Plastics

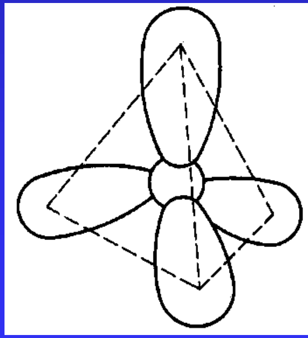
- Physical – chemical background
- Deformation
- Testing

Plastics

Plastics = polymer + filler + pigment + stabilizer + other additives

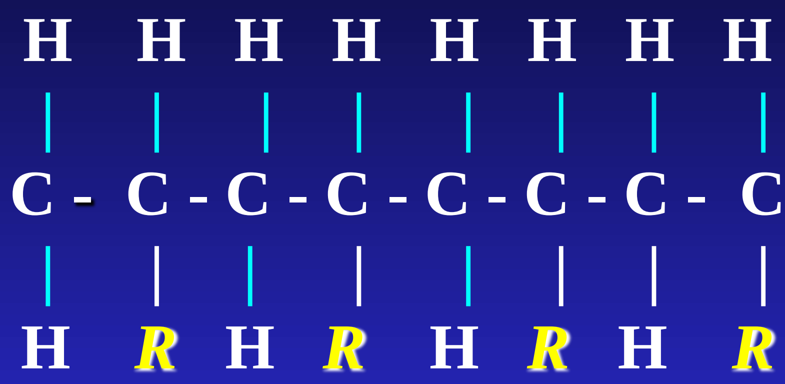
Polymer = chemically virgin (pure) macromolecular substance well defined by chemical formula

Carbon C – structure of organic substance



Four bonds - covalent bonding

covalent bonding of polymers



R ---- **H** **polyethylene** (pipes, isolators)

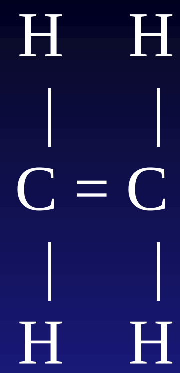
R ---- **CH3** **polypropylene** (resitant to light)

R ---- **Cl** **polyvinyl chloride PVC** (floor covering)

R ---- **C6H5** **polystyrene** (gramophone records, cutlery, insulations)

Polymer materials (plastics)

Ethylene

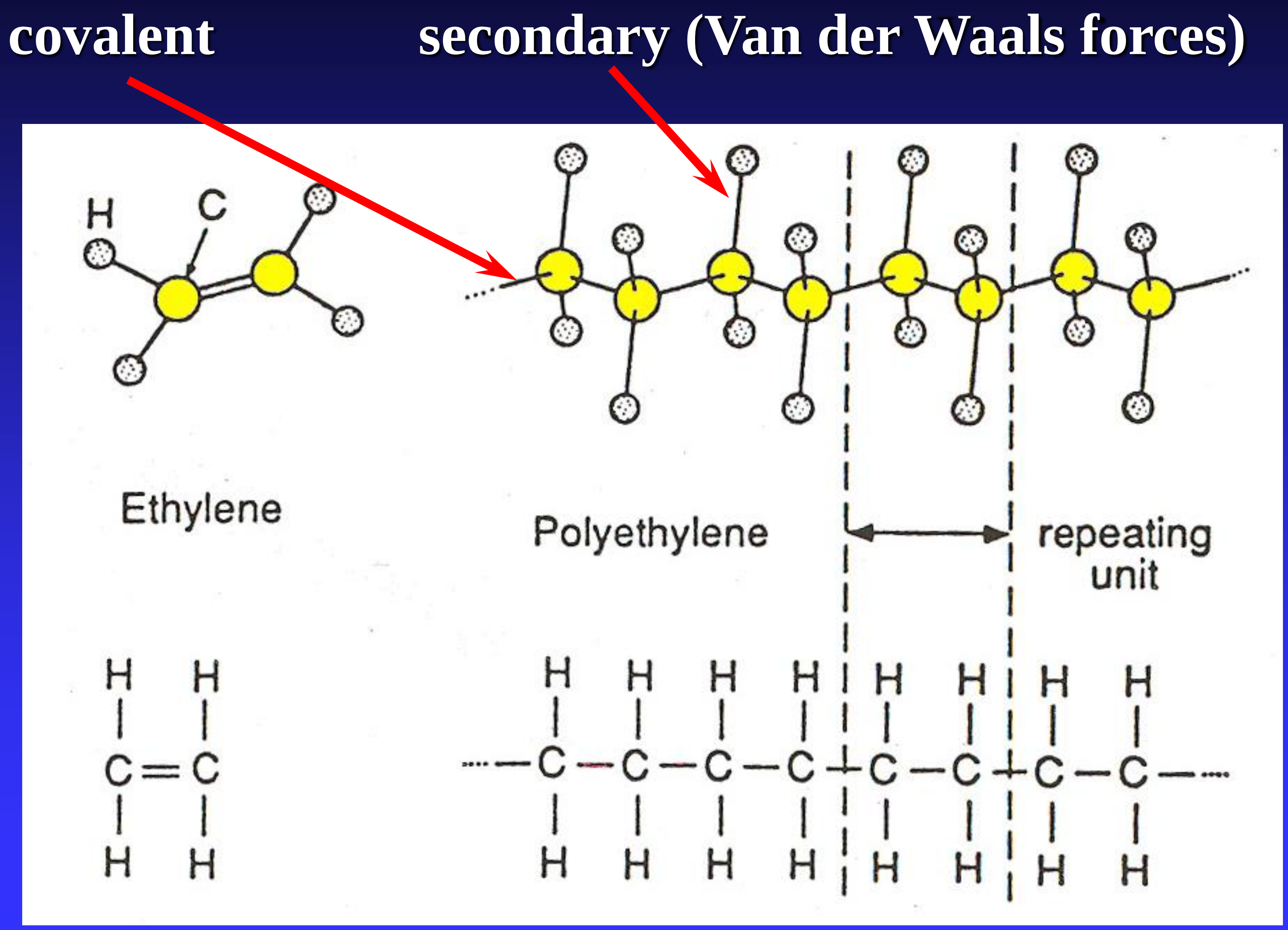


monomer

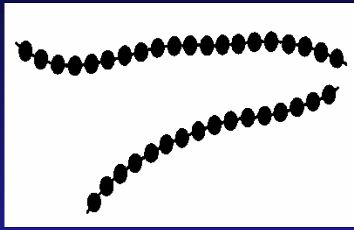
Number of monomers (n)	Softening temperature °C	character at +20°C
1	-167	gas
6	-12	liquid
35	37	oil
140	93	wax
430	109	solid substance

forming the polymer chain

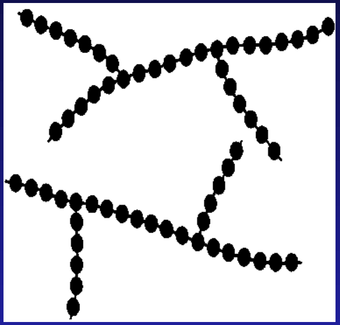
Bonding in polymer chains (plastics)



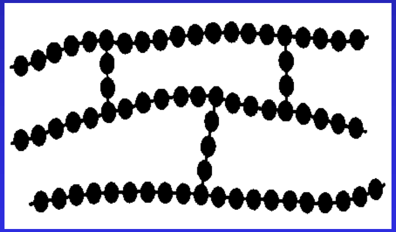
Polymer chain structure:



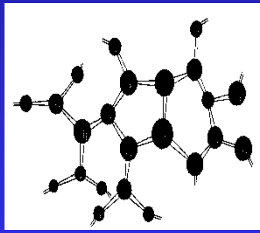
linear



splitted

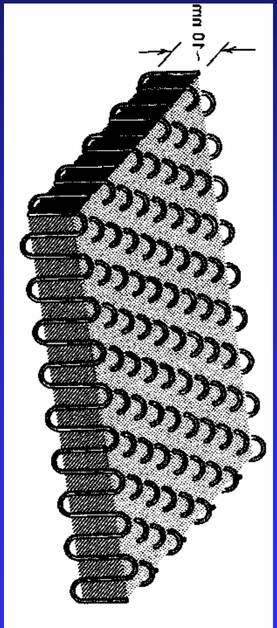


cross linked

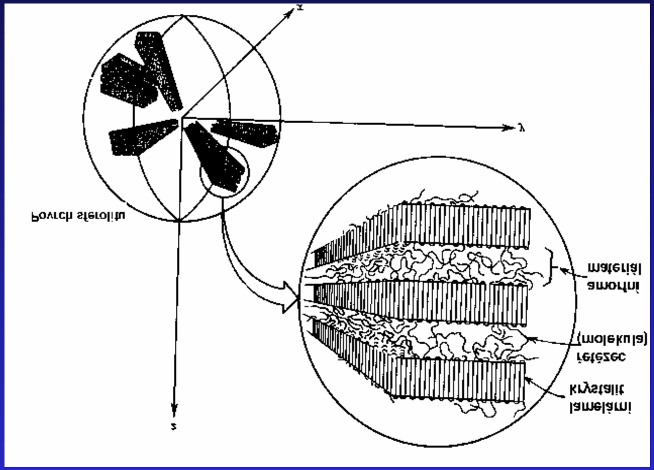


3D network

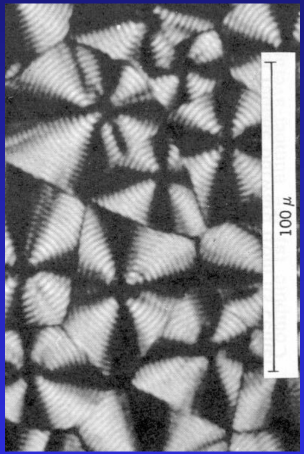
Material structuring according to crystallisation condition



