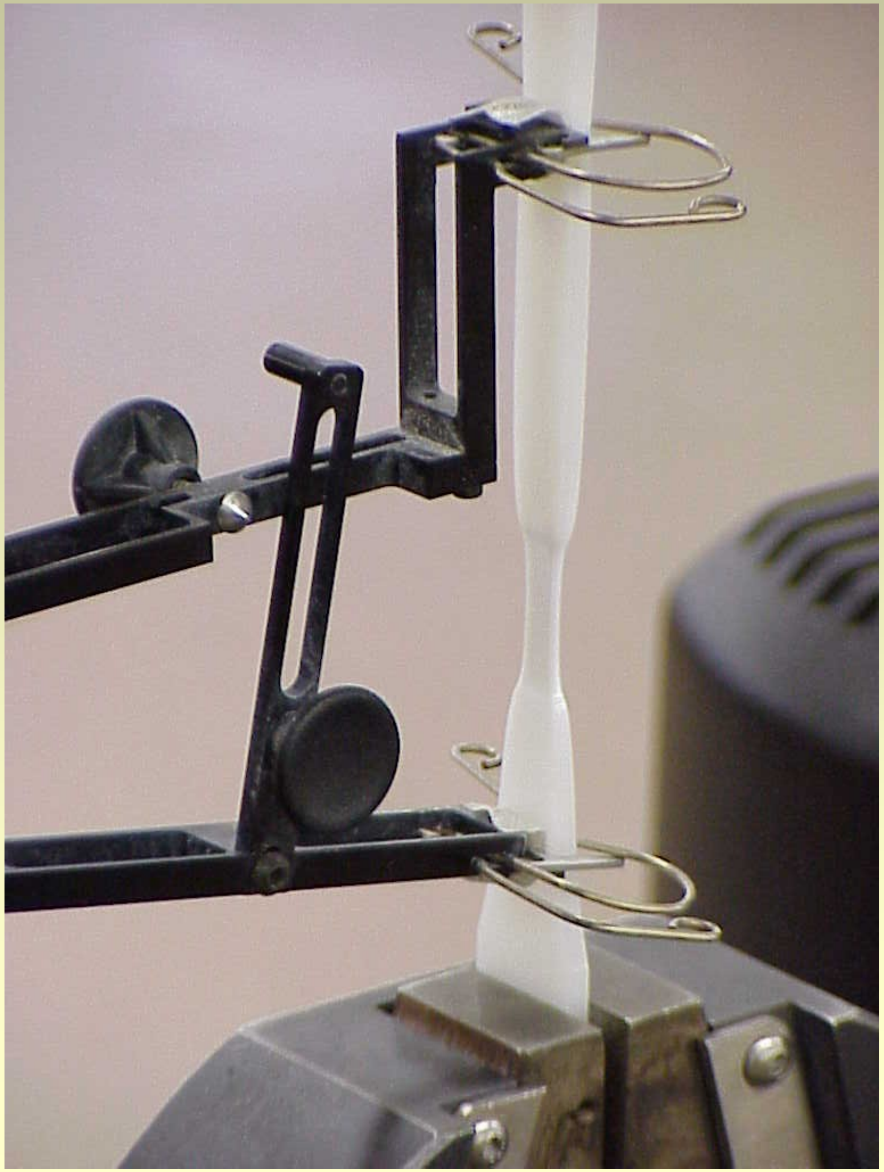
Tensile test machine

Load capacity: 100 kN

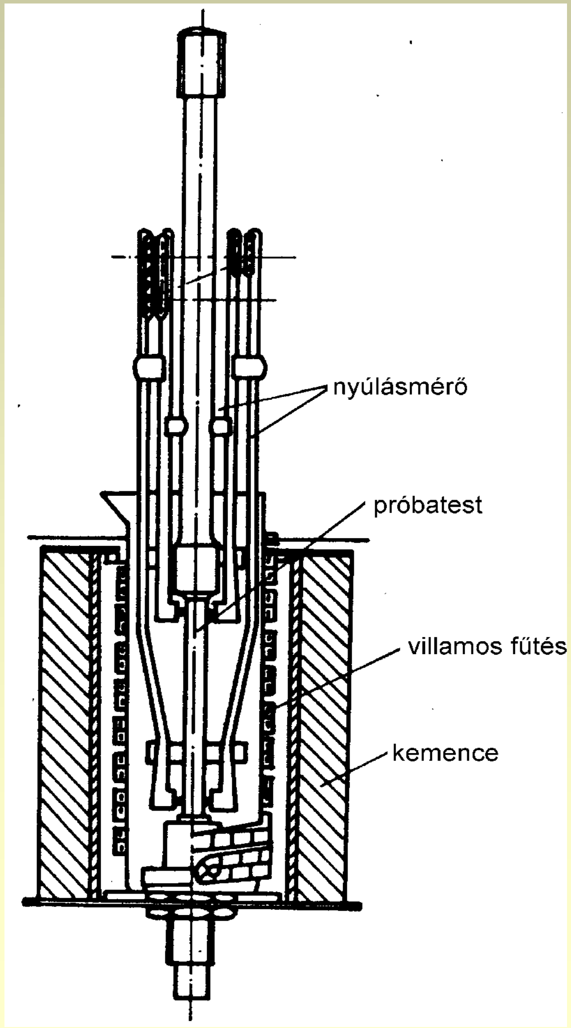
Elongation measurement with optical extensometer

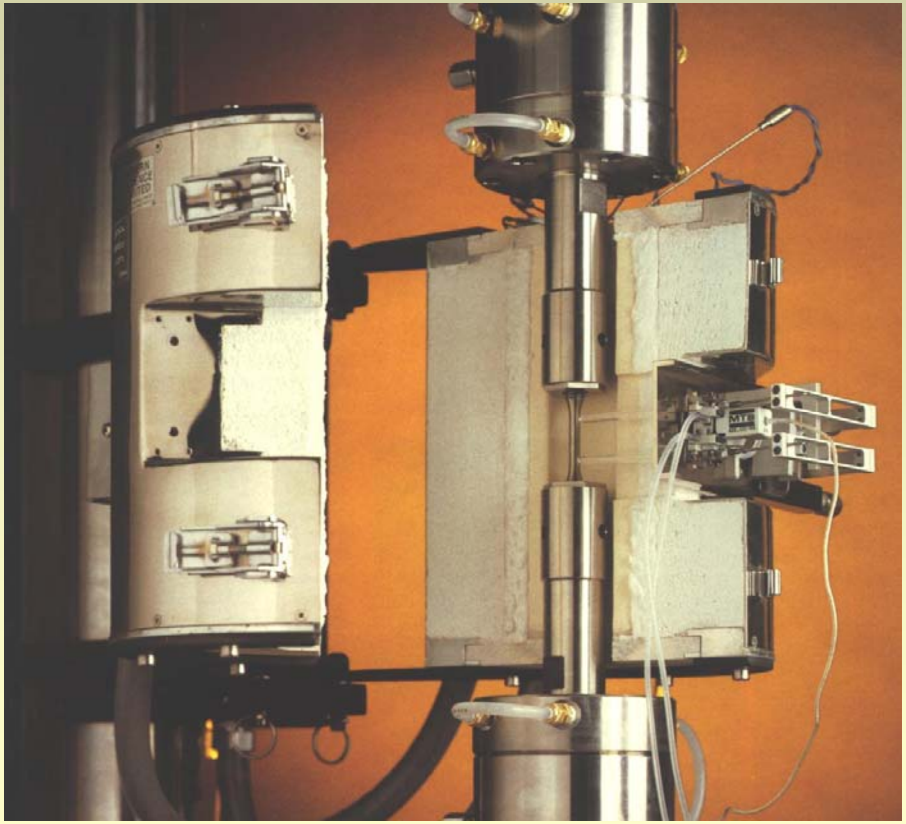
Automated evaluation of stress, strain, anisotropy, etc.

