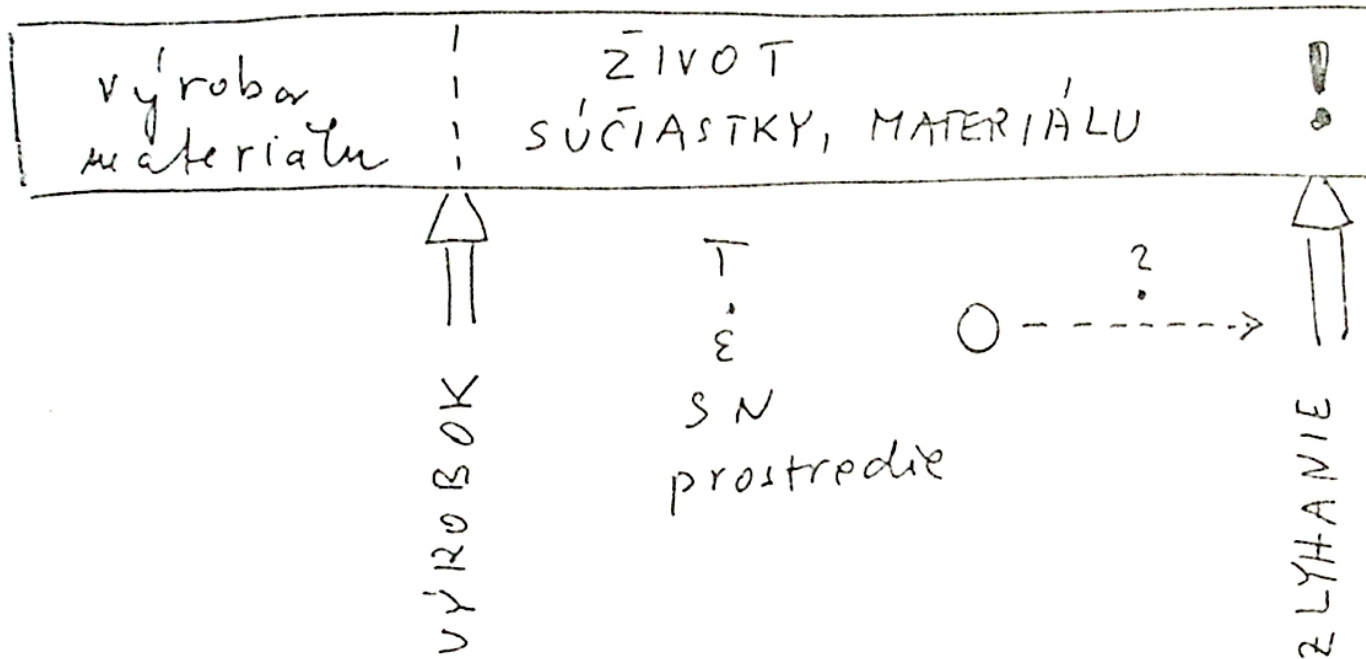


# **Mechanické vlastnosti povrchů a jejich zkoušení**

Ladislav Pešek

[ladislav.pesek@tuke.sk](mailto:ladislav.pesek@tuke.sk)

????????????

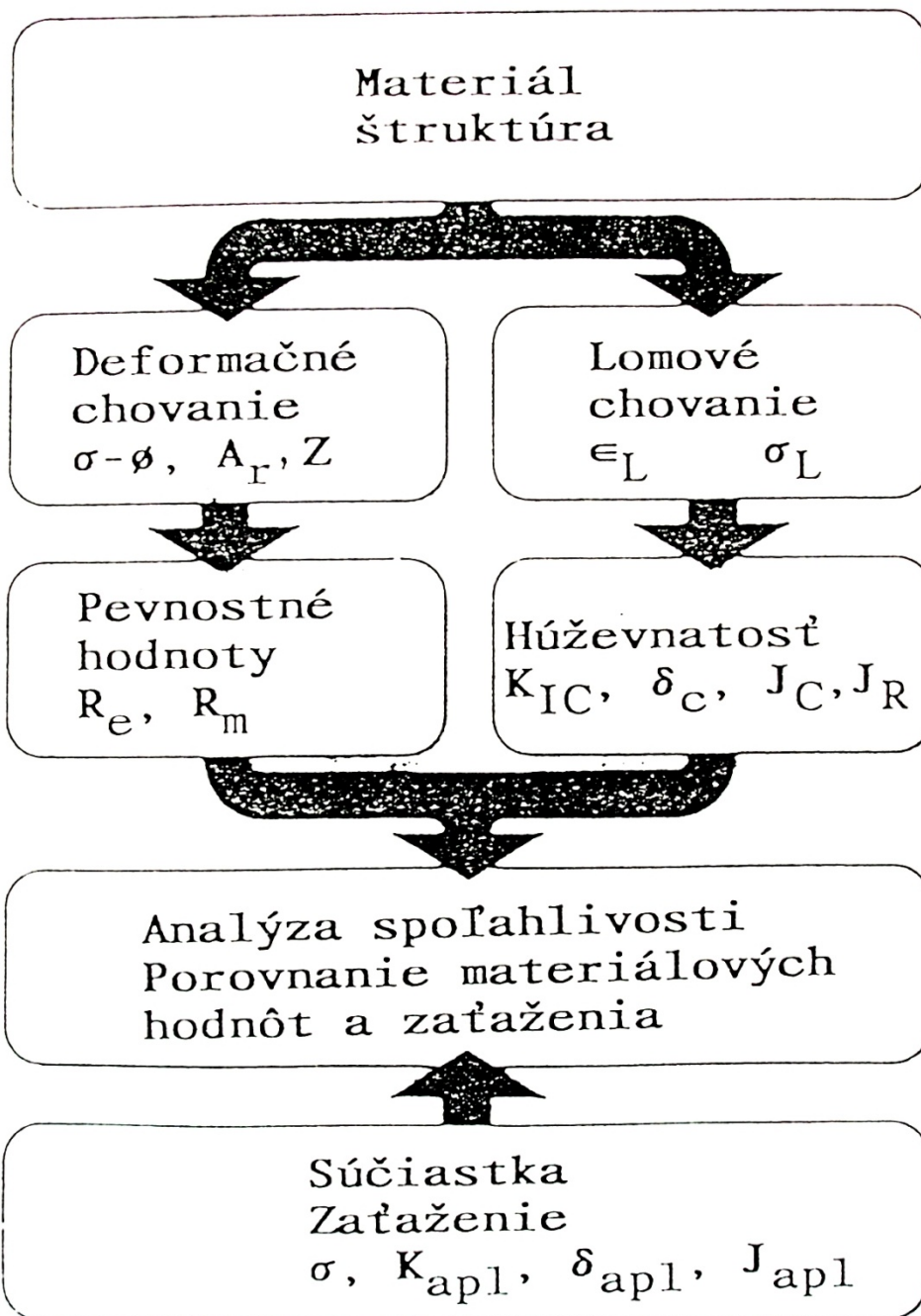


(?) Prečo?