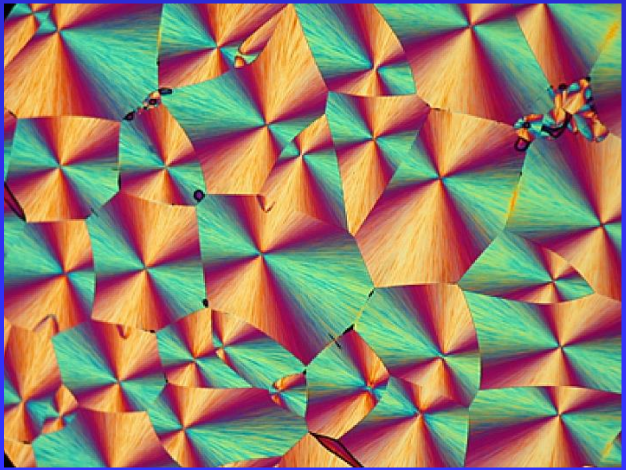
Lamela



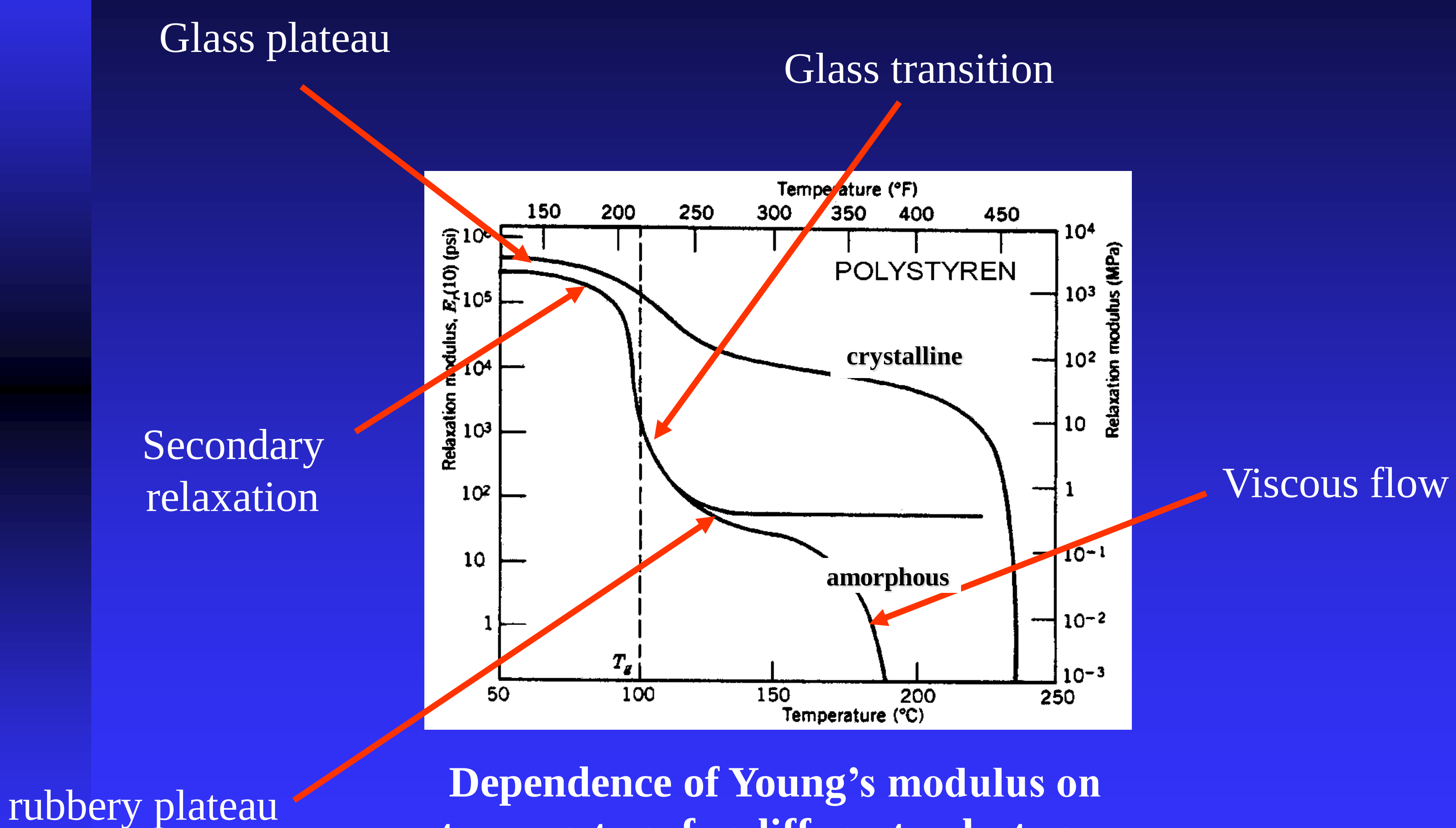
sperolite



spherolite



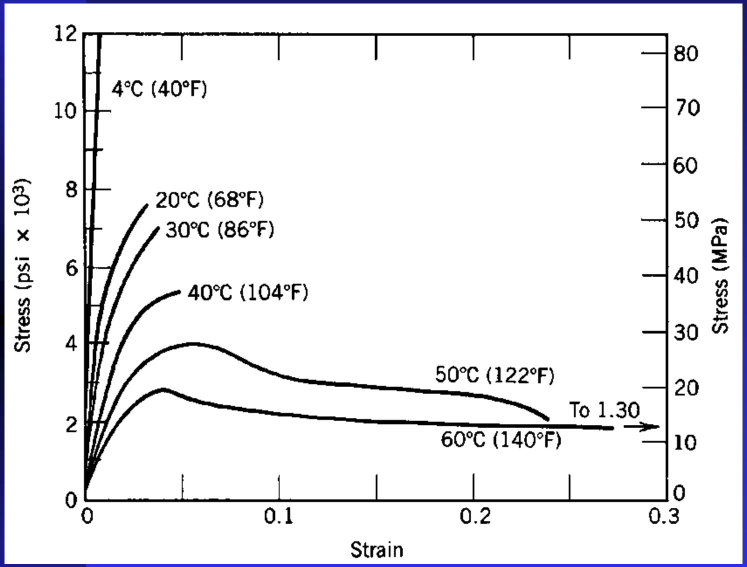
Young's modulus as a function of temperature and time



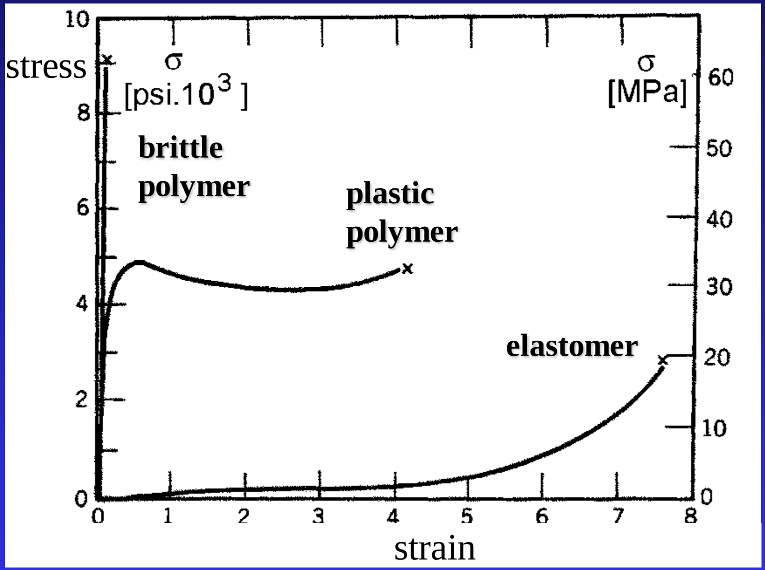
Dependence of Young's modulus on temperature for different polystyren forms