Tensile test machine: testing of polymers

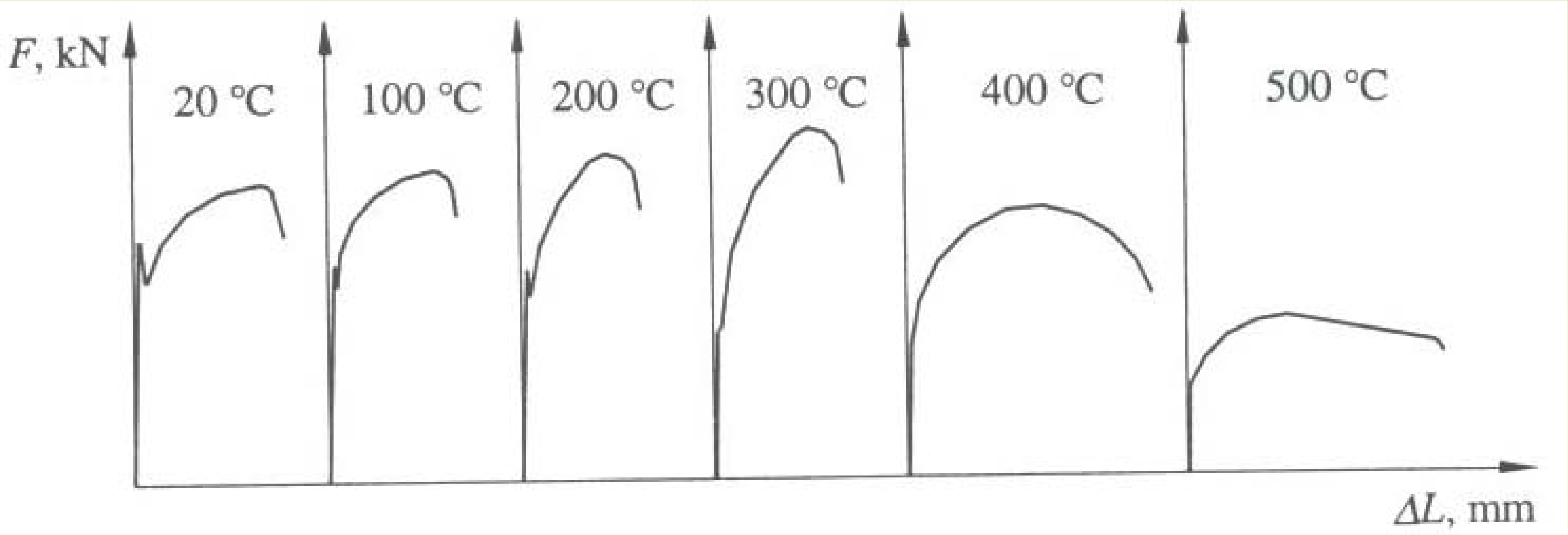


Tensile test at elevated temperature





Tensile diagrams of steel at elevated temperatures



Factors affecting the results of tensile test

specimen geometry, surface roughness

the rate of increase of load

testing conditions, ie. temperature

Hardness test

simple, short time

„non-destructive”

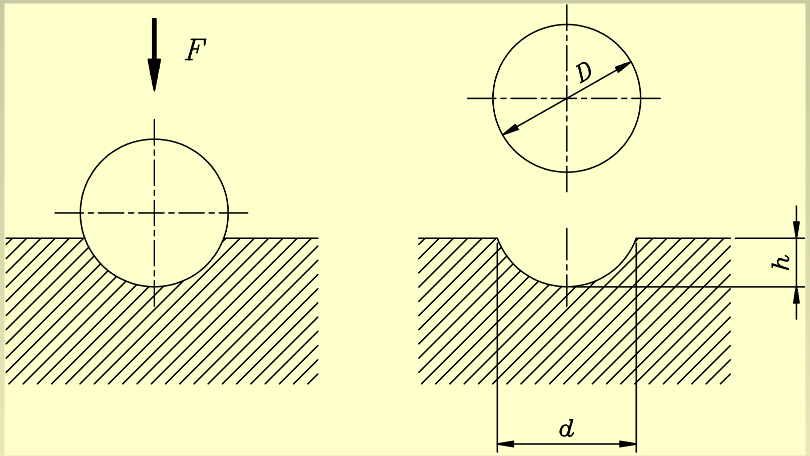
charaterises the mechanical parameters

fits to the technological line

- Indentation hardness tests (Brinell, Vickers, Rockwell)
- Rebound or dynamic tests

Brinell hardness test

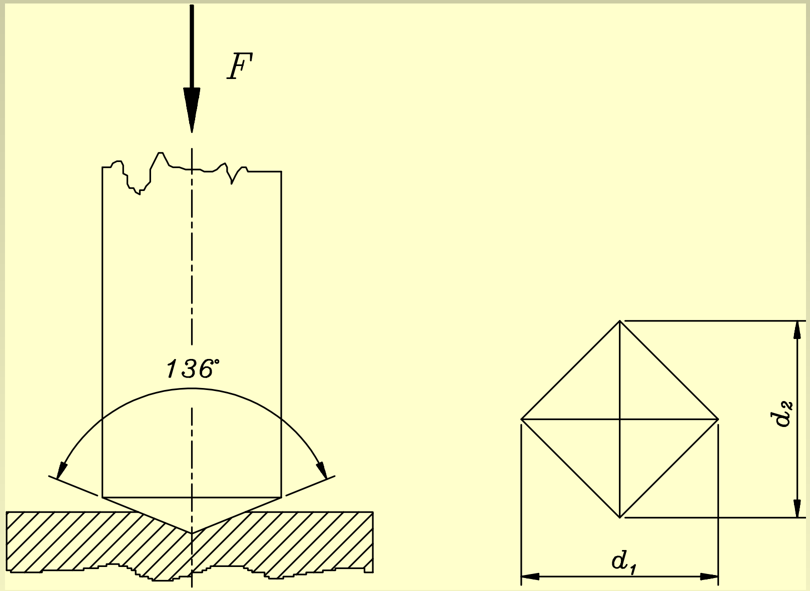
- Ratio of force (F) and the surface of indentation (A)
- Indentor: steel or tungsten carbide ball
- HB, depends on the force and on the ball diameter!
- No unit of measure!
- Standardized, table
- Used for castings, forgings, heavy sections



$$HB = \frac{0{,}102 \cdot F}{A} = \frac{0{,}102 \cdot 2F}{D\pi\left(D - \sqrt{D^2 - d^2}\right)}$$

Vickers hardness test

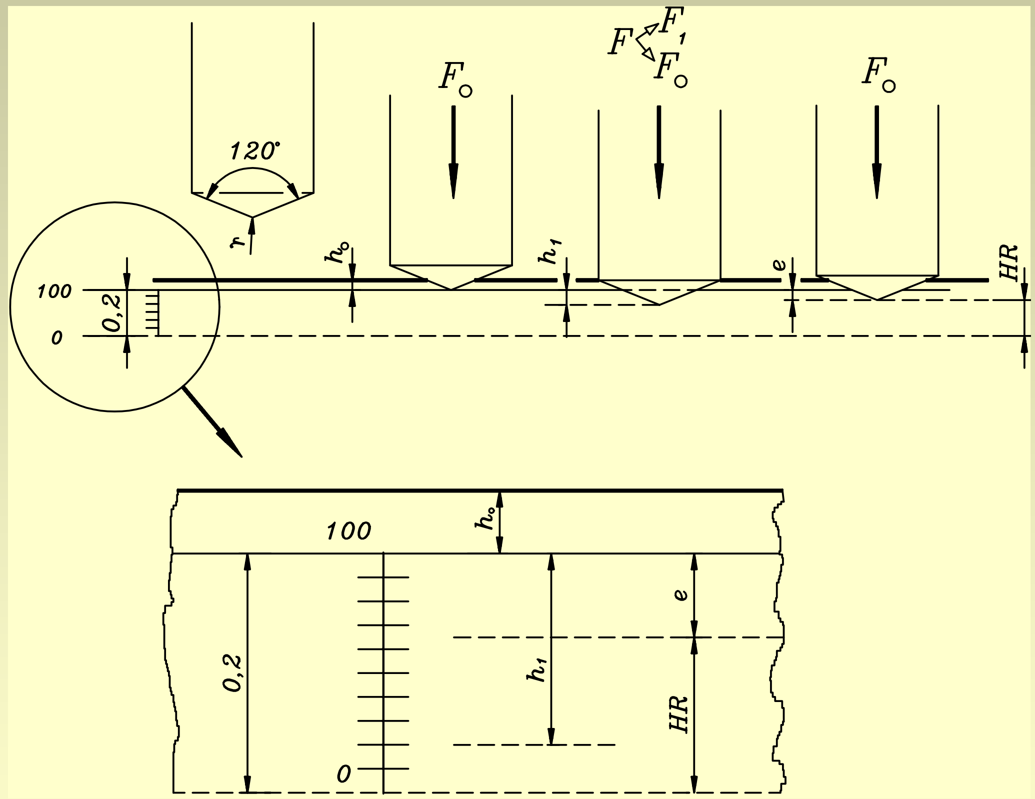
- Ratio of force and the surface of indentation
- Indentor: diamond pyramid
- HV, more or less undependent on the force, No unit of measure!
- Standardized, table evaluation
- Used for accurate measuring, hardness distribution, microhardness!