***Materiál  
Štruktúra***

***Povrch***

***Cez povrch  
do vnútra  
materiálu***



# Základy

$$F = m \cdot a$$

сила = масса · ускорение

$$\sigma = \frac{F}{S}$$

напряжение  
(механика) = сила / площадь

$$\text{práce} = F \cdot s$$

работа = сила · расстояние

$$\text{výkon} = \frac{\text{práce}}{\text{čas}}$$

мощность = работа / время

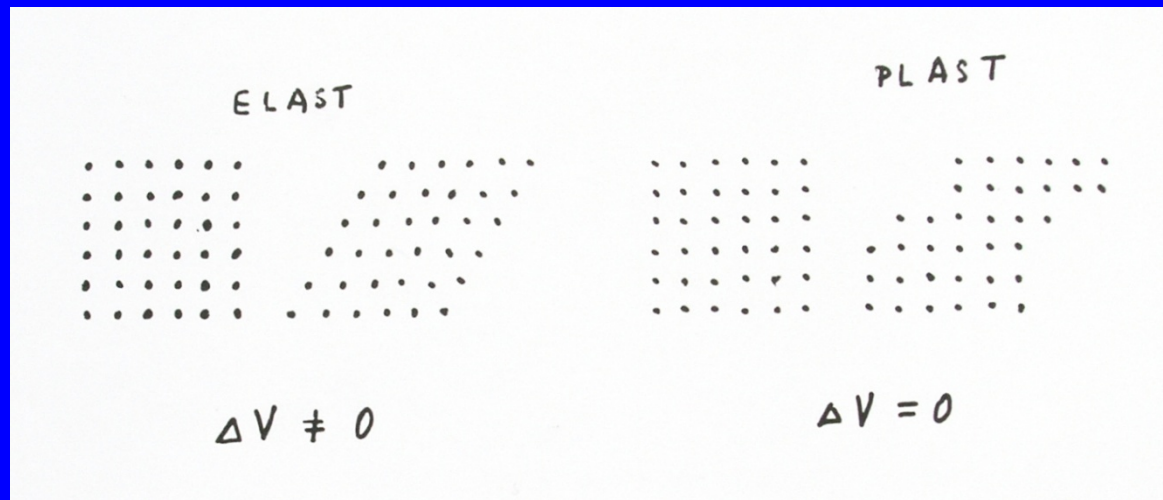
# stress – strain

$$\sigma - \varepsilon$$

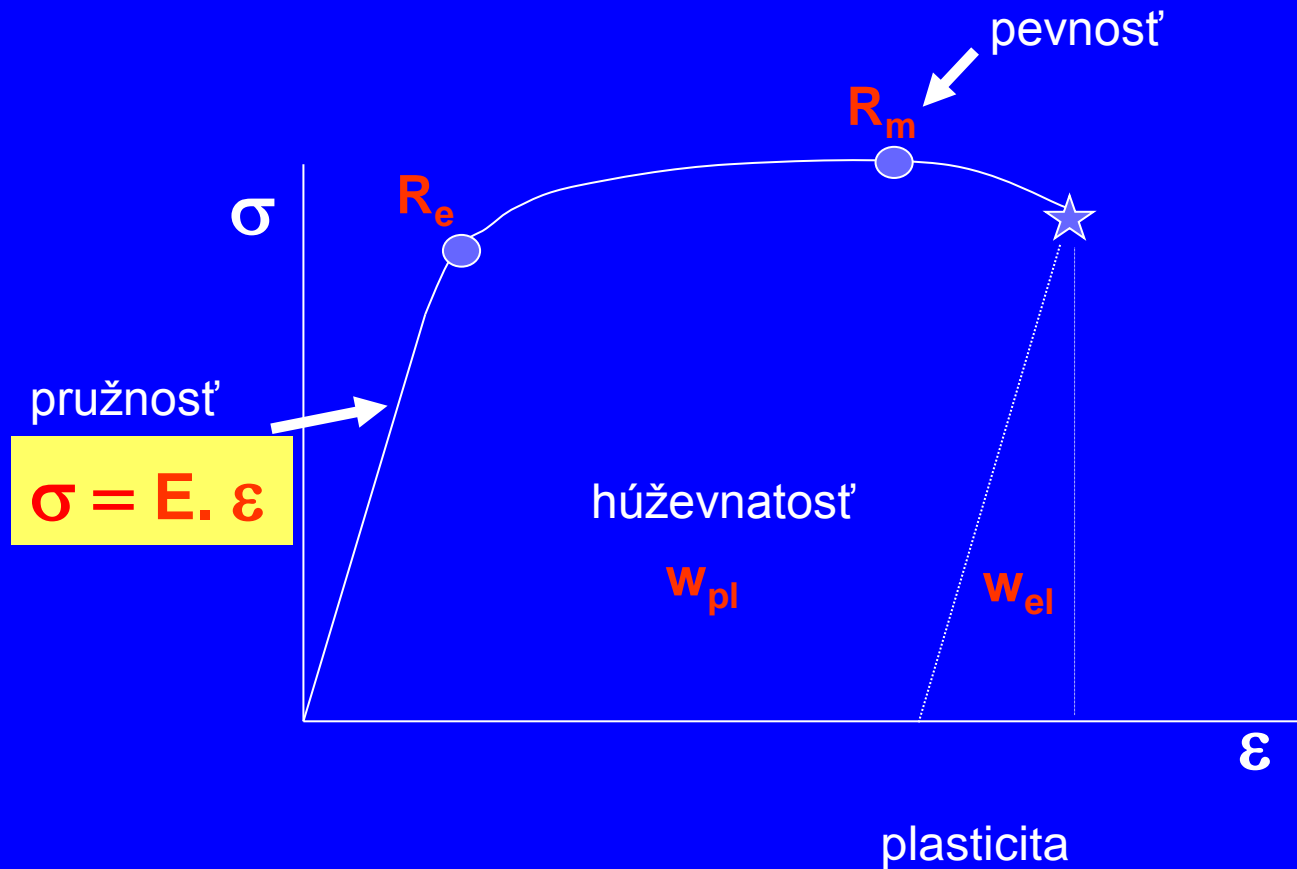
mechanisms:

elastic deformation (reversible)  $\Delta V \neq 0$

plastic deformation (irreversible)  $\Delta V = 0$  (dislocation movement)



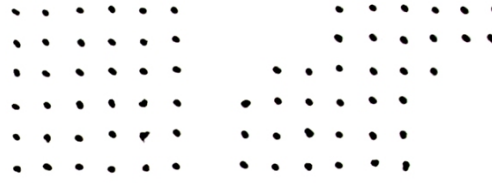
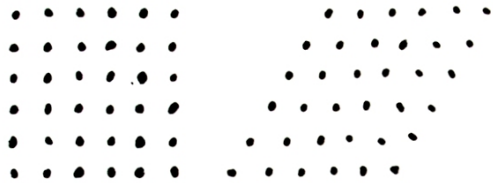
# Základné mechanické vlastnosti