Polymer behaviour at tension

Strong dependence: temperature, loading rate, environment



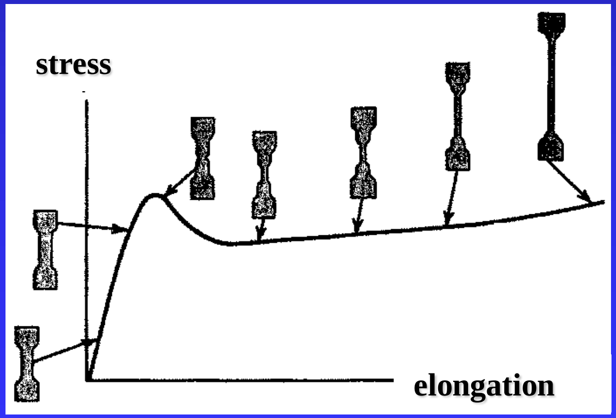
PMMA / temperature effect



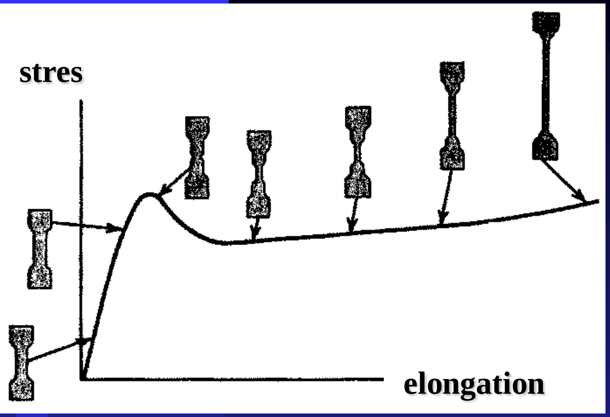
Different polymers

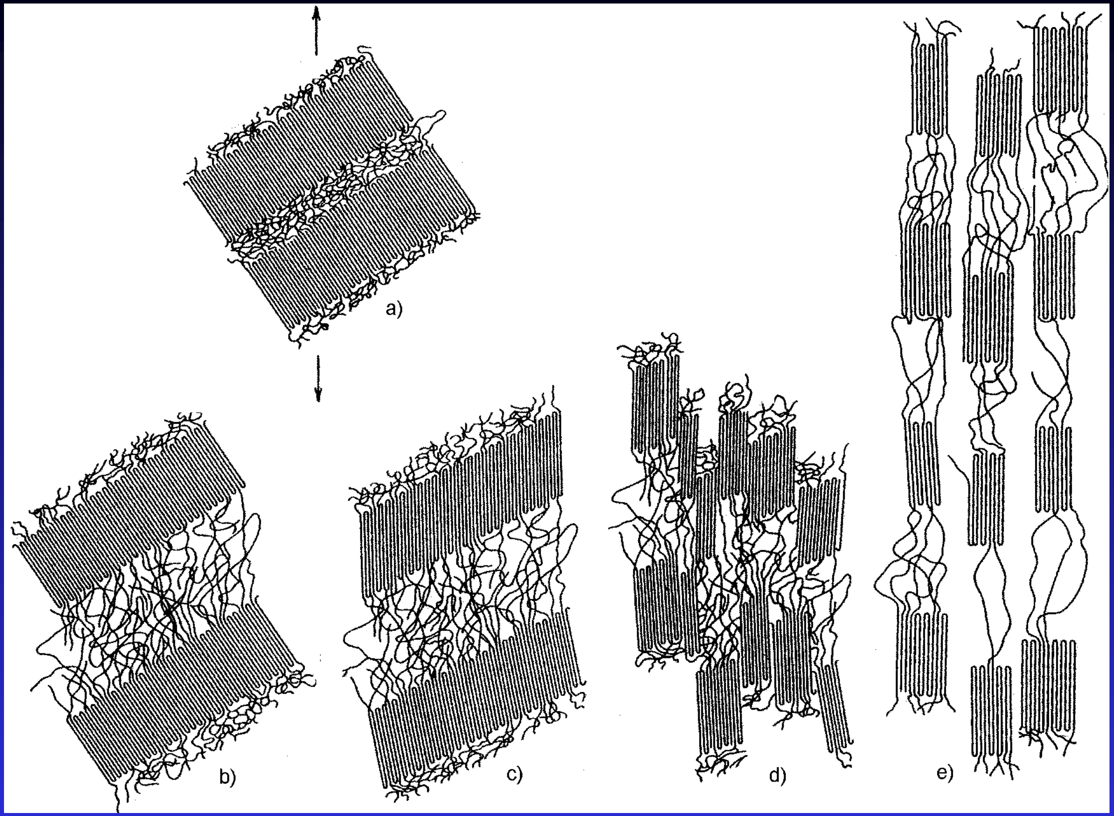
At tensile loading:

- two neighbouring lamela & amorphous material in between
- amorphous chains unravels > elongation
- change of amorphous fraction orientation in direction of tensile load
- lamelar part / broken to separate crystalline segments
- amorphous and crystalline blocks are oriented in direction of tensile load



Load curve and geometry



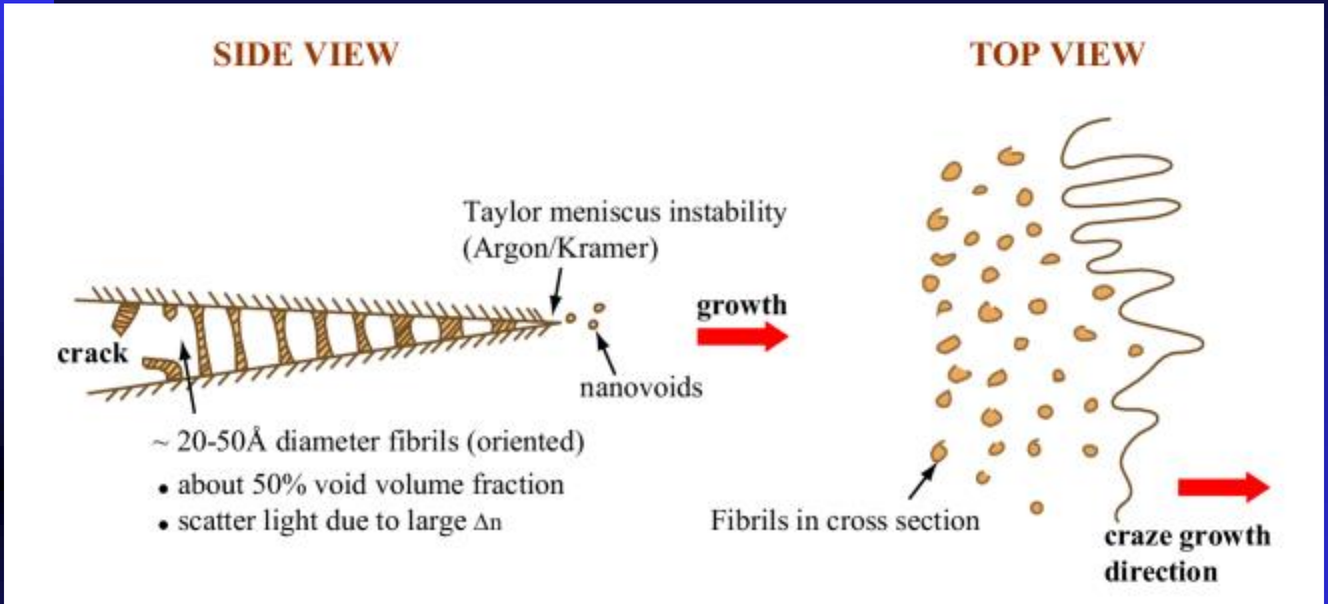


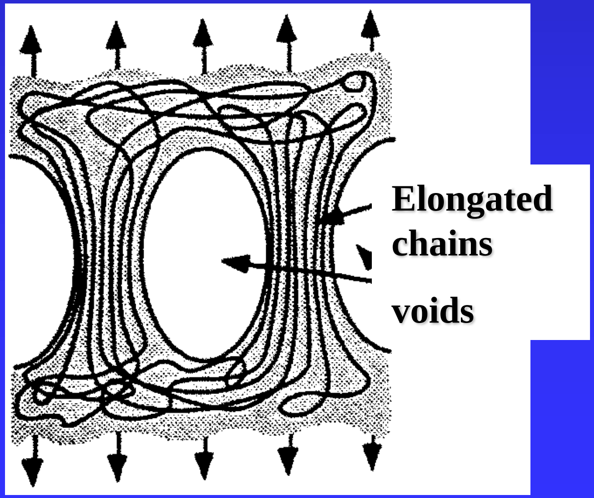
At tensile loading:

- two neighbouring lamella & amorphous material in between
- amorphous chains unravels > elongation
- change of amorphous fraction orientation in direction of tensile load
- lamellar part broken to separate crystalline segments
- amorphous and crystaline blocks both are oriented in direction of tensile load

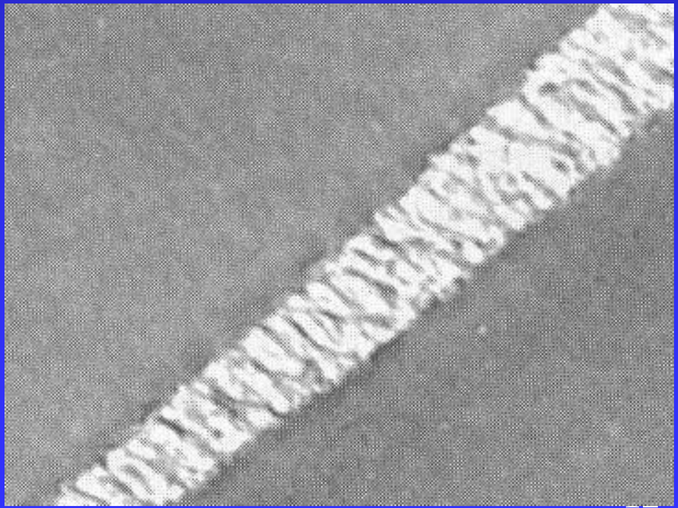
Crases

Discontinuities formed by elongated polymer chain network (chain bundles) and larger voids