$$HV = 0{,}102 \cdot 1{,}854 \cdot \frac{F}{d^2}$$

Rockwell hardness test

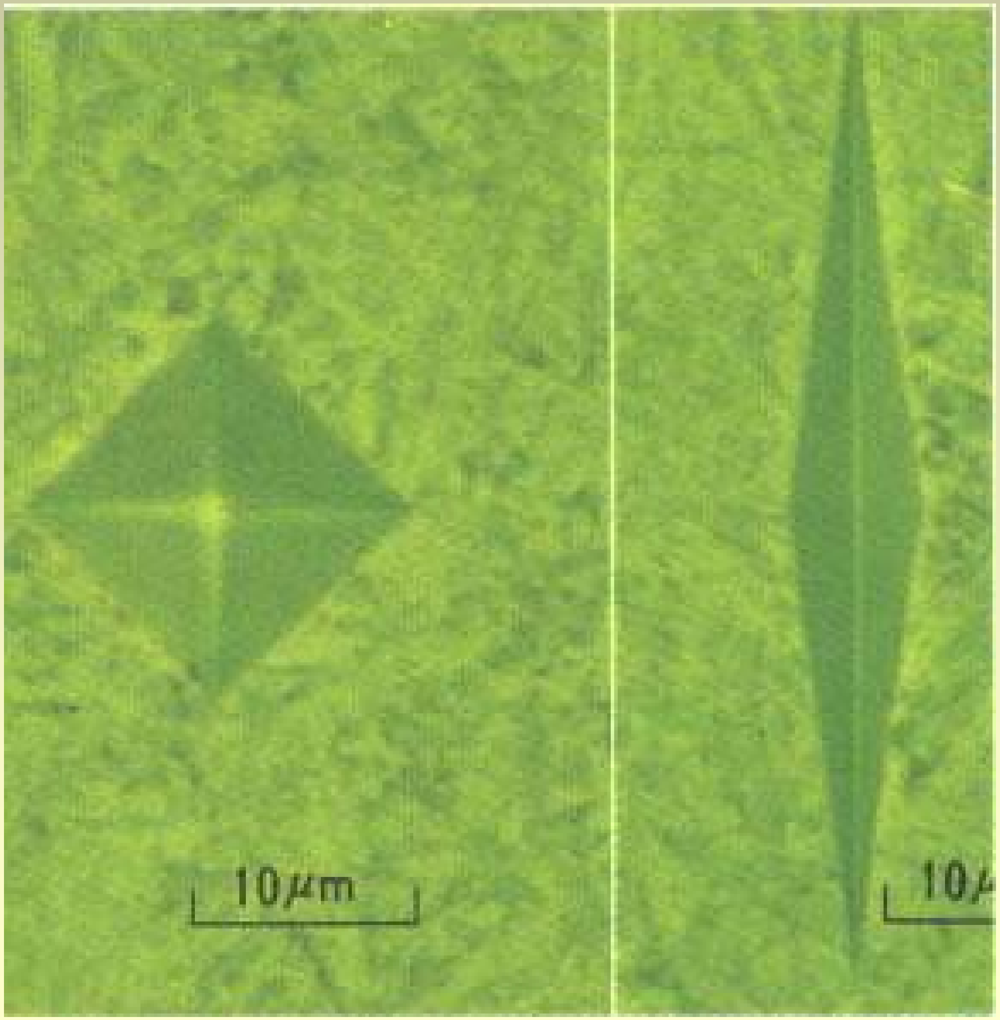
- diamond cone
- pre-load
- main-load
- pre-load
- HRC – depth of indentation