# Elasticita – pružnosť

E L A S T

P L A S T

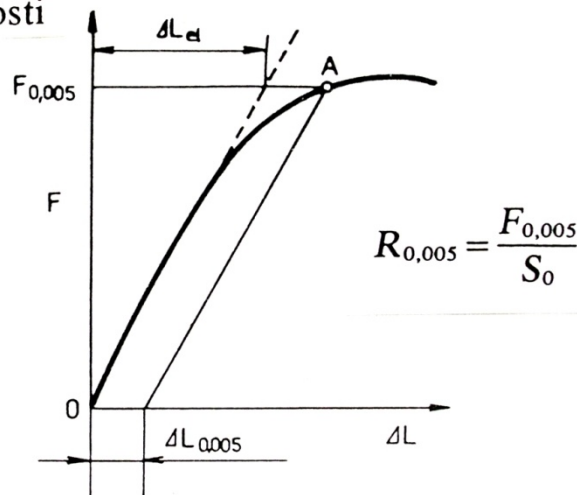


anelasticita

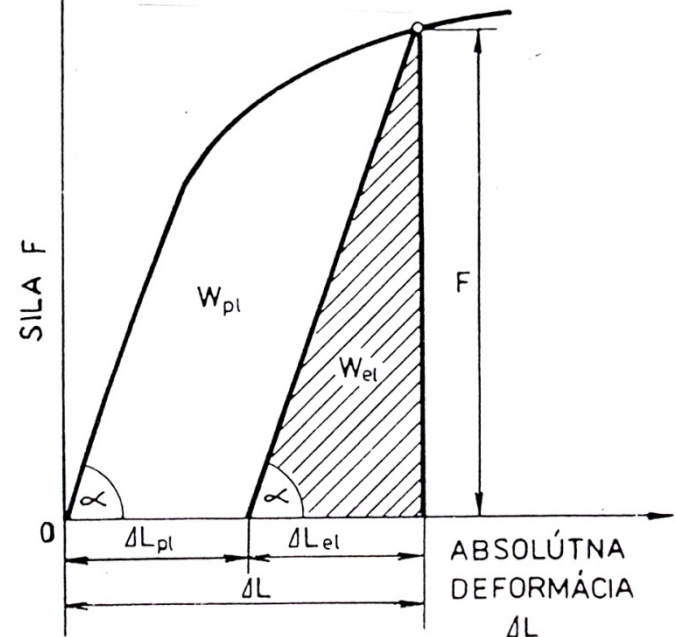
$$\Delta V \neq 0$$

$$\Delta V = 0$$

Konvenčná medza pružnosti

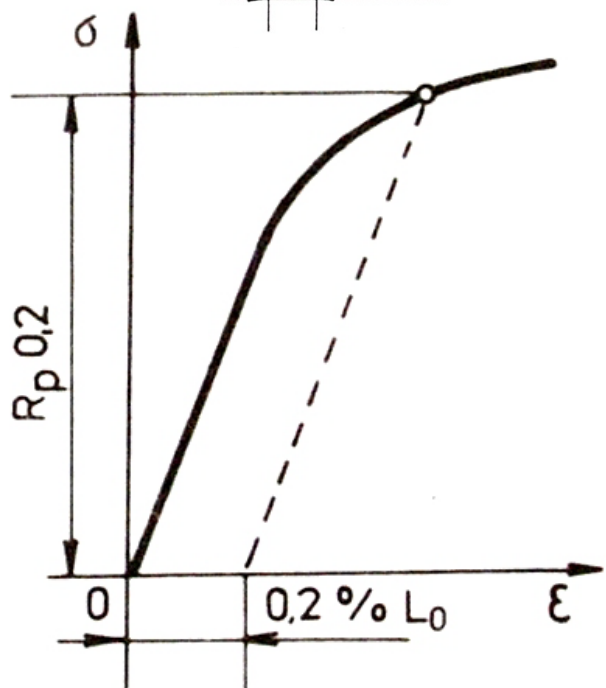
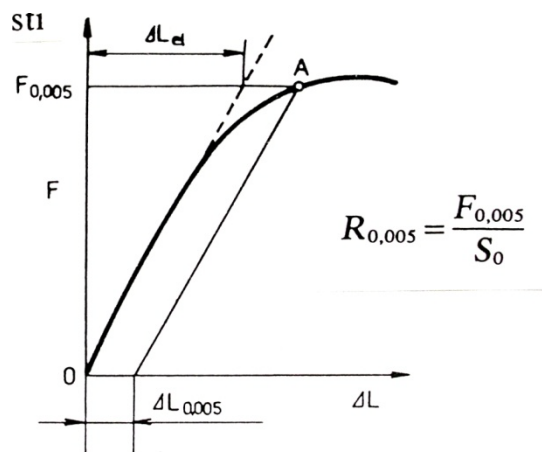


$$W_{el} = \frac{F \cdot \Delta L_{el}}{2} = \frac{\sigma^2}{2E} \cdot V_0 = w_{el} \cdot V_0$$

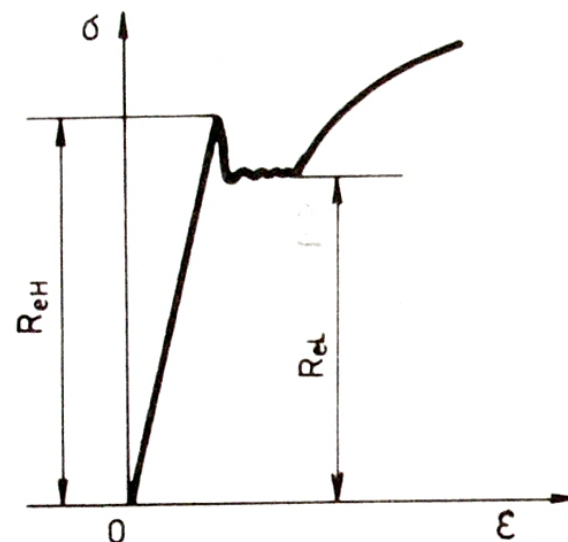


obr. 4.5. Spôsob stanovenia zmluvnej medze pružnosti  $R_{0,005}$

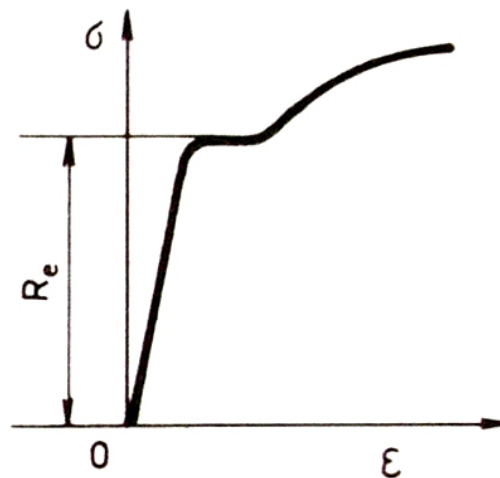
# Medza klzu - začiatok výraznej **plastickej** deformácie



$R_{p\ 0,2}$  určená z trvalej deformácie

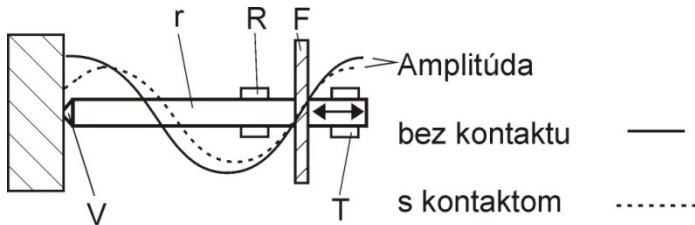


Obr. 4.6. Diskontinuitný priebeh zaťaženia pri výraznej medzi sklzu



Obr. 4.7. Výrazná medza sklzu  $R_e$

# UCI – Ultrasonic Contact Impedance



V Vickersov indenter  
r rezonančná tyč  
F uchytenie  
R snímač  
T generátor kmitov

Principle: ultrasonic frequency change due to contact with specimen surface

$$\Delta f = f(\overset{\text{specimen}}{A_S}, E_P, \nu_P, E_d, \nu_d, f_0)$$

$$A_S = g(E_d, \nu_d, E_P, \nu_P) \cdot h(\overset{\text{contact}}{\Delta f/f_0})$$