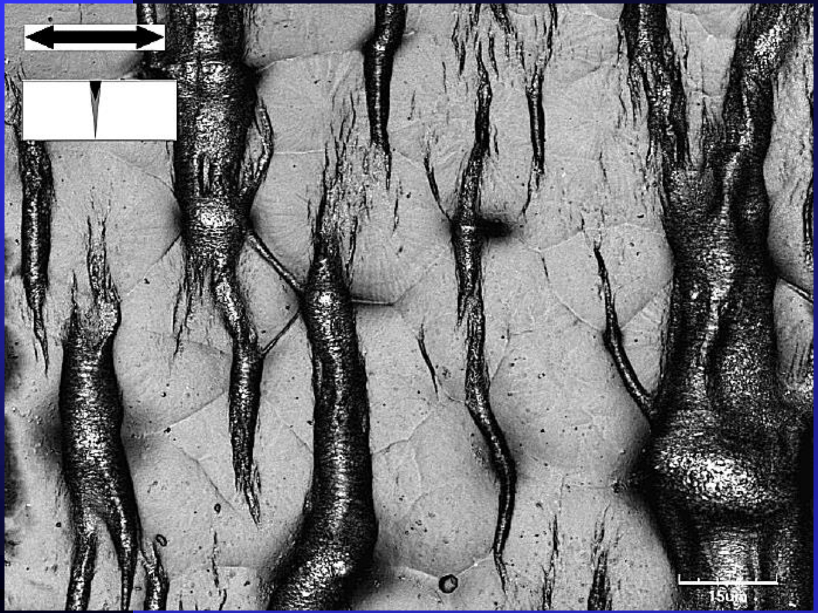


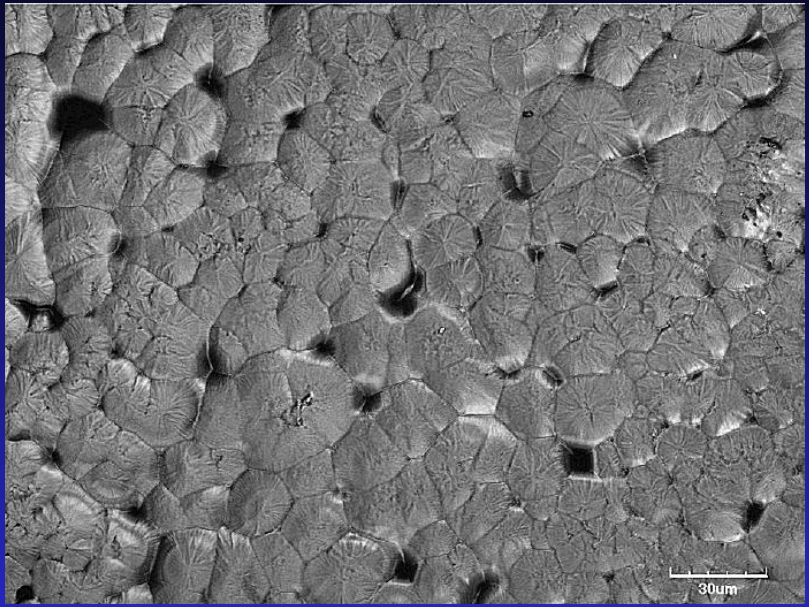
craze

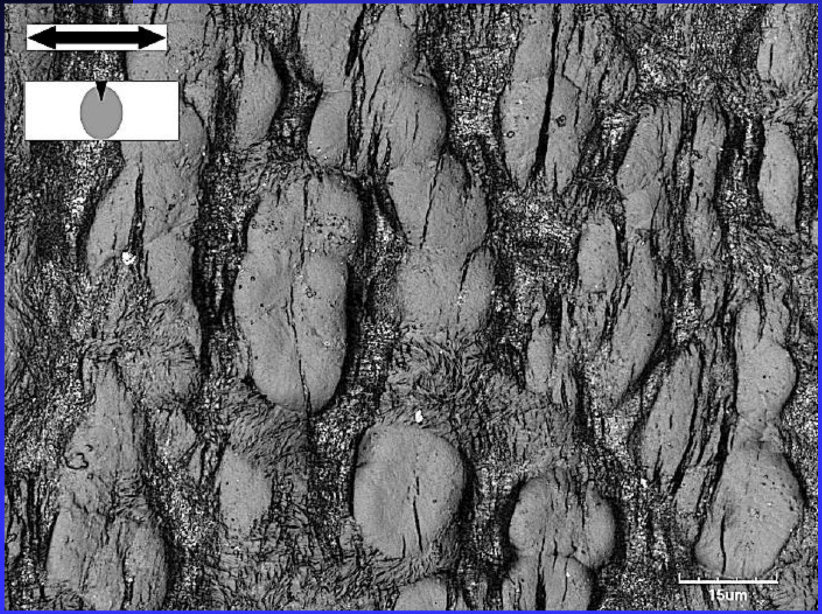


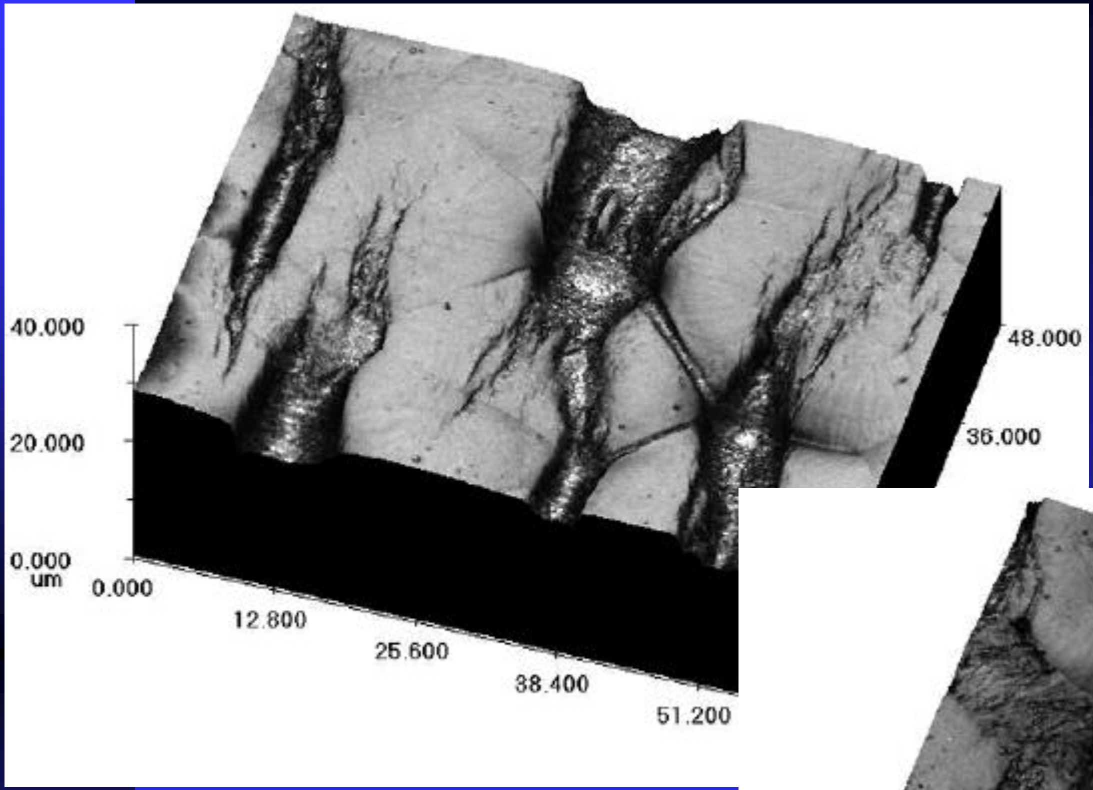
SEM of craze

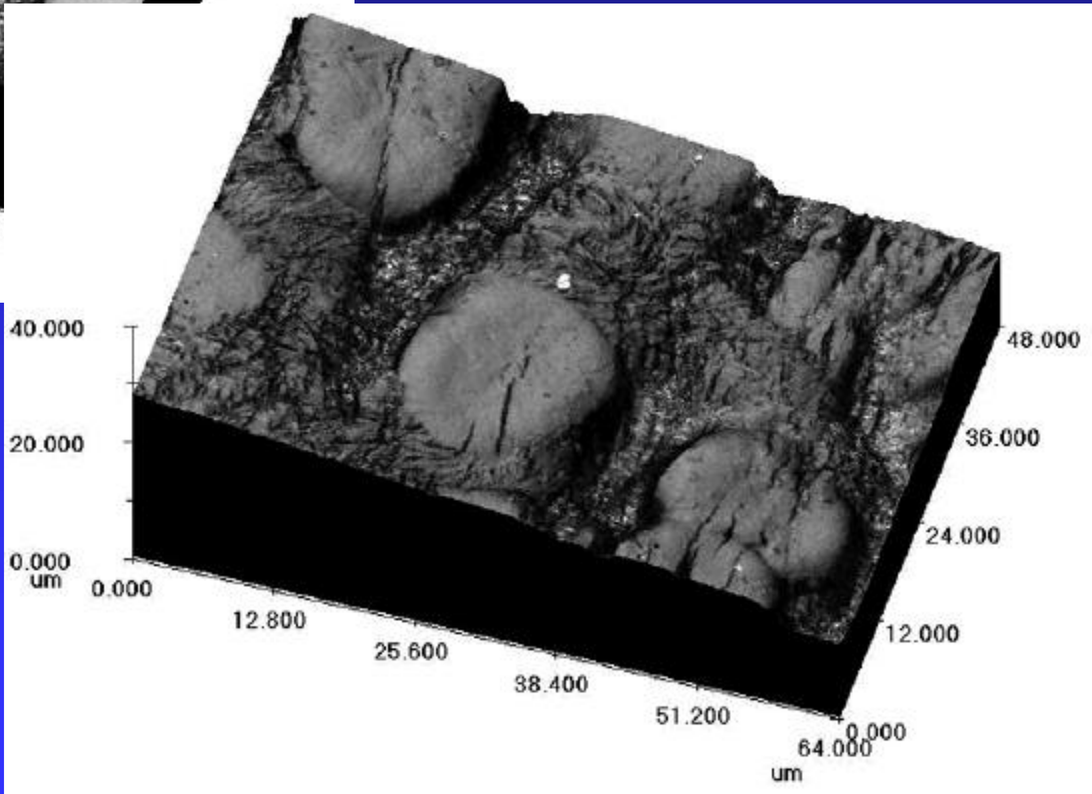
Polypropylene deformation








40.000
20.000
0.000
um
0.000
12.800
25.600
38.400
51.200
48.000
36.000


40.000
20.000
0.000
um
0.000
12.800
25.600
38.400
51.200
64.000
um
48.000
36.000
24.000
12.000
0.000