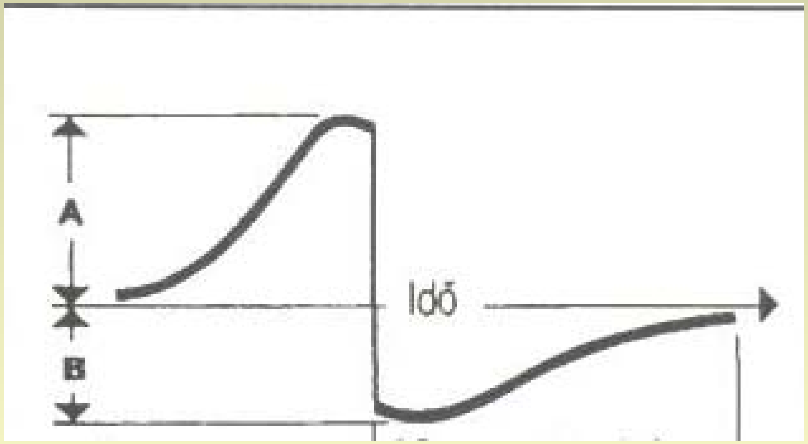
$$HRC = 100 – (h_1-h_0)/0,002$$

Példa: $h_1-h_0=0,08$ mm => $HRC = 100 – 0,08/0,002 = 60$

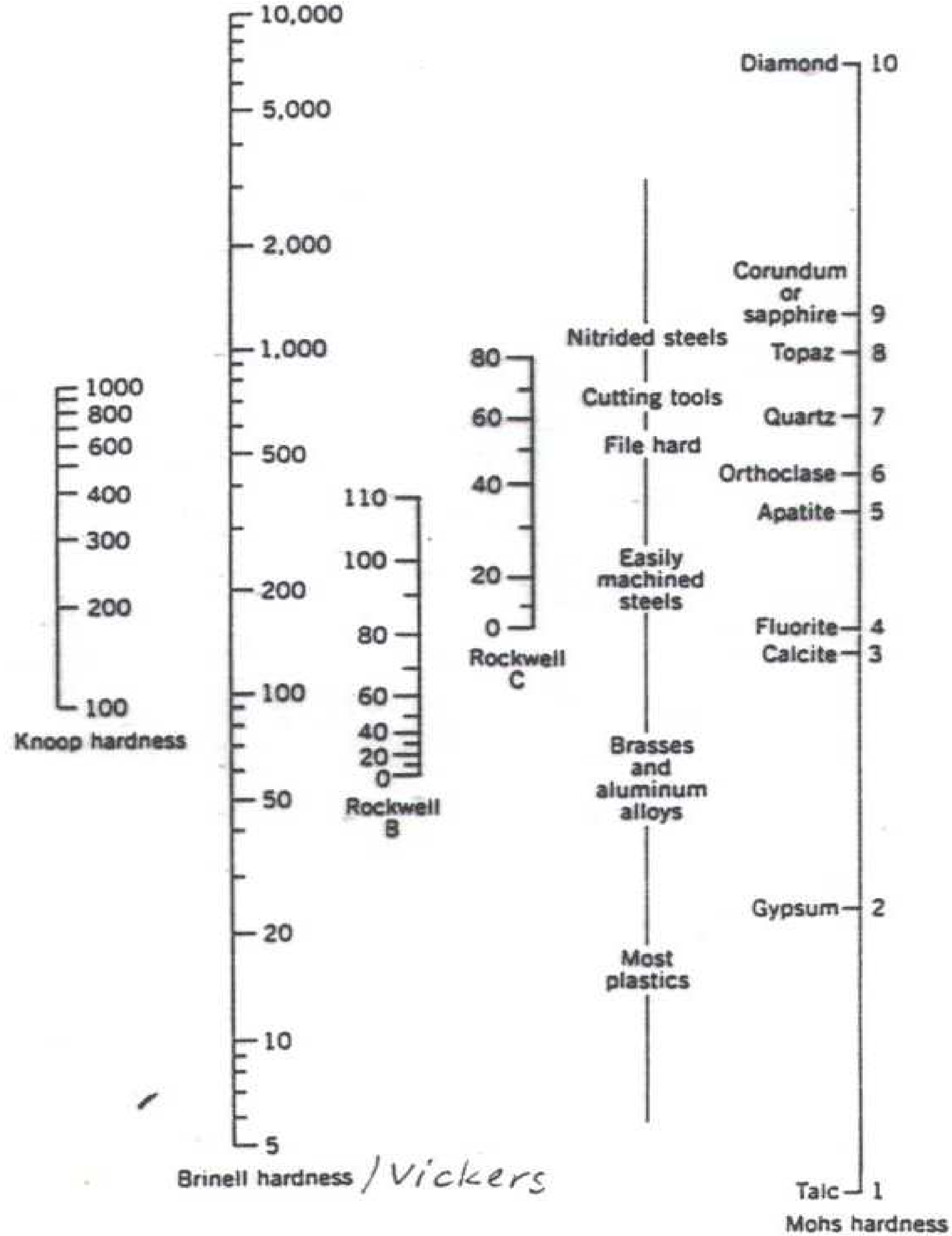

SERIES 200
START
TEST
INSTRON WOLPERT


10μm

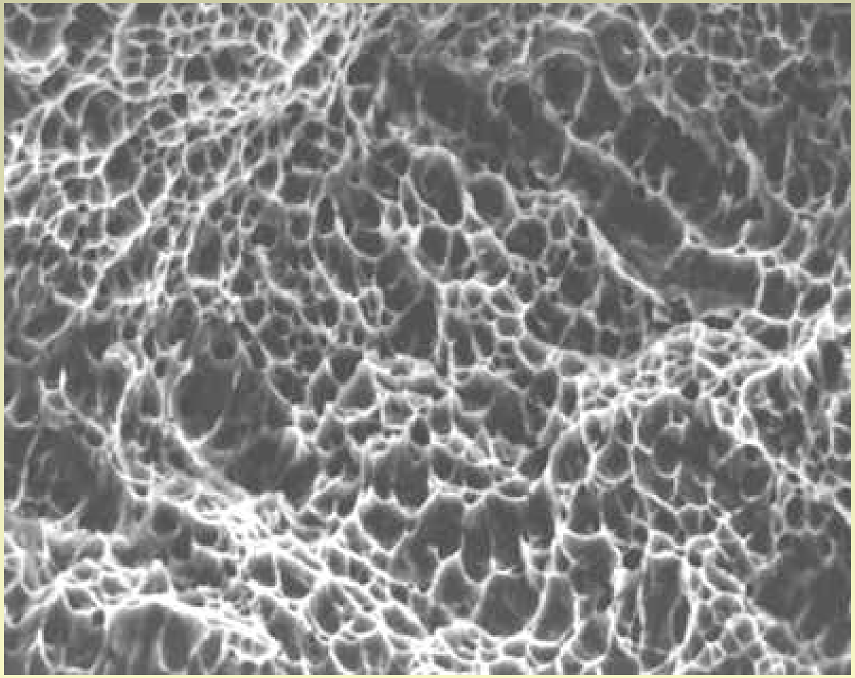
Rebound hardness test

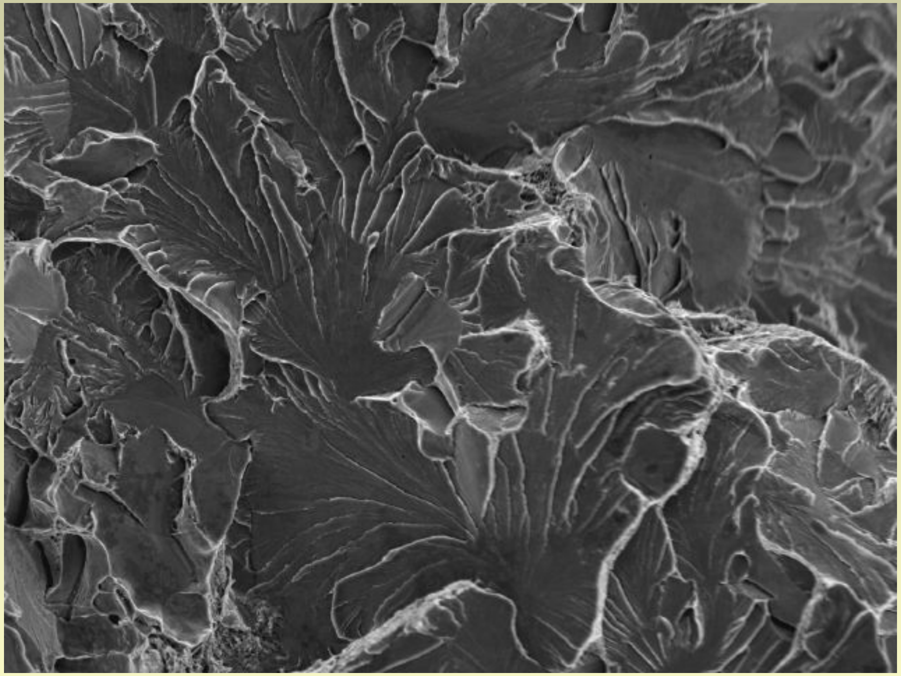


Comparison of hardness scales



TOUGH - BRITTLE behaviour

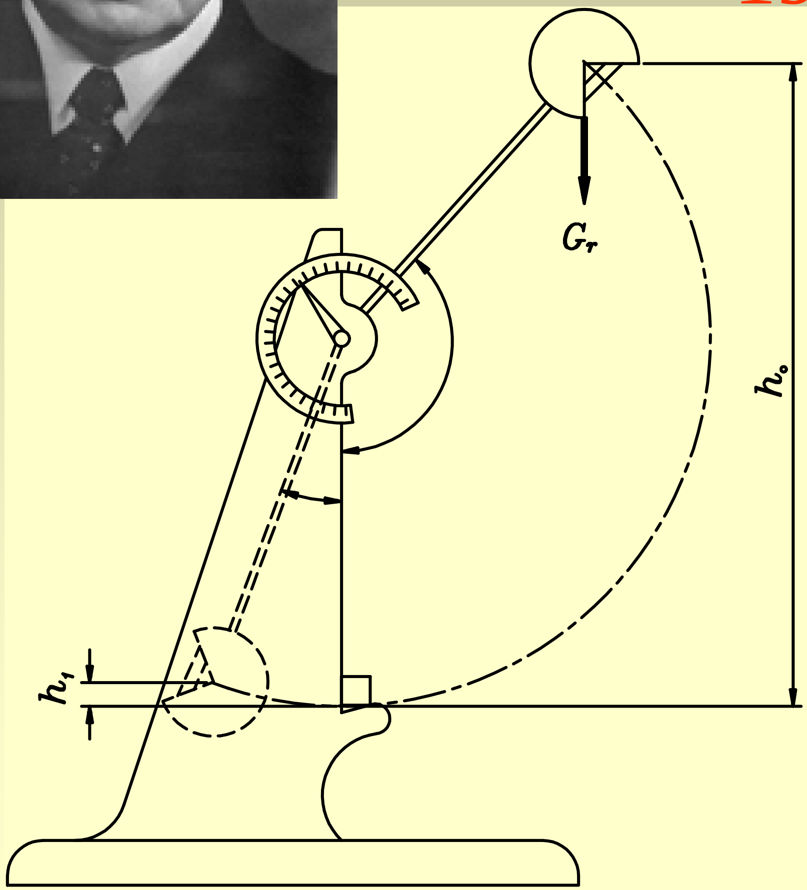


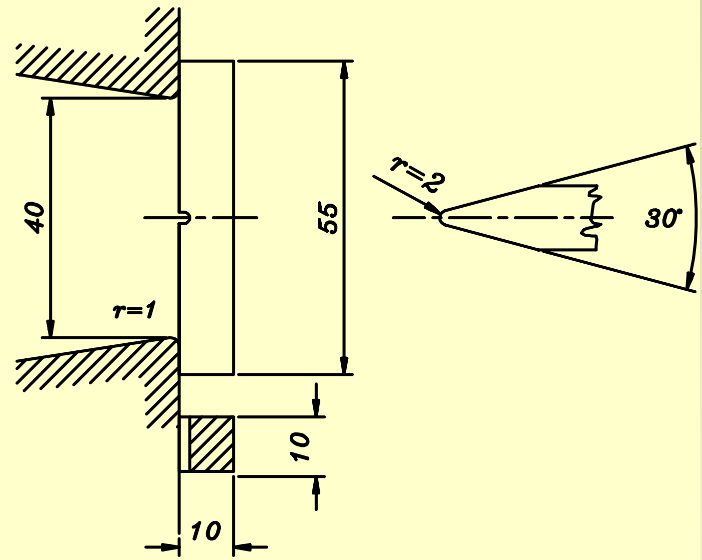


Difference: - plastic deformation -
-absorbed energy

Charpy test

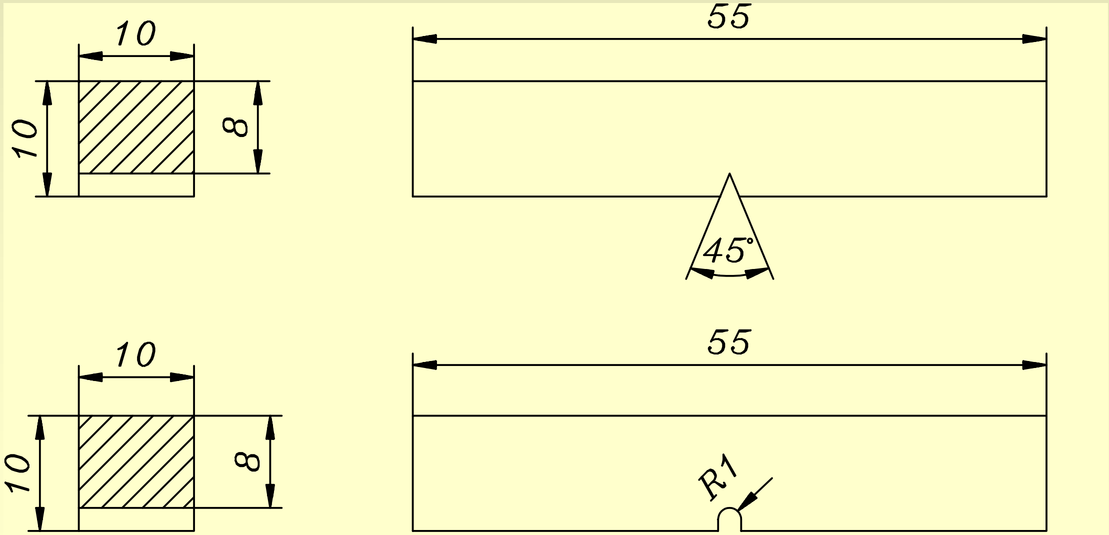
1901





Charpy specimen

The sizes of the specimen are: 10x10x55 mm with a 2 mm deep V or U shaped notch



Charpy test

The energy absorbed by the fracture can be calculated as follows:

$$K = G_r(h_o - h_1)\ [J]$$

Factors influencing ductile/brittle behaviour

- *Temperature*
- *The speed of deformation*
- *The stress state*

CREEP

The phenomenon of creep

Crrep is a slow, continuous deformation with time under constant load: the strain instead of depending only on stress, now depends also on time and temperature. At elevated temperatures the creep can accelerate, ending in fracture.