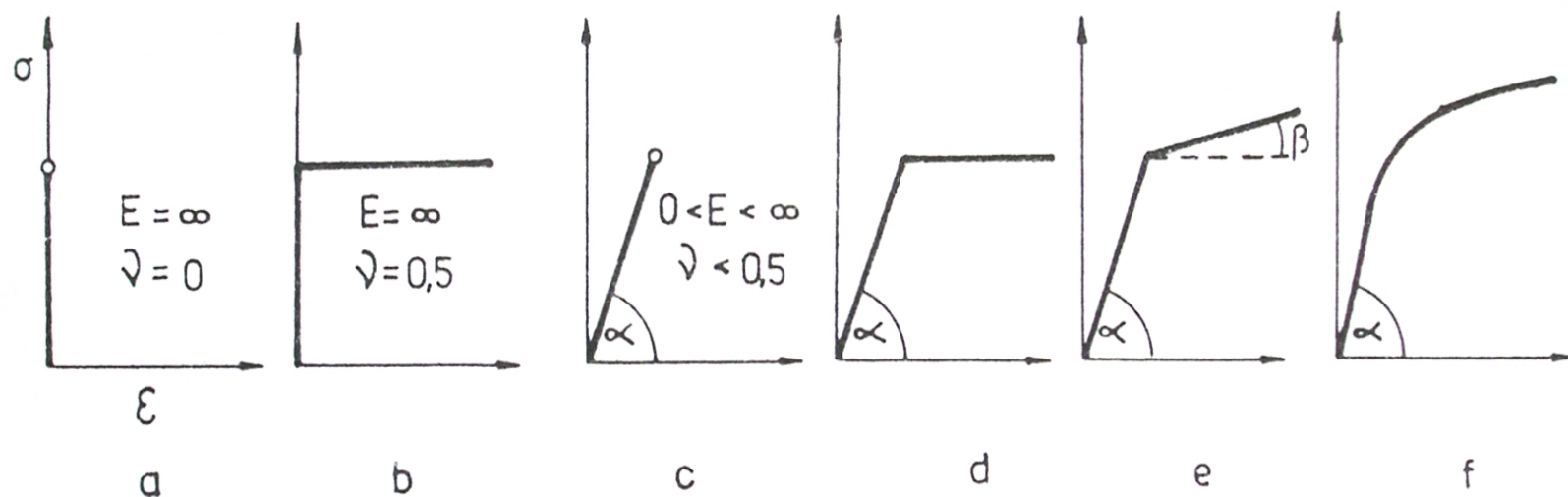
$$\Delta f \rightarrow A_S \rightarrow H$$

$$HV = F / A_S$$

N – reference block  
I – diamond (indenter)  
P - specimen

$$HV = HV_{UCI} \left( \frac{1/E_N + 1/E_I}{1/E_P + 1/E_I} \right)^2$$

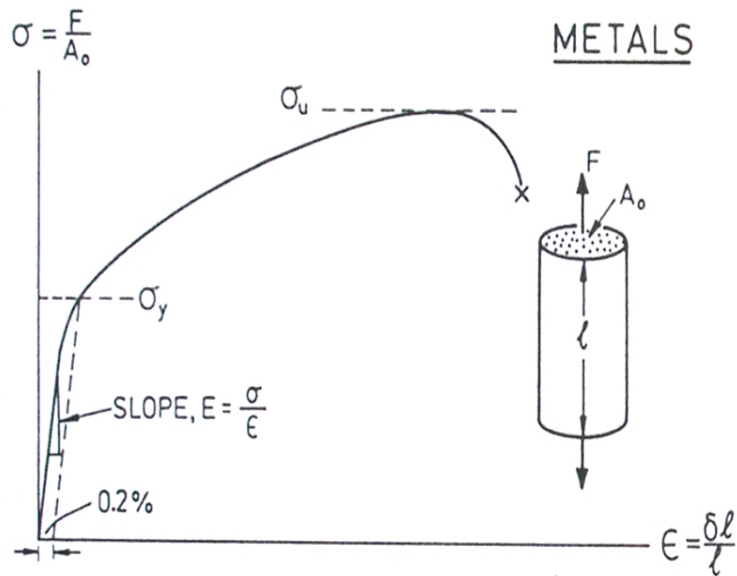
$$\Rightarrow E_P$$



br. 3.7. Ťahové diagramy tuhých telies  
až e — základné typy idealizovaných ťahových diagramov, f — typ reálneho ťahového diagramu

Poissonovo číslo:  $\nu = - \epsilon_{\text{prična}} / \epsilon_{\text{pozdĺžna}}$

# Kovy - t'ah



$$E = \frac{3G}{1 + G/3K} ; \quad G = \frac{E}{2(1 + \nu)} ; \quad K = \frac{E}{3(1 - 2\nu)}$$

$$\begin{aligned} \nu &\approx 1/3 \\ G &\approx 3/8E \\ K &\approx E \end{aligned}$$

FIG. 3.2 The stress-strain curve for a metal, showing the modulus,  $E$ , the 0.2% yield strength,  $\sigma_y$ , and the ultimate strength,  $\sigma_u$ .

# Plasty - t'ah

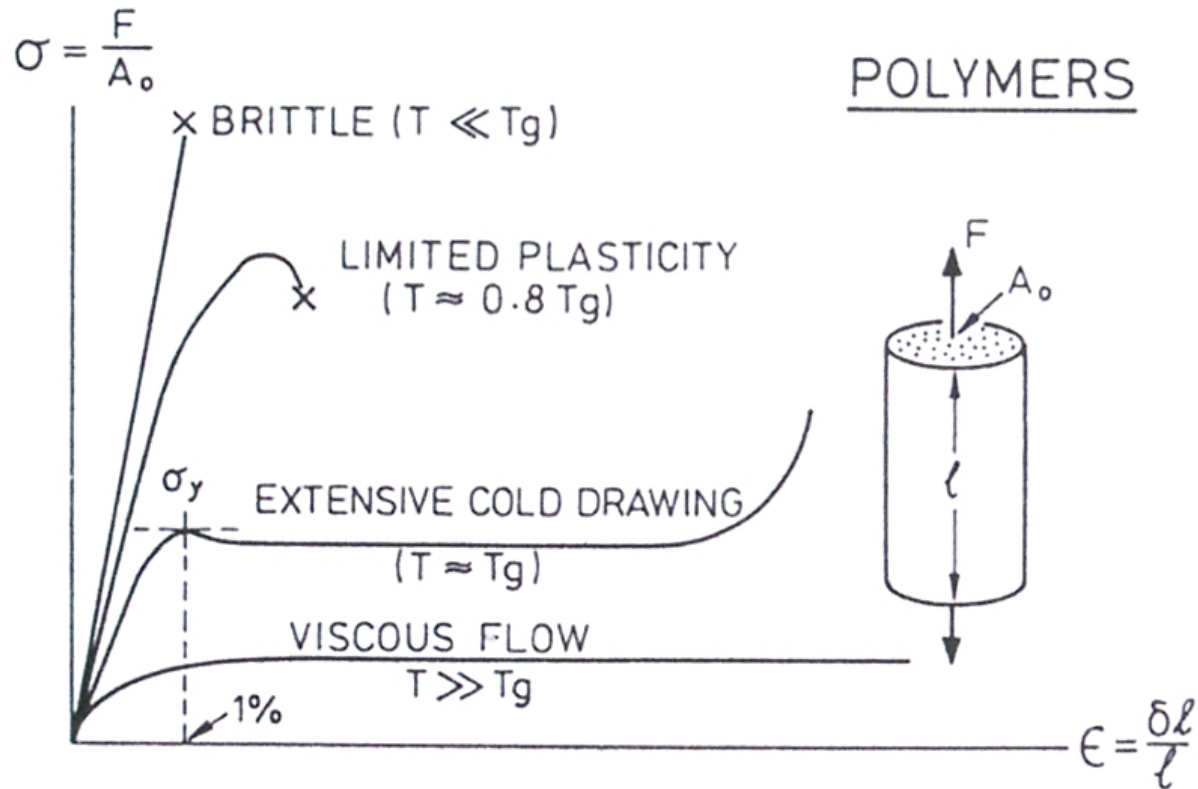


FIG. 3.3 Stress–strain curves for a polymer, below, at and above its glass transition temperature,  $T_g$ .