Plastics testing

Short time tests

tension

compression

fracture toughness

Dynamic tests:

dynamic tensile

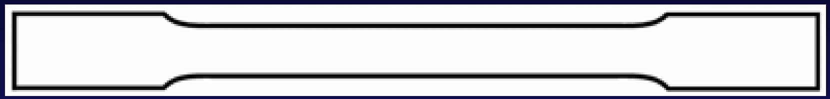
dynamic test according to Carpy

Fatigue tests

Creep tests

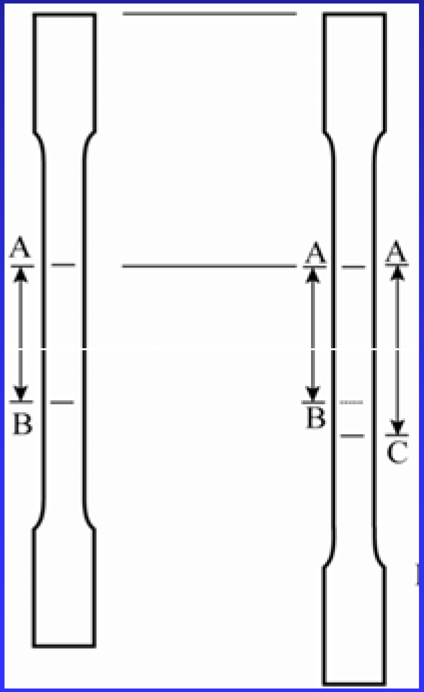
Component tests.