$T > (0,3 \ldots 0,4)\ T_m$ (K), for metals

$T > (0,4 \ldots 0,5)\ T_{me}$ (K), for ceramics

Stress , temperature and time

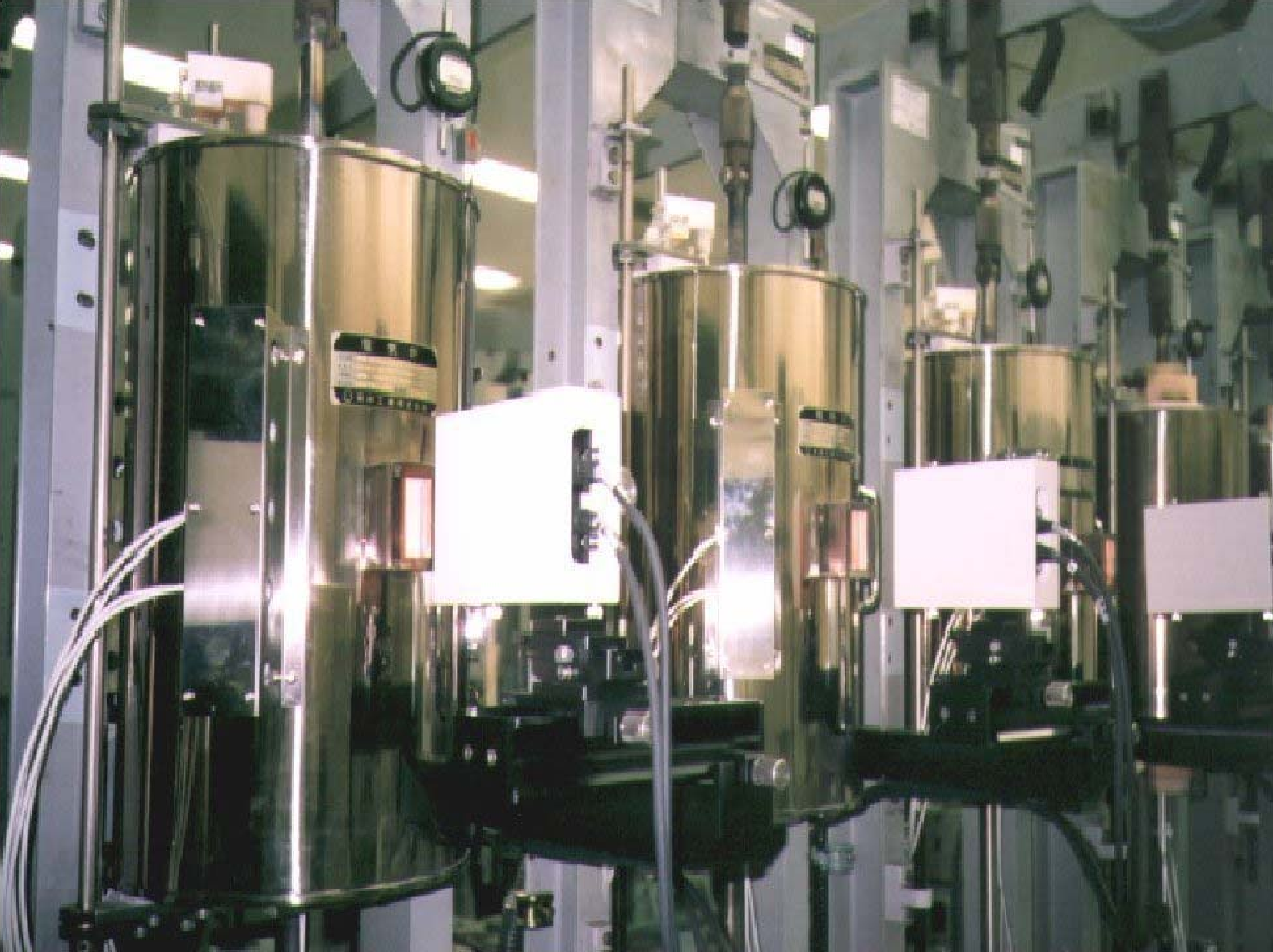
The creep behaviour is well understood in general, that is the higher is the temperature and the higher is the stress, the greater is the creep rate and the shorter is the time to fracture. The complete quantitative description of the creep process is lenghty and complex..

Stress, temperature and time

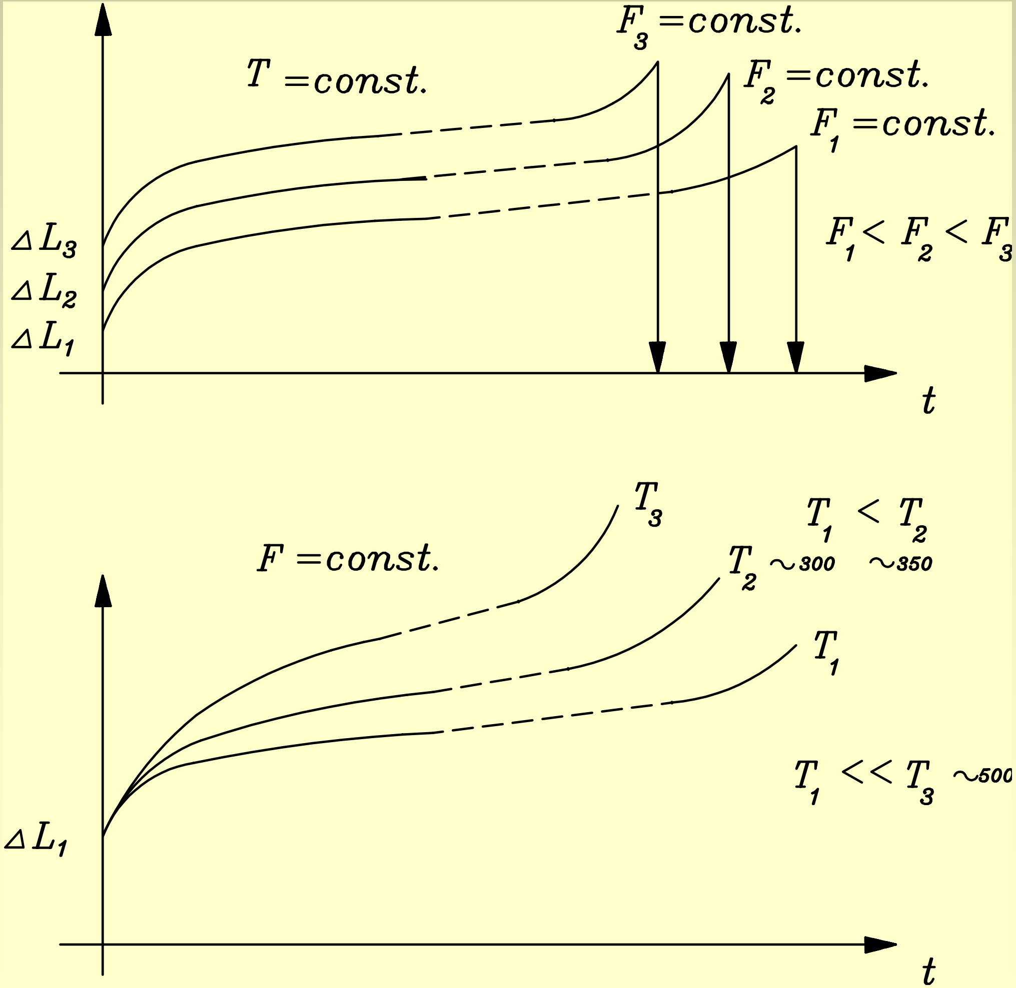
Creep behaviour is best characterised by creep curves.