# Keramika: t'ah, tlak

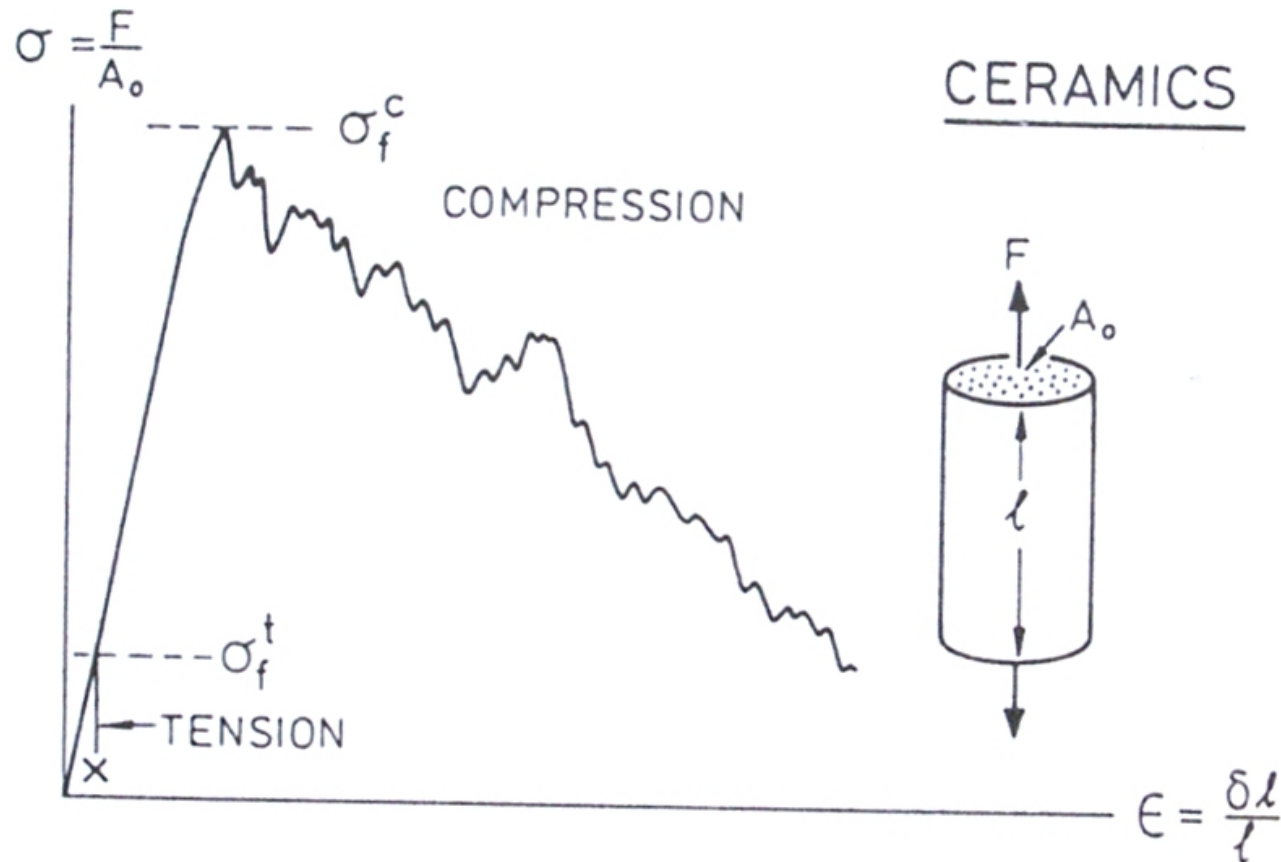
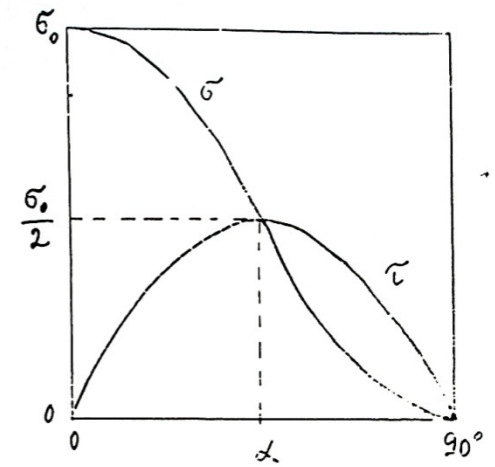
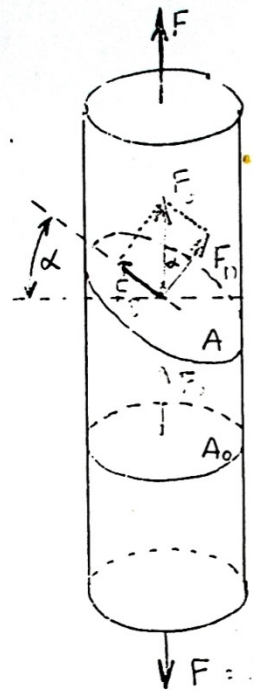


FIG. 3.4 Stress – strain curves for a ceramic in tension and in compression. The compressive strength  $\sigma_c$  is 10 to 15 times greater than the tensile strength  $\sigma_t$ . We identify  $\sigma_f$  with  $\sigma_c$ .

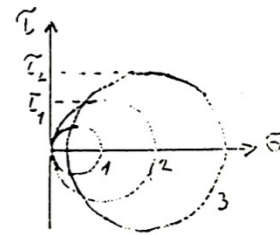
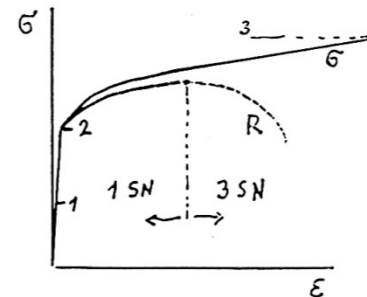
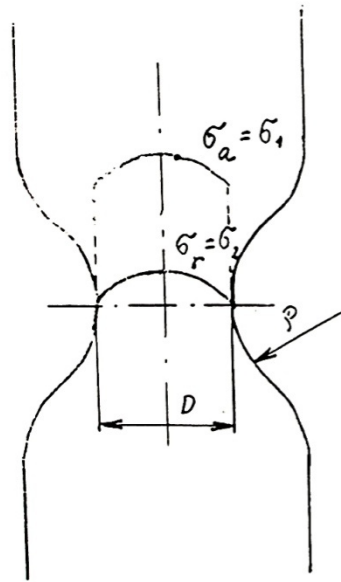
# Napätost'



$$\sigma = \frac{F_n}{A} = \frac{F_0 \cos \alpha}{\frac{A_0}{\cos \alpha}} = \sigma_0 \cos^2 \alpha$$

$$\tau = \frac{F_t}{A} = \frac{F_0 \sin \alpha}{\frac{A_0}{\cos \alpha}} = \frac{1}{2} \sigma_0 \sin 2\alpha$$

$$\sigma_0 = \frac{F_0}{S_0}$$



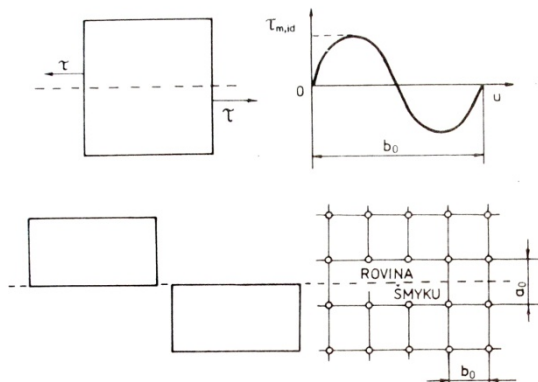
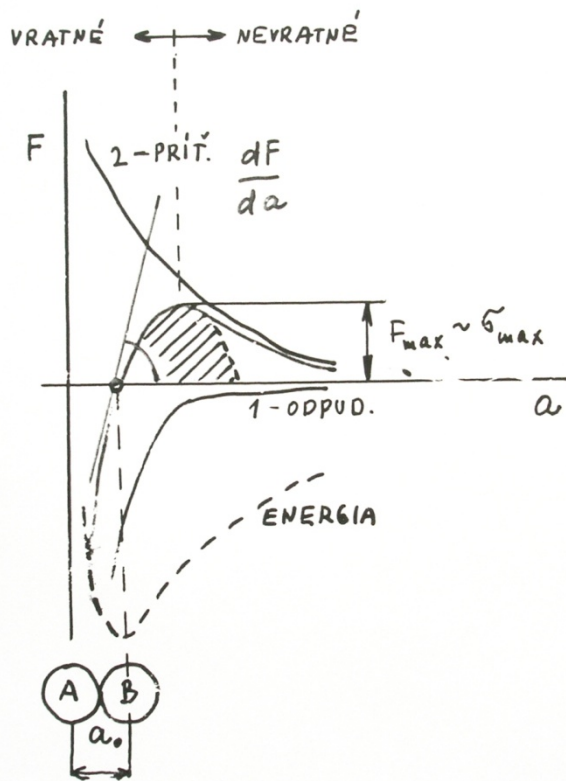
$\epsilon_1$ : sk/z  
 $\epsilon_2$ : lom smyk.