Tensile test



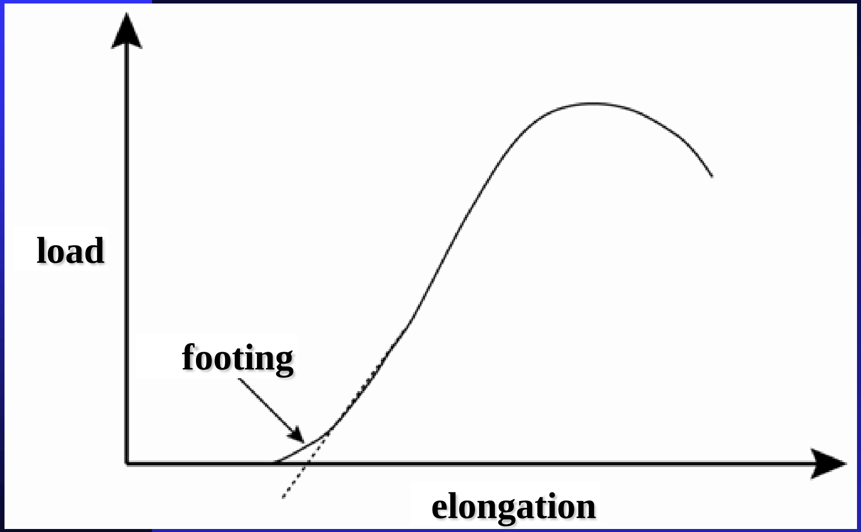
Test specimen for tensile test

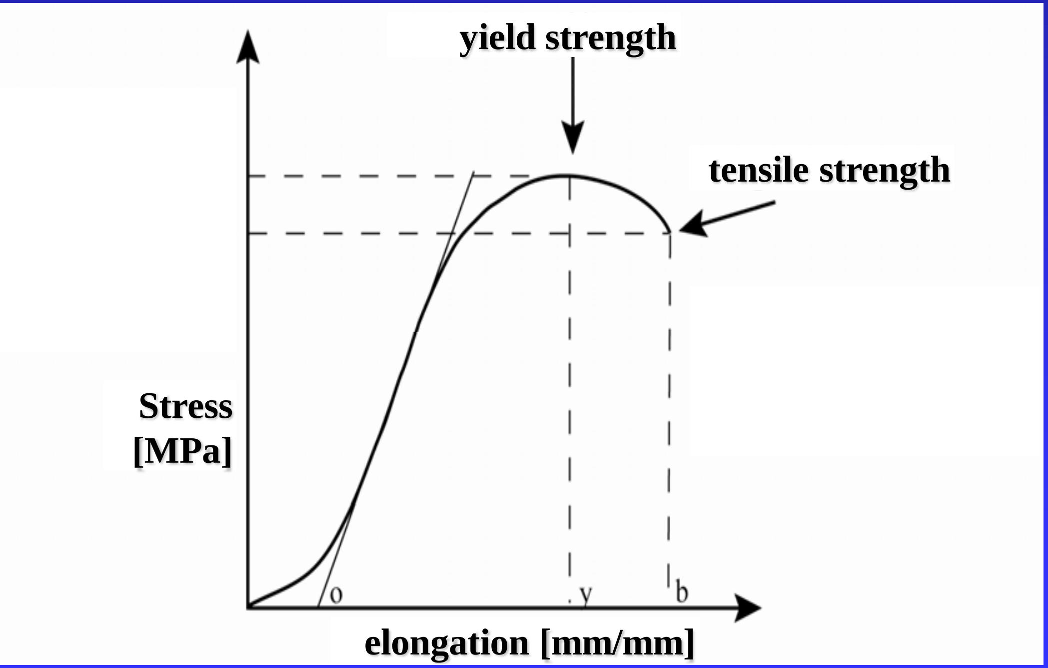
• elongation measurements

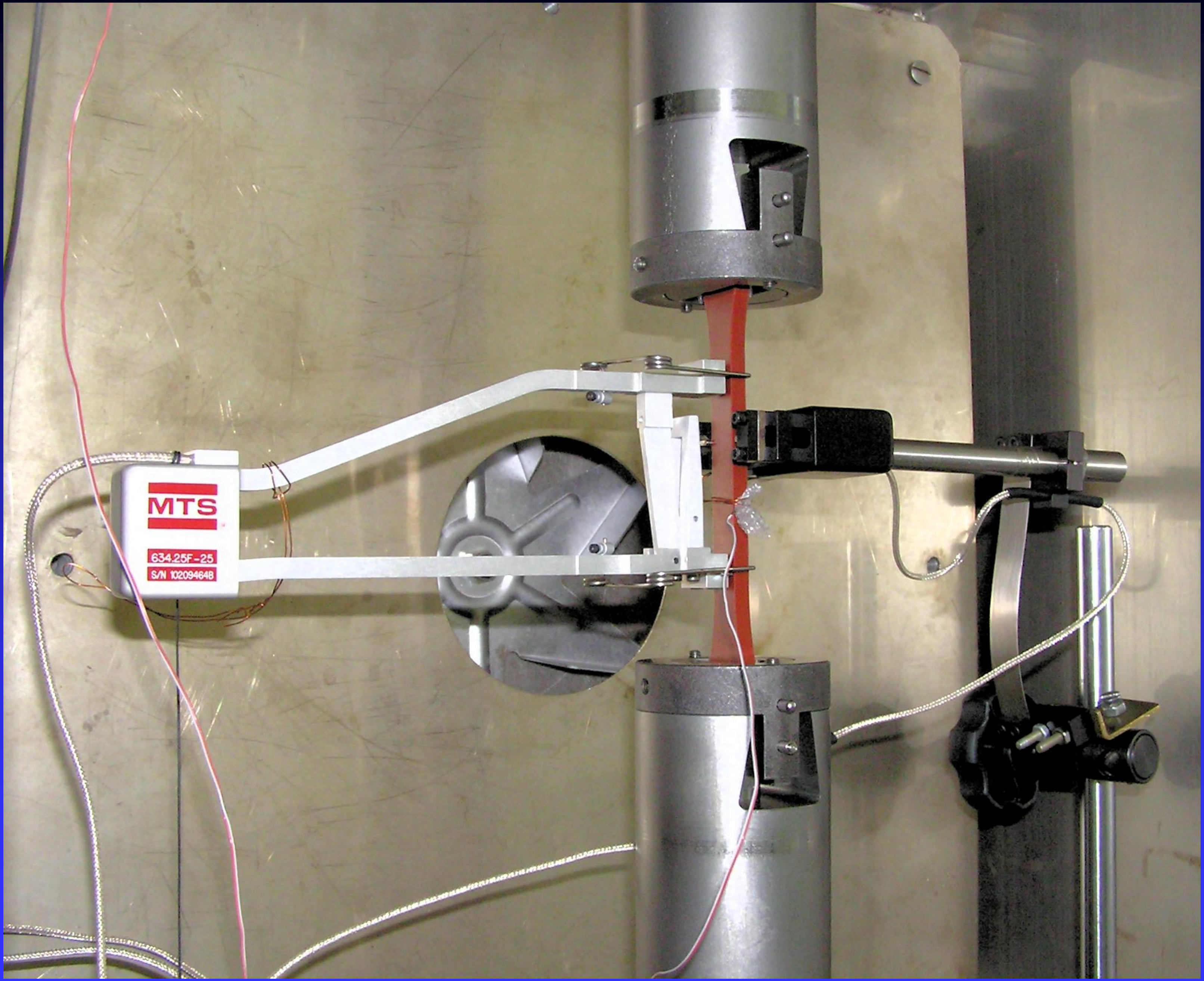


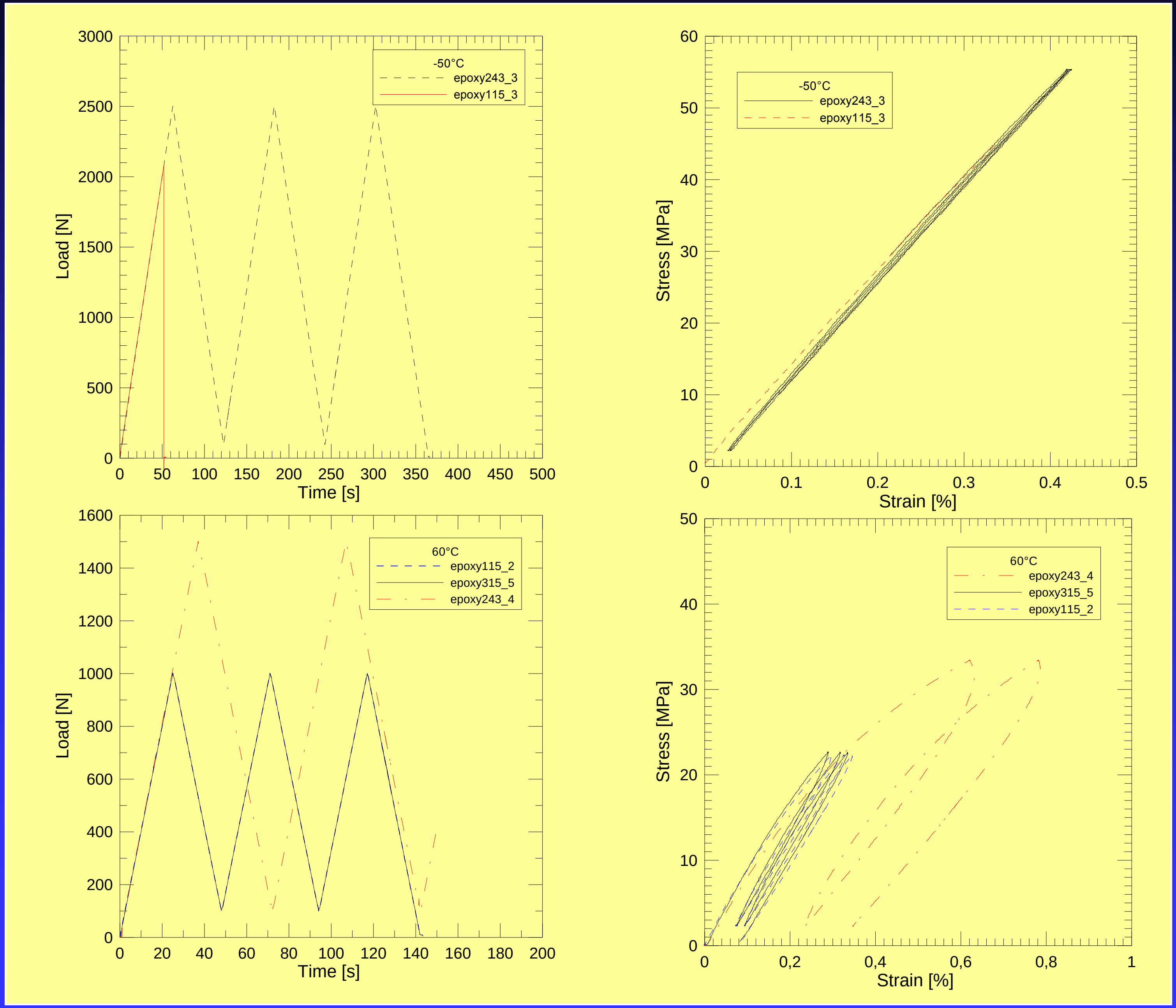
Elongation
BC = AC – AB

Tensile test

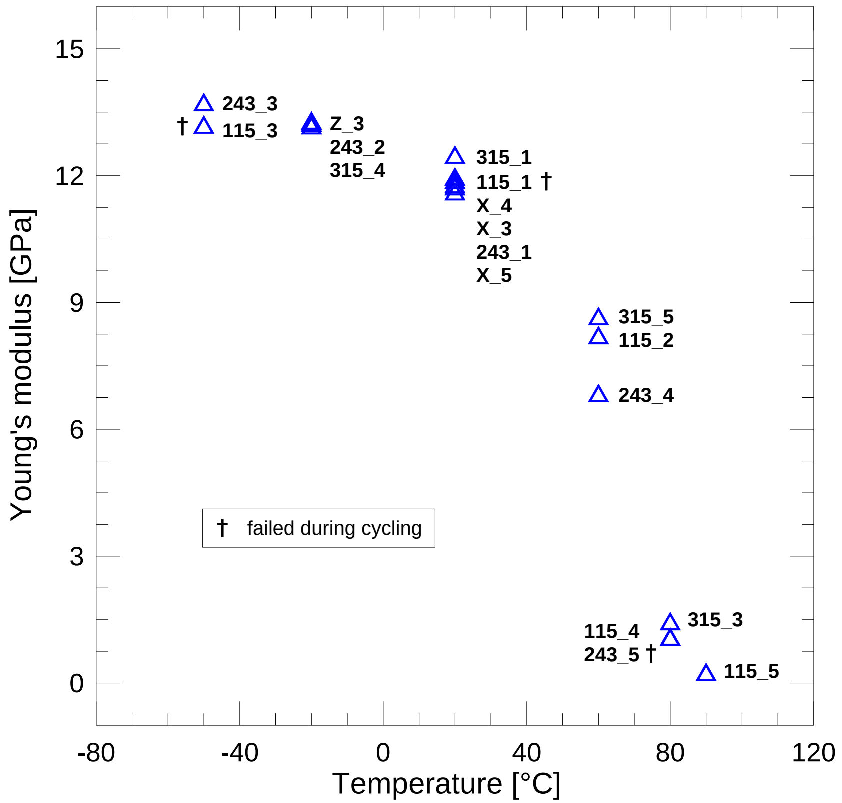


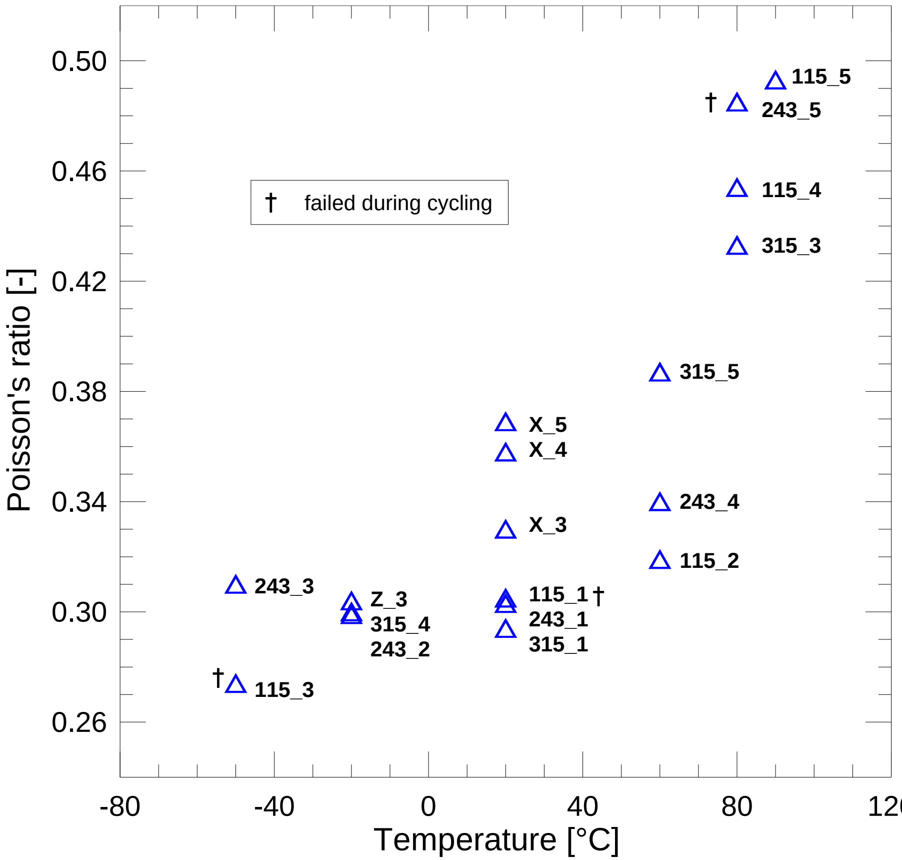



MTS
634.25F-25
S/N 10209464B


Load [N]
Time [s]
-50°C
epoxy243_3
epoxy115_3
Stress [MPa]
Strain [%]
-50°C
epoxy243_3
epoxy115_3
Load [N]
Time [s]
60°C
epoxy115_2
epoxy315_5
epoxy243_4
Stress [MPa]
Strain [%]
60°C
epoxy243_4
epoxy315_5
epoxy115_2