Creep curves can be determined by applying constant load on specimens heated in resistance furnaces. The furnaces are equipped with extensometer so the strain versus time valuaes can be plotted.

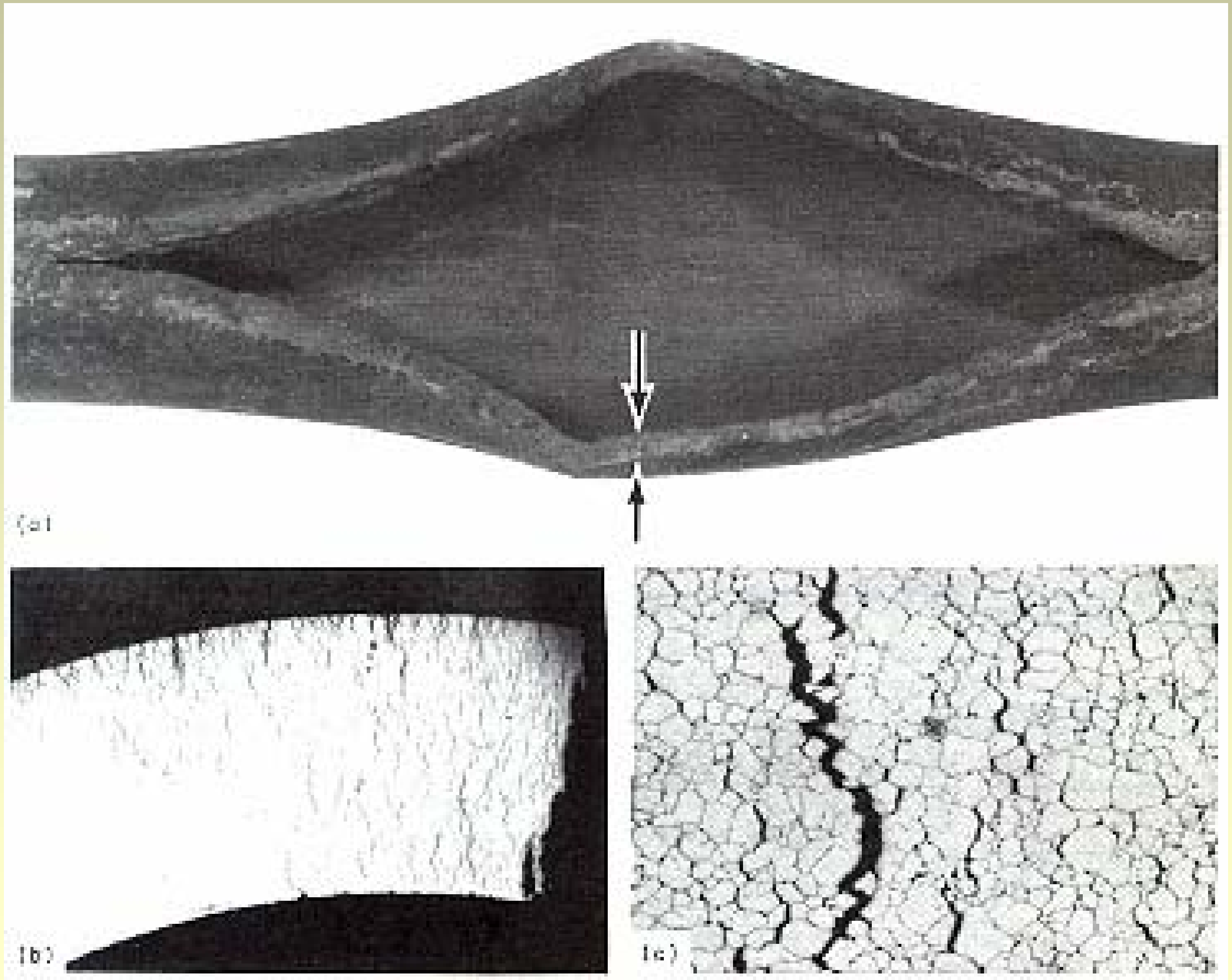
Creep curves have three distinctive parts.



The effect of stress and temperature on creep



Fracture of a boiler pipe.



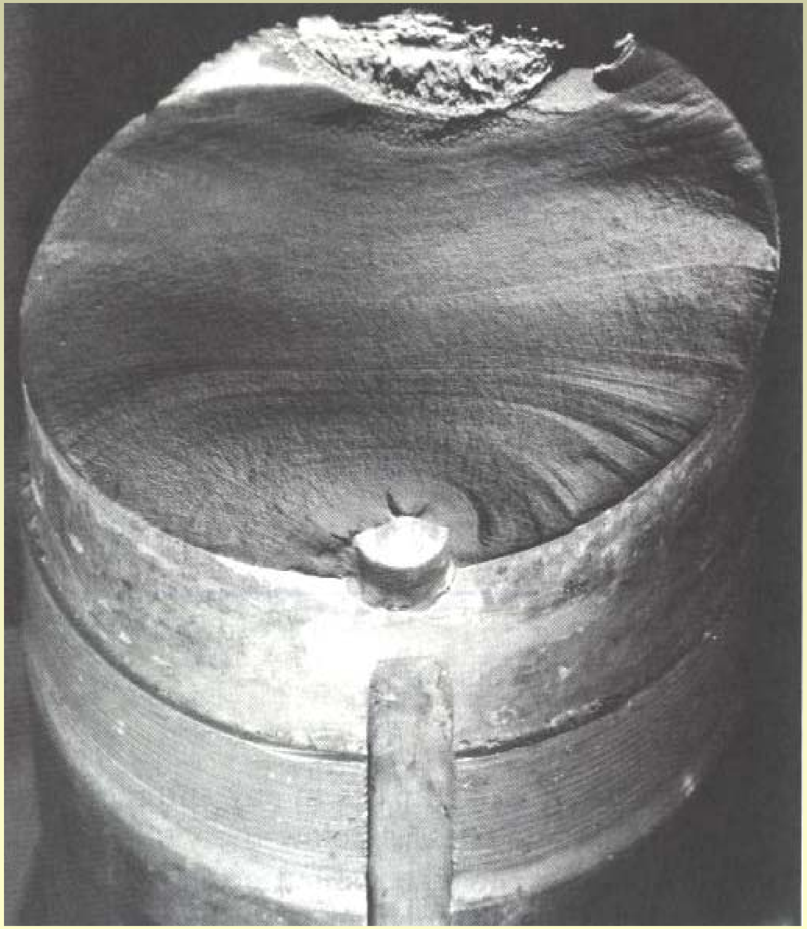

Fatigue

The fatigue phenomenon

If a component is subjected to repeated stress cycles, like the loading on a connecting rod of an engine or on the wing of an aircraft, it may fail at stresses far below the yield strength of the material. This phenomenon is called fatigue.

The fatigue fracture surface has a characteristic clamshell pattern.

Characteristics of the fatigue fracture surface



The process of fatigue

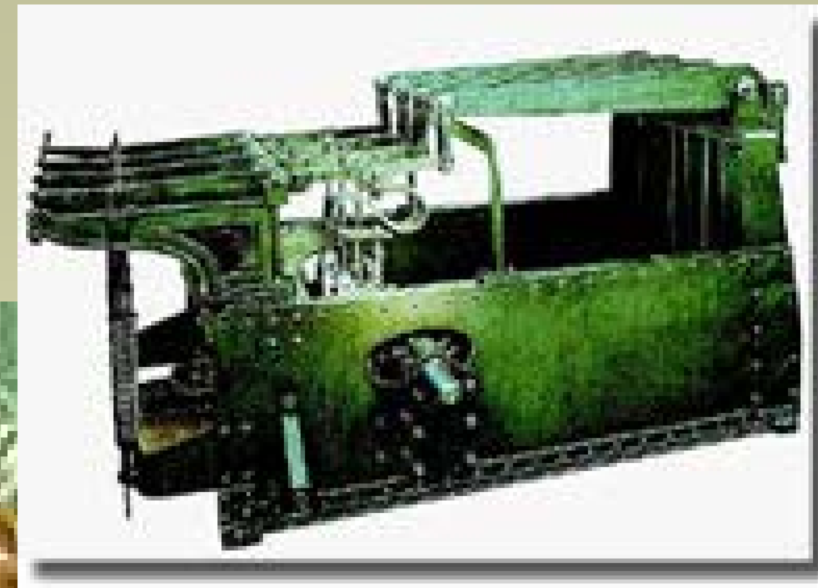
$$\sigma < R_{\mathrm{p0,2}}$$

There is no macroscopic plastic deformation,

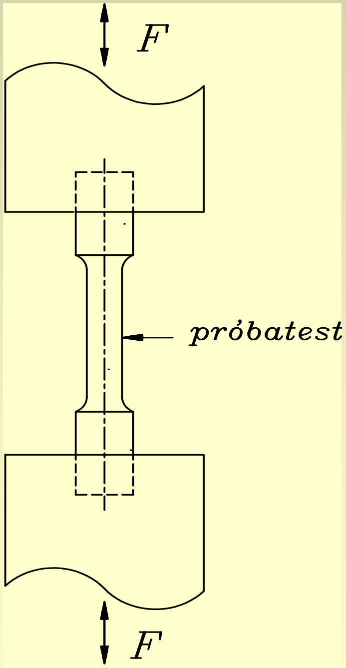
but on microscopic level plastic deformation may occur, because enginnering materials are:

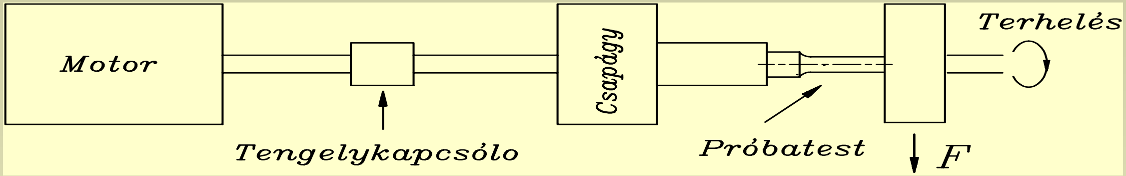
- not homogenous and they are anizotropic
- the orientation of crystallites are diffrent
- there are inclusions and flaws in the material

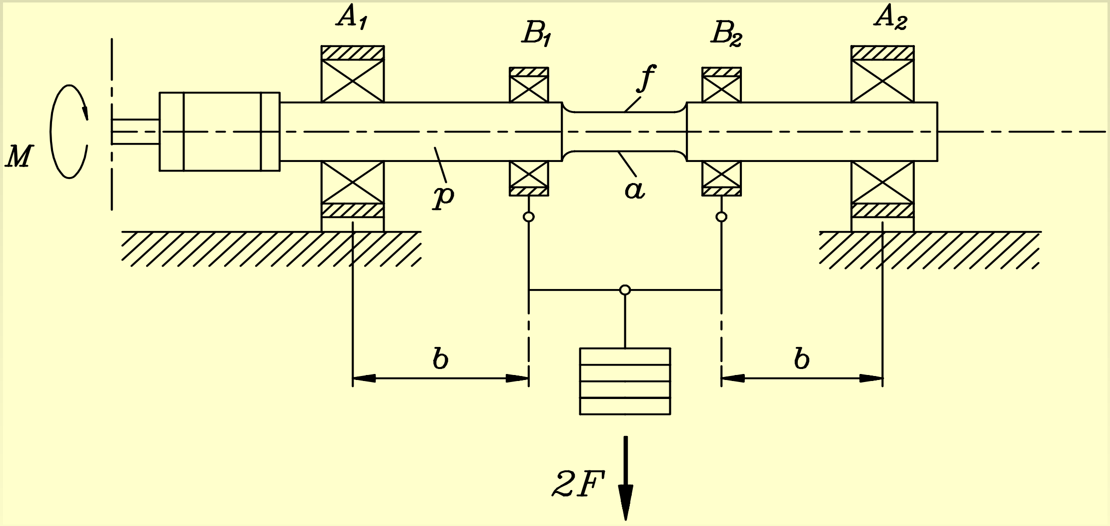
August Wöhler, 1858



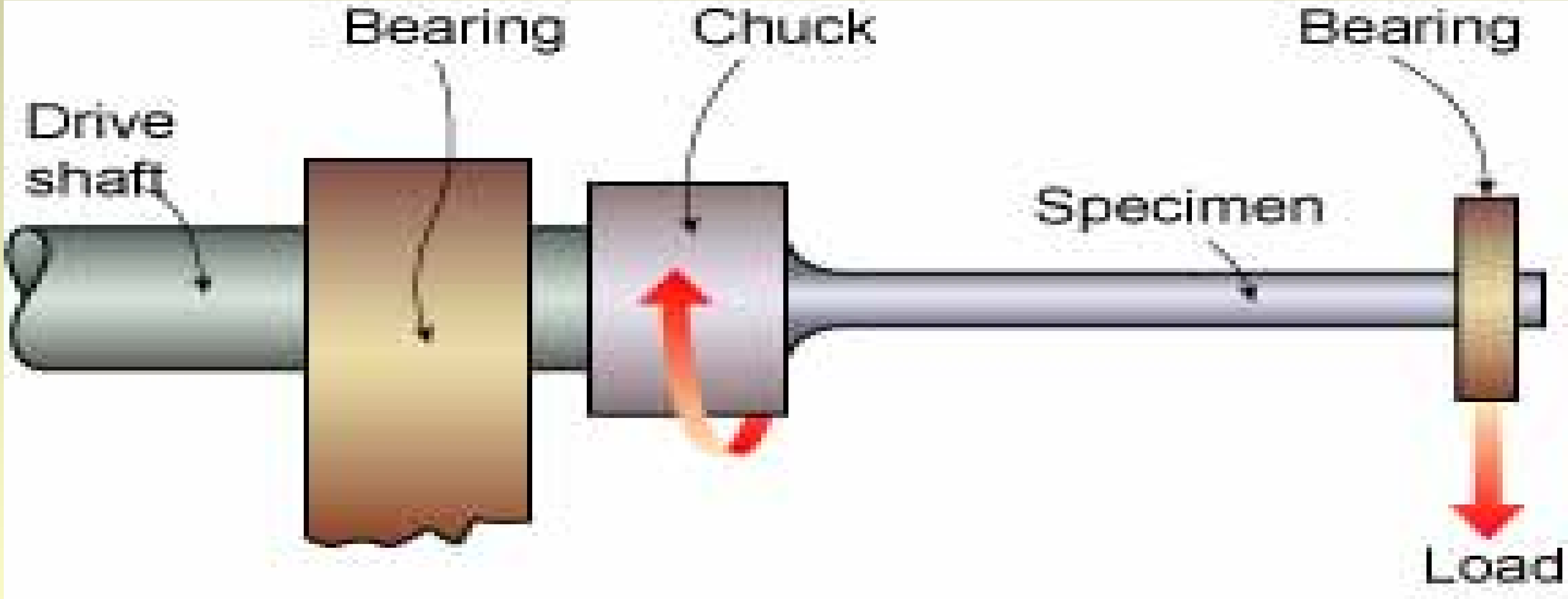
Arrangement of fatigue tests







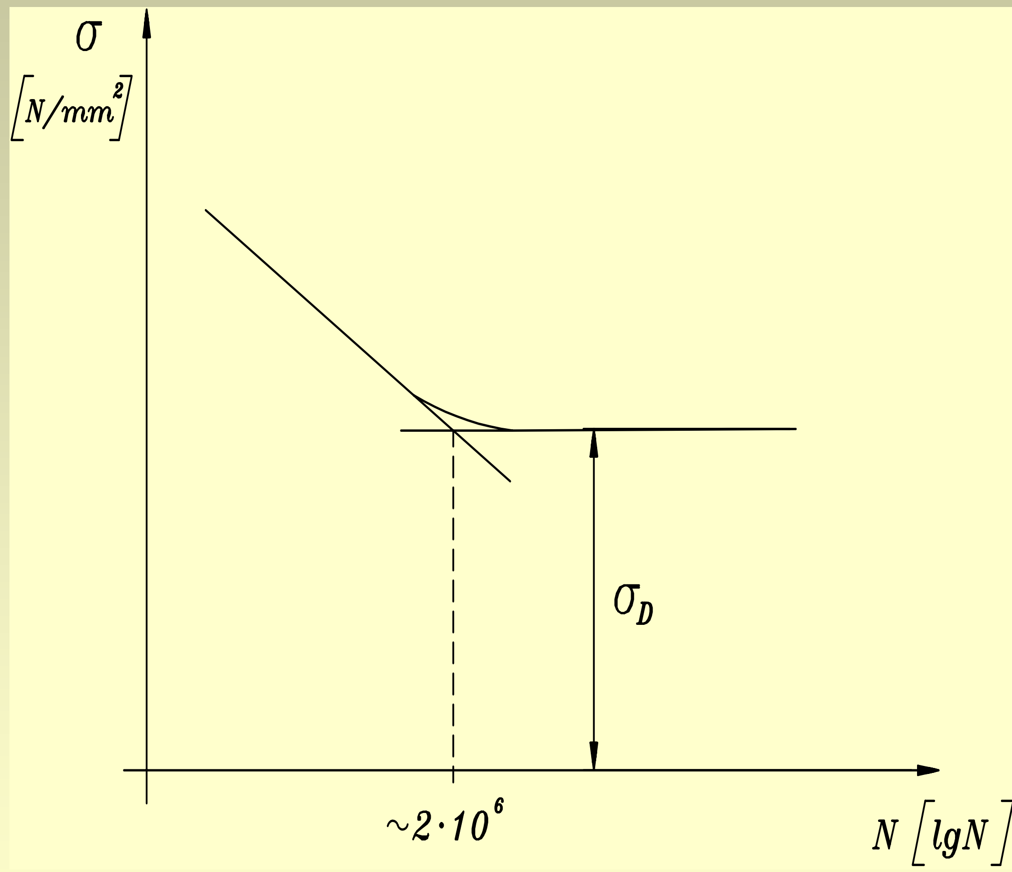
Arrangement of the rotary-beam fatigue test