ideálna  
skutočná  
konvenčná

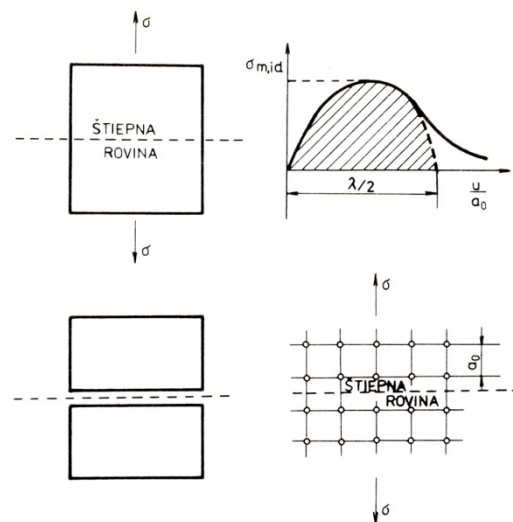
# Pevnosť

t'ah  
tlak  
ohyb  
krut  
šmyk

## Ideálna



Obr. 3.15. Schéma šmykového porušenia



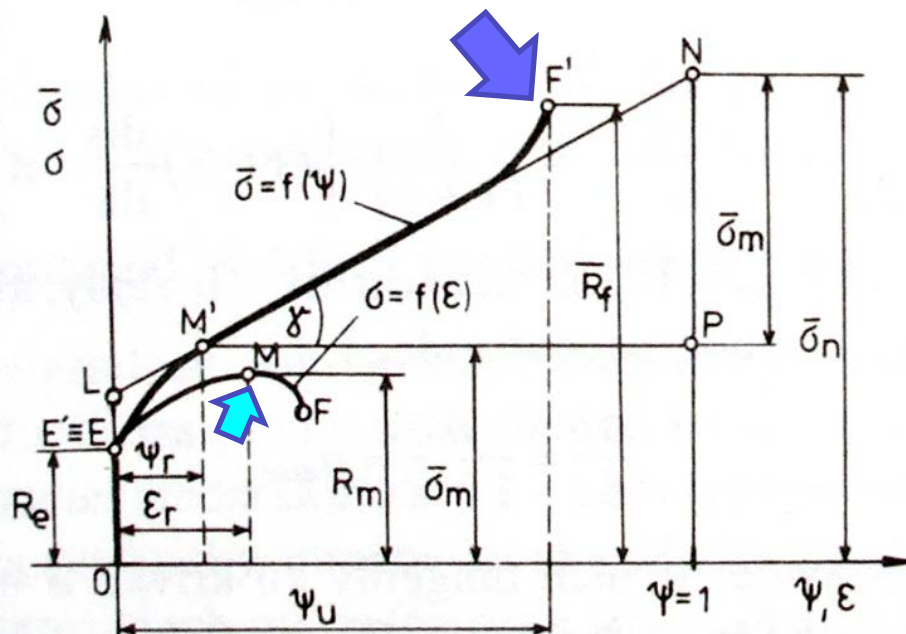
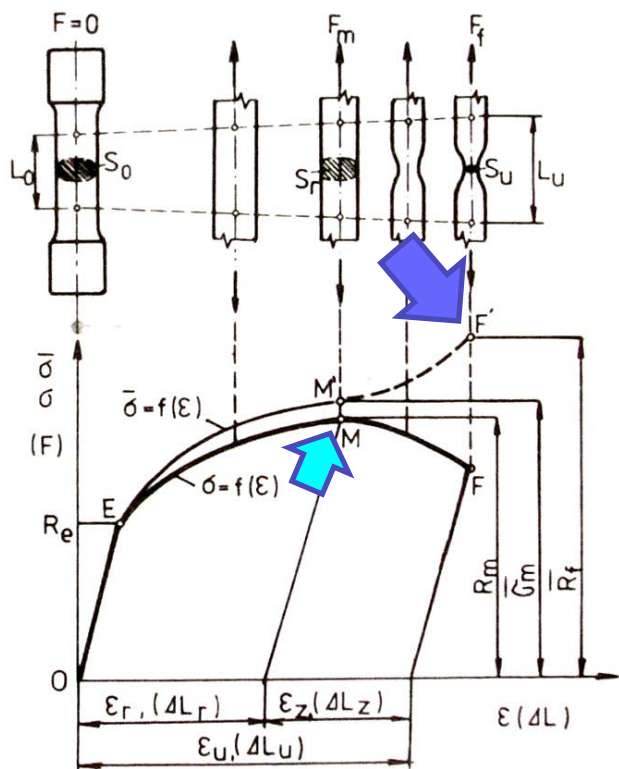
poruchy –  
zníženie pevnosti

ideálna  
skutočná  
konvenčná

# Pevnosť

Skutočná  
Konvenčná

ťah  
tlak  
ohyb  
krut  
šmyk



ťahový diagram (O-E-M-F) a skutočný ťahový diagram (O-E-M'-F')