Tensile test



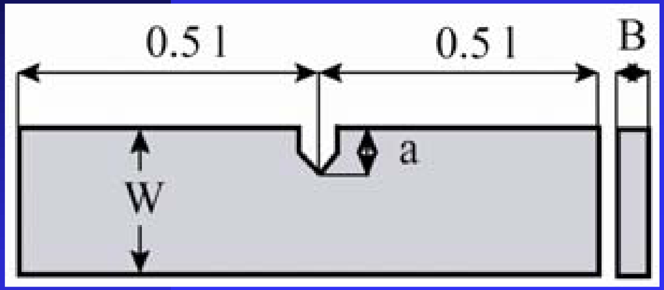


Fracture toughness

Dynamic vs quasistatic

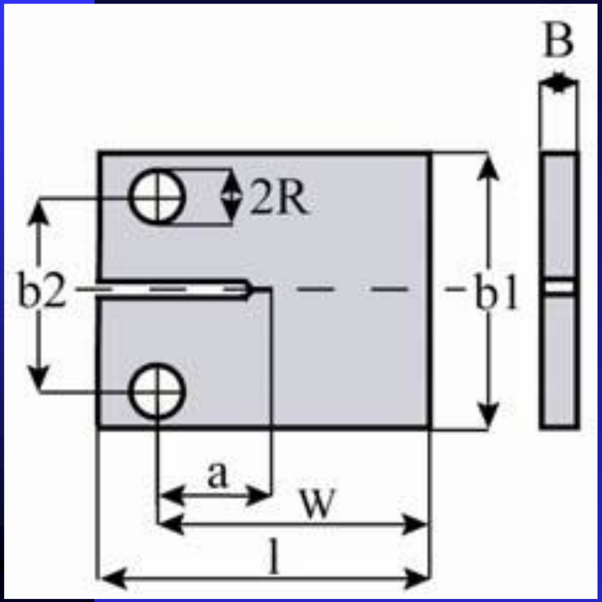
Quasistatic tests

- Flexural test specimens (three point bending)
- Compact tension



W…. width
l...... length > 4,2 W
B…. thickness $W/2 > B > W/4$
a_0…. crack length (notch depth + depth of sharpening) $0.45\ W \leq a_0 \leq 0.55\ W$
S.... span = 4B

Fracture toughness



W.. width

l.... total length of sample 1.25 $W \pm$ 0.01 W

b1.. height 1.20 $W \pm 0.01\ W$

R .. whole radius 0.125 $W \pm 0.005\ W$

B .. Specimen thickness 0.4 $W < B <$ 0.6 W

a0.. crack length (measured from loading axis) 0.45 $W \leq a0 \leq 0.55\ W$

Fracture toughness

Test procedure:

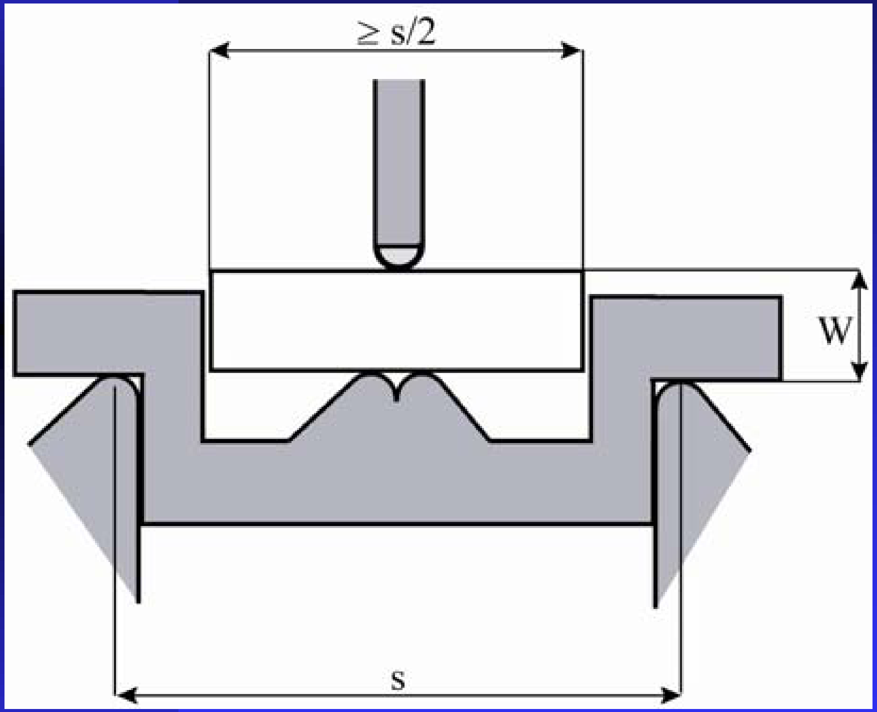
1. Correction for deformation in contact between loading rollers and tested sample

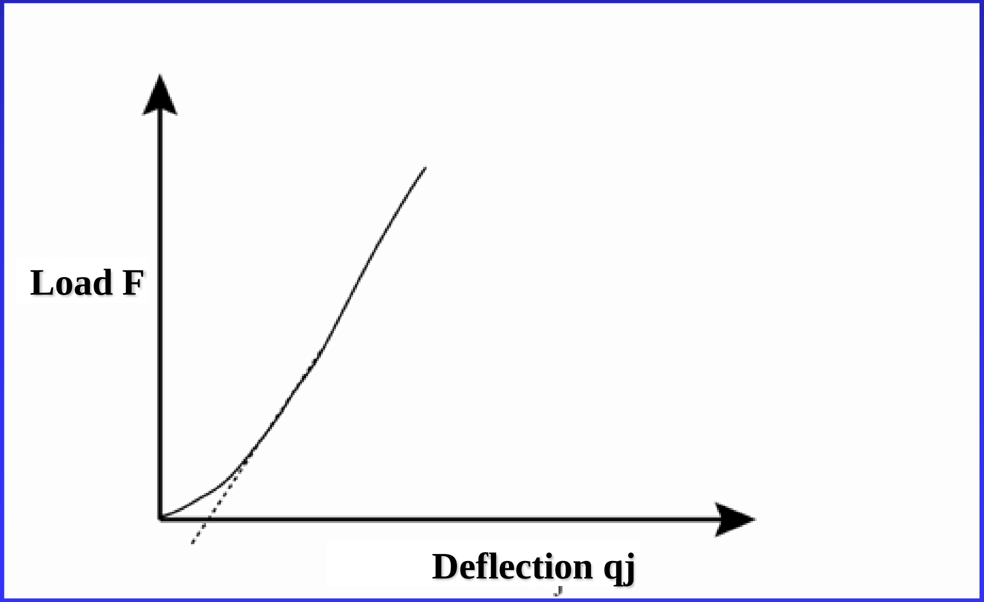
Load deflection trace containing:

- specimen deflection
- sample deformation in contact with rollers
- deformation of fixture itself

W_B - are below load – deflection trace, corresponding to pure deflection (deformation) of pre-cracked specimen

Q – rigidity of test specimen is given by ratio of load and deflection F/q correction curve - F-qj as a results of flexural test on full specimen without notch and crack in special fixture in which the rollers are as close as possible and in the middle of the sample





Subtracting the curve for full specimen and curve for pre-cracked specimen

Slope of the obtained curve corresponds to Q

Area below the curve coresponds to deformation energy to fracture initation W_B

2. Determintaion F_Q

F_Q = load corresponding to crack initiation from corrected dependence of F-q (linear, non linear)

Linear dependence F-q (I) $\Rightarrow F_Q = F_{max}$

Non-linear dependence F-q - need to investigate the origin

- plastic deformation
- nonlinear elasticity
- viscous flow
- stable crack propagation

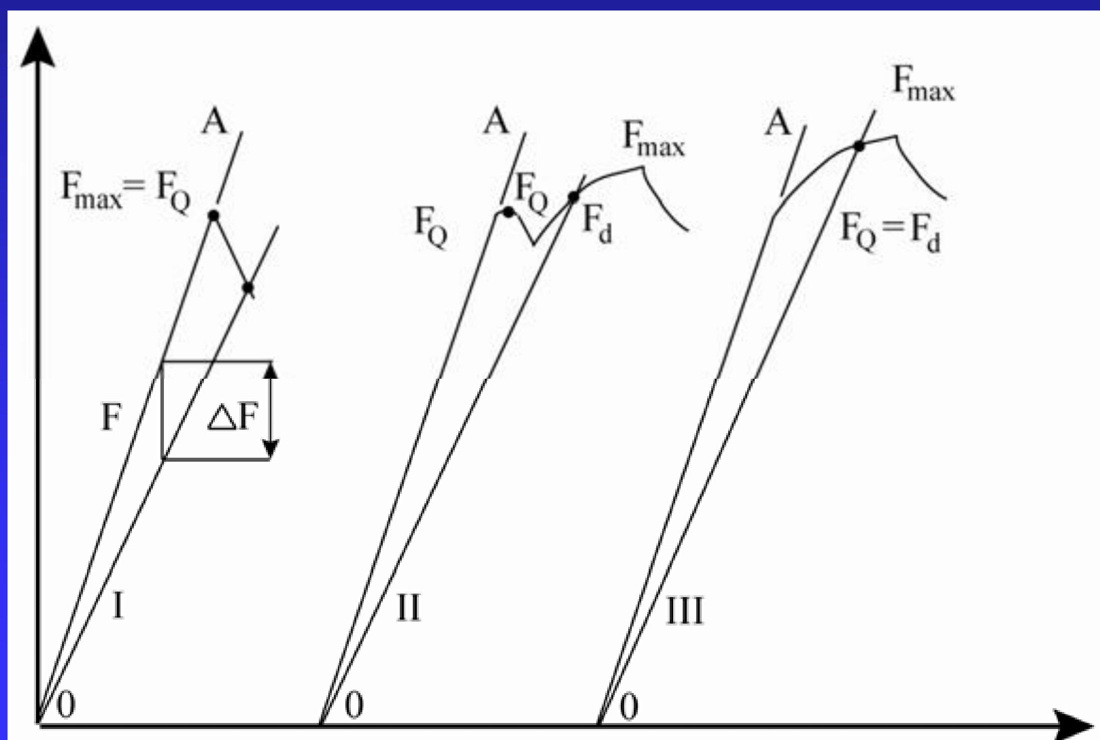
The LELM principles are not kept >> need to use the criterion of 5% secant to determine the initiation load