Wöhler diagram

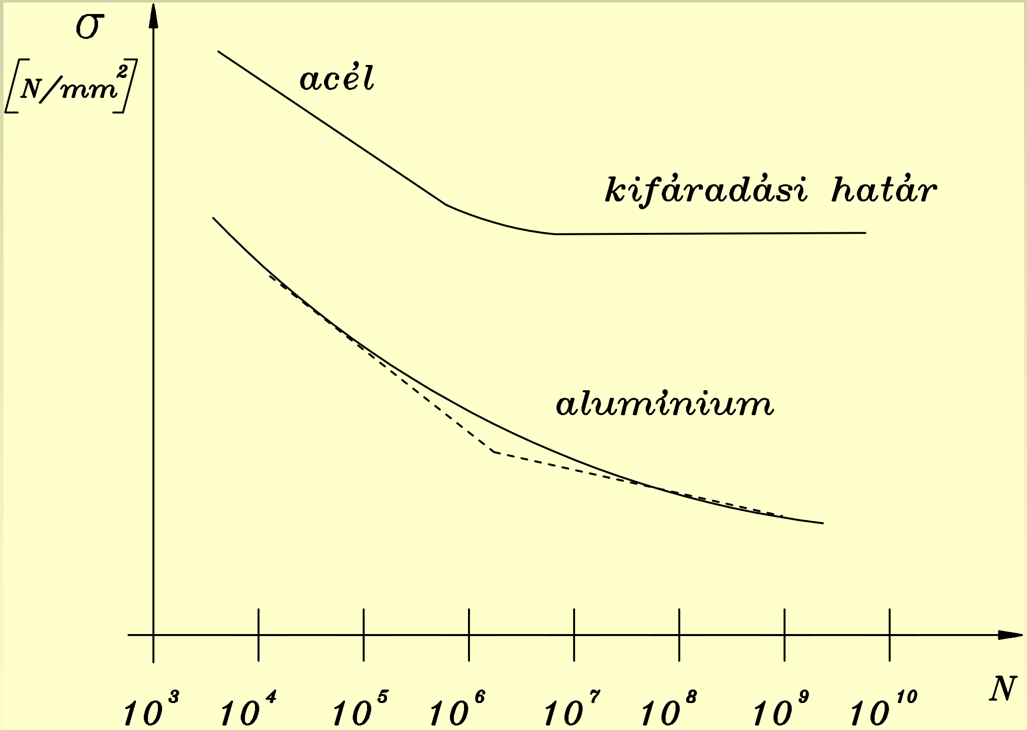
In case of steels the curve approaches a stress value in assimptotic way

Gradually reducing the load a characteristic stress can be determined that could be applied infinitive times without causing fracture. This value is the fatigue limit, also called endurance limit.



Not every material has fatigue limit

In case of Al-alloys, stainless steels, high strength steels the second part of the Wöhler diagram is not horizontal, these materials do not have fatigue limit.



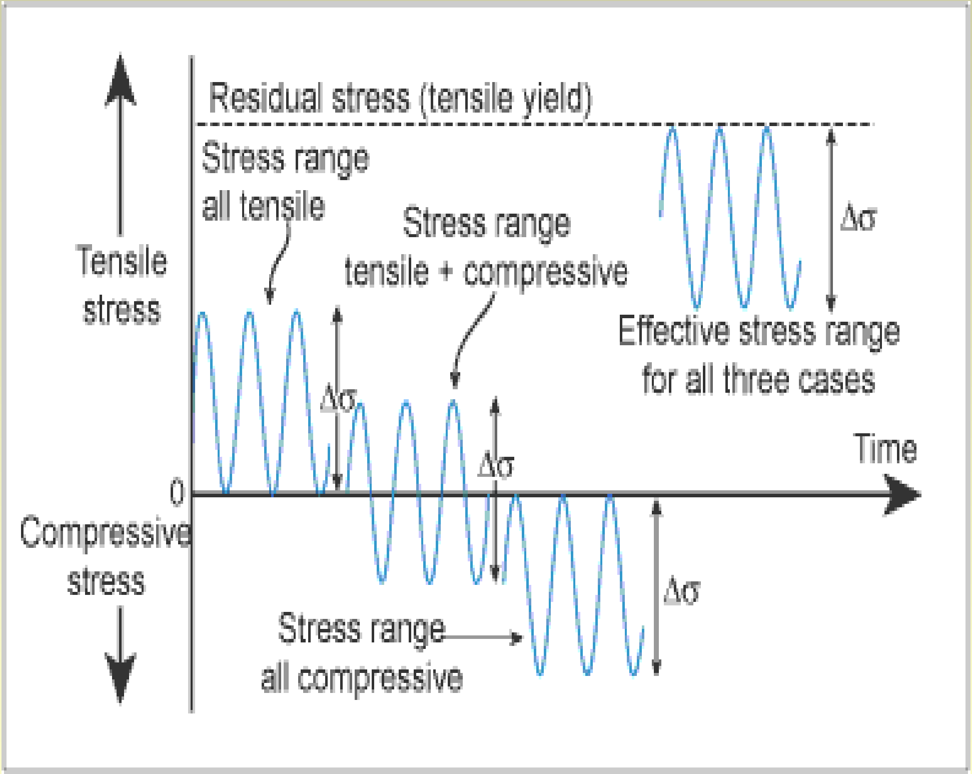
Fatigue behaviour of nonmetallic materials

- The fatigue behaviour of polymers is similar to that of the metals, although the microscopic process is different in them.
- Ceramics are brittle, they do not exhibit fatigue behaviour

The variation of stress with time

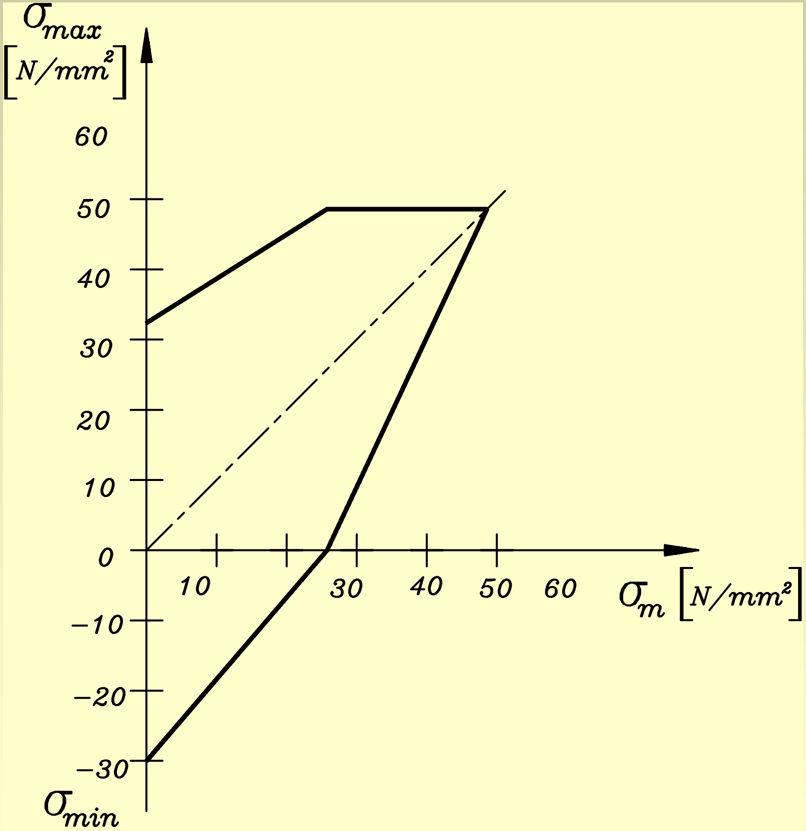
Under cyclic load the stress varies with time sinusoidally either in swinging or pulsating way.

The stress may be characterised its medium, maximum and minimum value.



Safety area
Smith-diagram

In the Smith diagram the maximum and minimum stresses belonging to a given number of cycles are plotted against the medium stress.



Factors influencing the fatigue behaviour

Many factors affects the data of the fatigue test, such as:

- the type of load
- design
- microstructure
- environment
- surface finish and treatment

F/A -18 Full Scale Fatigue Test