# Plasticita (plastickosť)

$$\sigma = k \varepsilon^n \text{ deformačné spevňovanie}$$

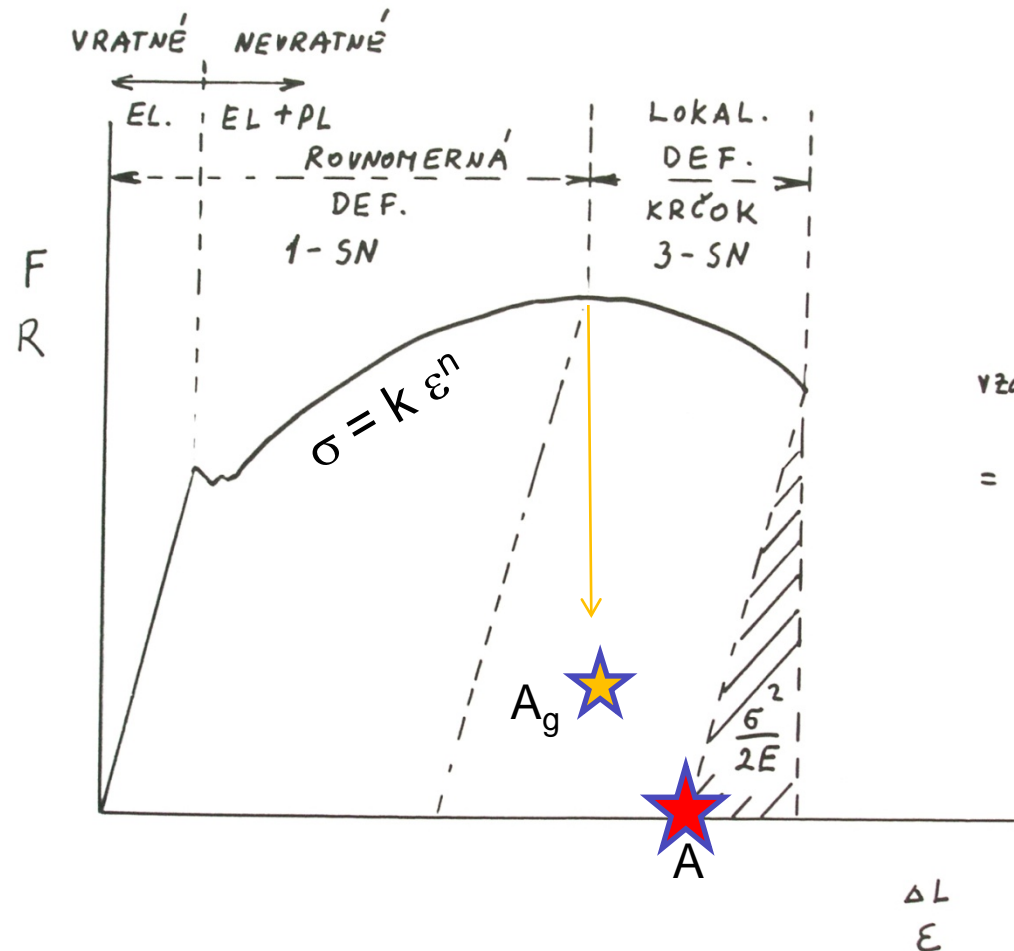
Ťažnosť A

$\sigma$  = skutočné napätie

$\varepsilon$  = skutočná deformácia =  $\ln (S_0/S)$

Rovnomerná ťažnosť  $A_g$

Kontrakcia Z



SNÍMANIE:

$F$

$\Delta L$

$\Delta d$

vzájomne  
al.  
 $= f(t)$

# Húževnatosť

energia

na plastickú deformáciu

do porušenia

$$w_{pl} = \int_0^{\varepsilon_f} \sigma d\varepsilon - \frac{\sigma_f^2}{2E}$$

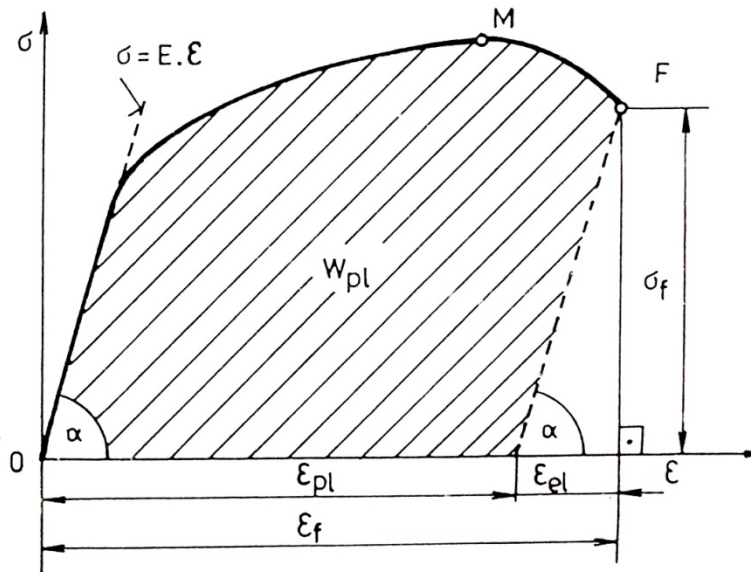
$$\varepsilon_f = \frac{\Delta L_f}{L_0}$$

$$\sigma_f = \frac{F_f}{S_0}$$

vrubová húževnatosť

lomová húževnatosť

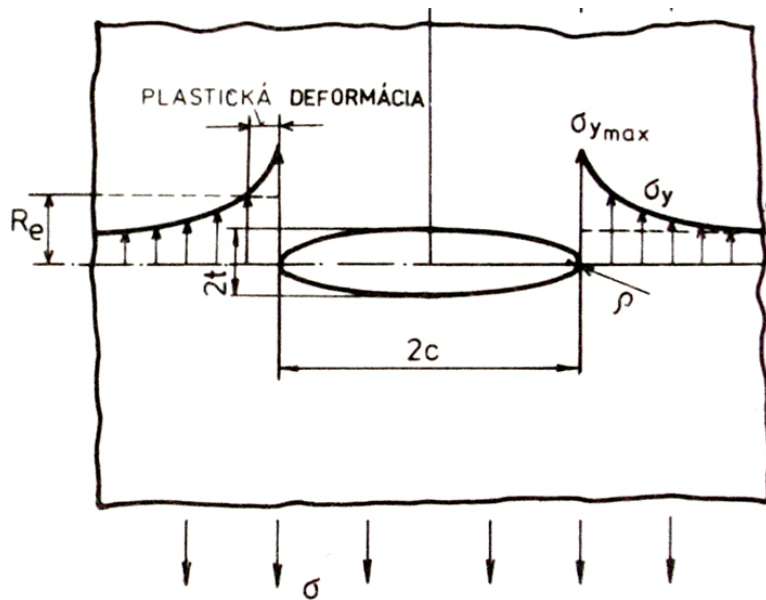
$$\bar{w}_{pl} = \int_0^{\bar{\varepsilon}_f} \bar{\sigma} d\bar{\varepsilon} - \frac{\bar{\sigma}_f^2}{2E}$$



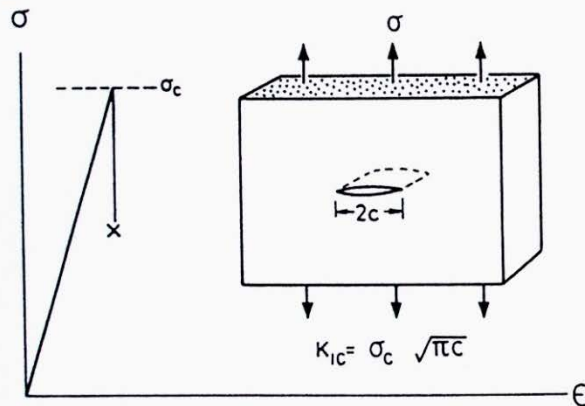
Obr. 3.17. Grafické vyjadrenie húževnatosti do porušenia kovu pri jednoosovom ťahu