$F_{max} < F_d$, then $F_Q = F_{max}$

$F_{max} > F_d$, then $F_Q = F_d$

For the second condition, F_Q may be applied only when

$$\frac{F_{max}}{F_Q} \langle 1,1$$



3. Preliminary G_Q value determination

G_Q = energy release rate for initiation condition

$$G_Q = \frac{W_B}{B \cdot W \cdot \phi\left(\frac{a}{W}\right)}$$

W – width

B – thickness

W_B – energy needed for specimen deformation until crack initiation (by integration of area below curve *F* – *q*)

φ(*a/W*) – energetic calibration factor

a) For flexural specimen

$$\phi\left(\frac{a_0}{W}\right) = \frac{A + 18{,}64}{\dfrac{dA}{d\alpha}}$$

$$\alpha = \left(\frac{a_0}{W}\right)$$

$$A = \frac{16\alpha^2}{(1-\alpha)^2}\left(8.9 - 33.717\,\alpha + 79.616\,\alpha^2 - 112.952\,\alpha^3 + 84.815\,\alpha^4 - 25.672\alpha^5\right)$$

$$\frac{dA}{d\alpha} = \frac{16\alpha^2}{(1-\alpha)^2}\left(-33.717 + 159.232\,\alpha - 338.856\,\alpha^2 + 339.26\,\alpha^3 - 128.36\alpha^4\right) +$$
$$16\frac{\left(2\alpha(1-\alpha) + 2\alpha^2\right)}{(1-\alpha)^3}\left(8.9 - 33.717\,\alpha + 79.616\,\alpha^2 - 112.952\,\alpha^3 + 84.815\,\alpha^4 - 25.672\alpha^5\right)$$

b) For compact specimen

$$\phi\left(\frac{a_0}{W}\right) = \frac{A(1-\alpha)}{B+2A} \qquad \alpha = \left(\frac{a_0}{W}\right)$$

$$A = (1{,}9118 + 19{,}118\alpha - 2{,}5122\alpha^2 - 23{,}226\alpha^3 + 20{,}54\alpha^4)$$

$$B = (19{,}118 - 5{,}0244\alpha - 69{,}678\alpha^2 + 82{,}16\alpha^3)(1-\alpha)$$

4. Determination of preliminary K_Q value

$$K_Q = \frac{F_Q \cdot f\left(\frac{a}{W}\right)}{B \cdot W^{0,5}}$$

W - width

B - thickness

F_Q - force corresponding to crack initation

f(a/W) – geometrical calibration factor *a) for flexural specimen*

$$f\left(\frac{a_0}{W}\right)=\frac{6\left(\frac{a_0}{W}\right)^{0,5}\left[1,99-\left(\frac{a_0}{W}\right)\left(1-\frac{a_0}{W}\right)\left(2,15-3,93\left(\frac{a_0}{W}\right)+2,7\left(\frac{a_0}{W}\right)^2\right)\right]}{\left(1-\frac{2a_0}{W}\right)\left(1-\frac{a_0}{W}\right)^{1,5}}$$

b) for compact specimen

$$f\left(\frac{a_0}{W}\right)=\frac{\left(2+\frac{a_0}{W}\right)\left[0,886+4,64\left(\frac{a_0}{W}\right)-13,32\left(\frac{a_0}{W}\right)^2+14,72\left(\frac{a_0}{W}\right)^3-5,6\left(\frac{a_0}{W}\right)^4\right]}{\left(1-\frac{a_0}{W}\right)^{1,5}}$$

5. Validity criteria for K_Q a G_Q

Control of crack tip plastic zone dimensions

h - characteristic dimension of plastic zone

- thickness $B > 2.5*h$ [mm]
- crck length $a > 2,5*h$ [mm]
- ligament $(W-a) > 2,5*h$ [mm]

For determination of characteristic dimension (of plastic zone)

From preliminary value of K_Q

$$h = \left(\frac{K_Q}{\sigma_Y} \right)^2$$

From preliminary value of G_Q

$$h = \frac{2 \cdot \left[f\left(\frac{a}{W}\right) \right]^2 \cdot \phi\left(\frac{a}{W}\right) \cdot Q \cdot G_Q}{B \cdot \sigma_Y^2}$$

6. *Valid valus of K_{IC} a G_{IC}*

Based on fulfilling the validity criteria

$$G_Q = G_{IC}$$
$$K_Q = K_{IC}$$

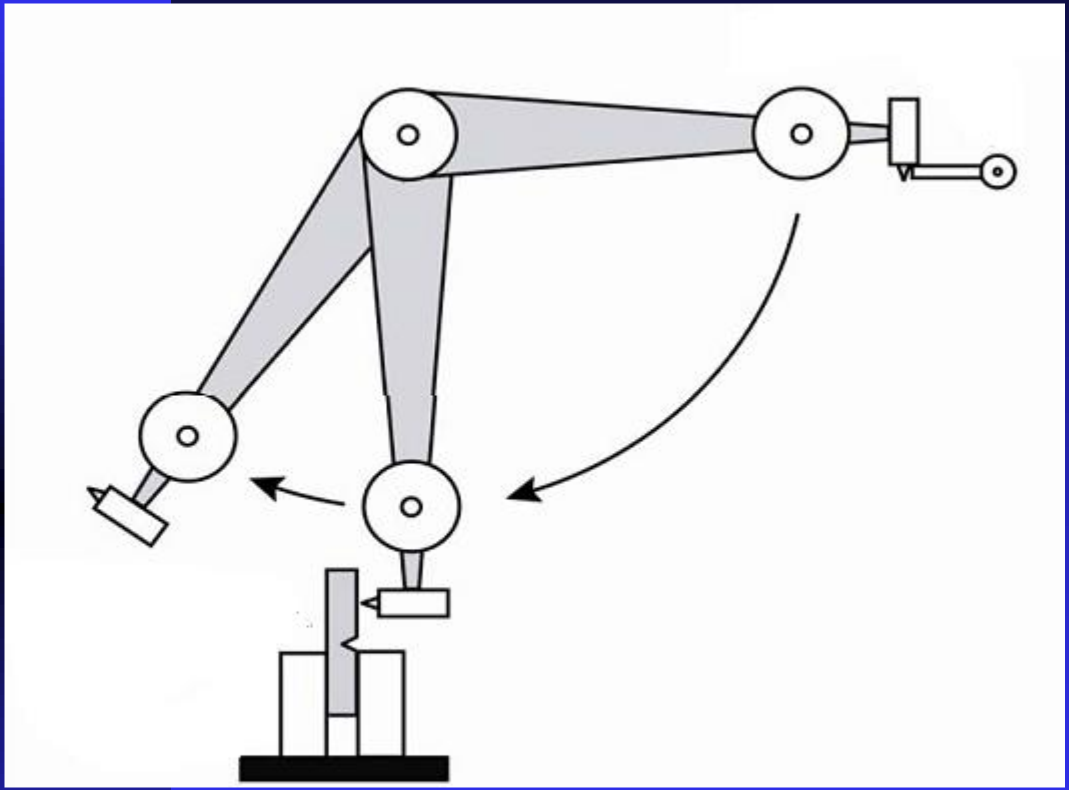
7. Cross checking of results

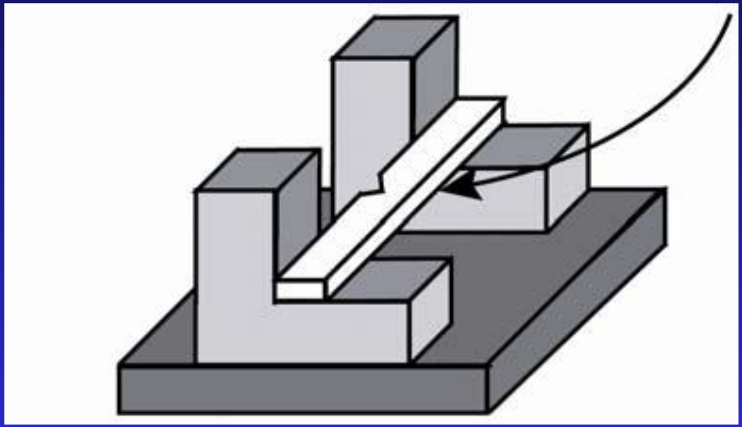
This is base on relation between Young's modulus E and specimen rigidity and K_{IC} a G_{IC} values.

$$E_{rigidity} = \frac{2 \cdot \left[f\left(\frac{a}{W}\right)\right]^2 \cdot \phi\left(\frac{a}{W}\right) \cdot Q}{B}$$

$$E_{fracture} = \frac{(K_{IC})^2}{G_{IC}}$$

Impact tests:





Impact energy for sample without notch a_{cU} or with a_{cN}.

Impact test of tensile sample