# Lomová húževnatosť

## Koncentrácia napätí



$$PZ = a (K_t/R_e)^2$$

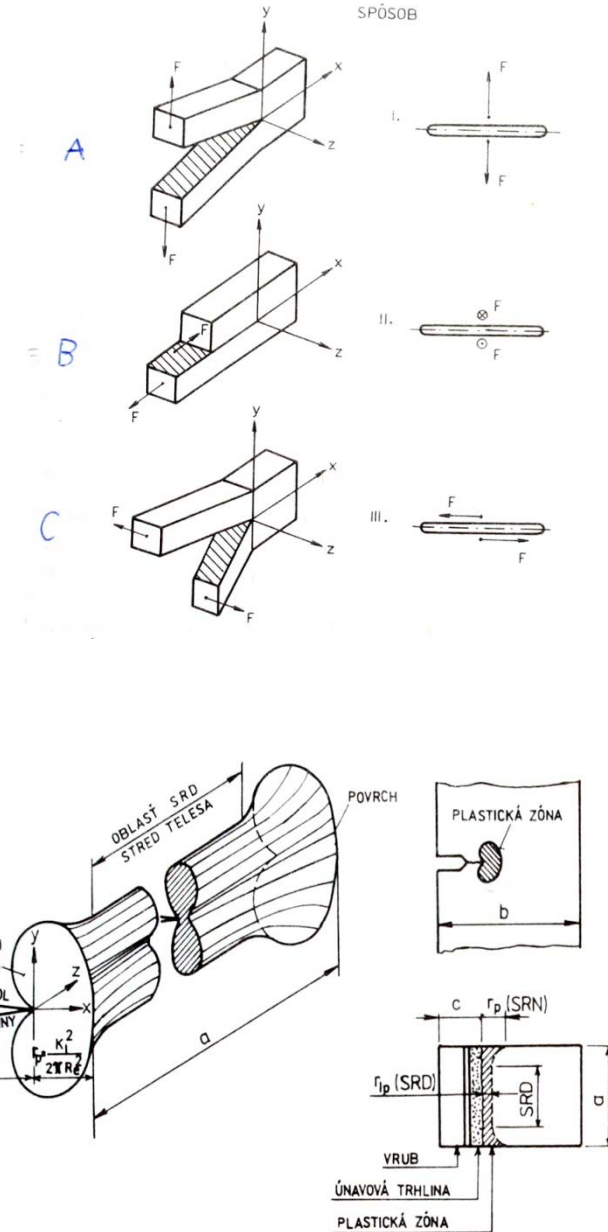


$$K_c = Y\sigma_c\sqrt{\pi c}$$

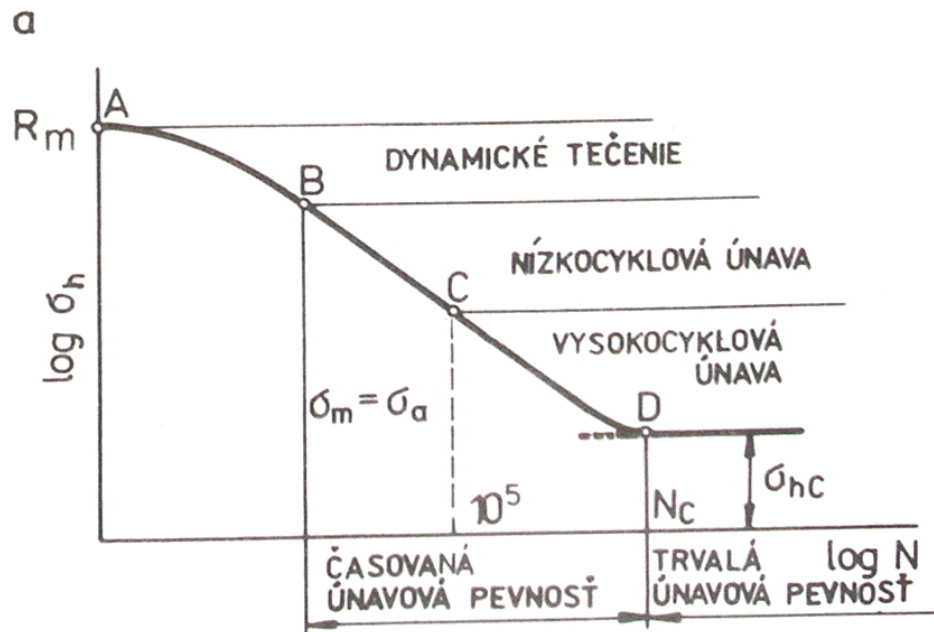
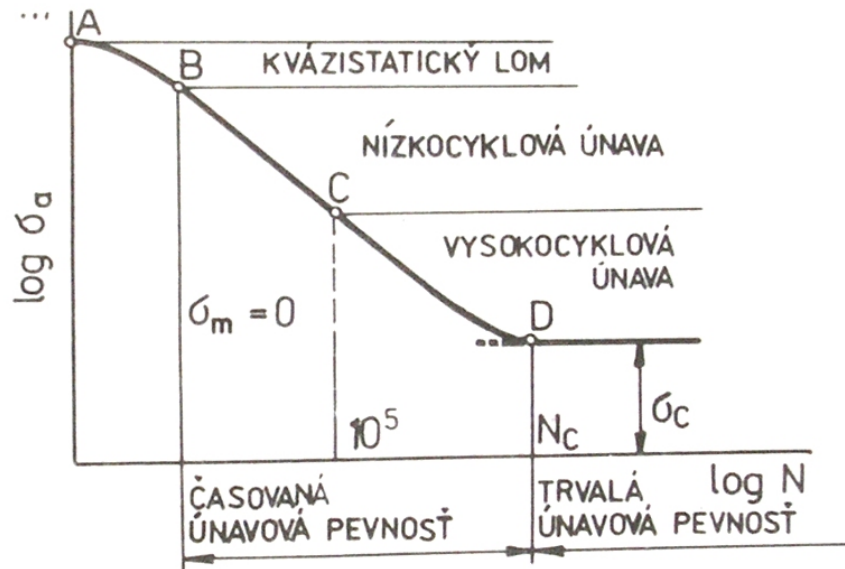
$$G_c = \frac{K_c^2}{E(1+\nu)}$$

FIG. 3.6 The fracture toughness,  $K_c$ , measures the resistance to the propagation of a crack. The failure strength of a brittle solid containing a crack of length  $2c$  is  $\sigma_f = YK_c/\sqrt{\pi c}$ , where  $Y$  is a constant near unity.

## Otváranie trhliny

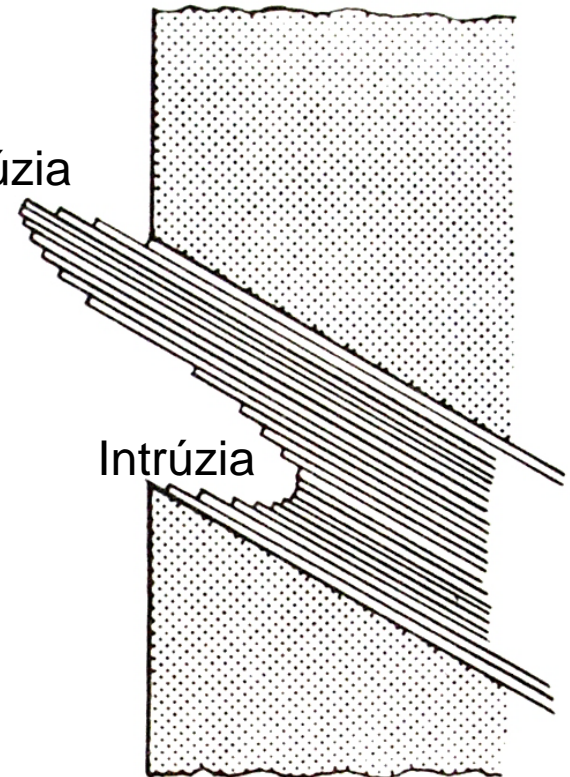


# Únava



Extrúzia

Intrúzia



# Tečenie - creep

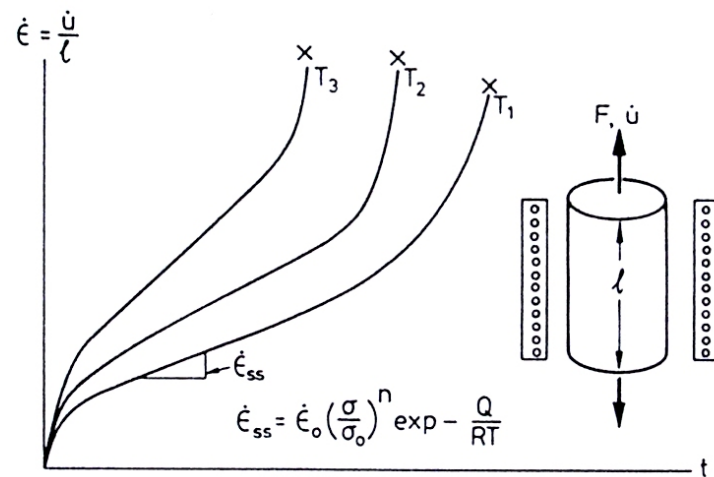
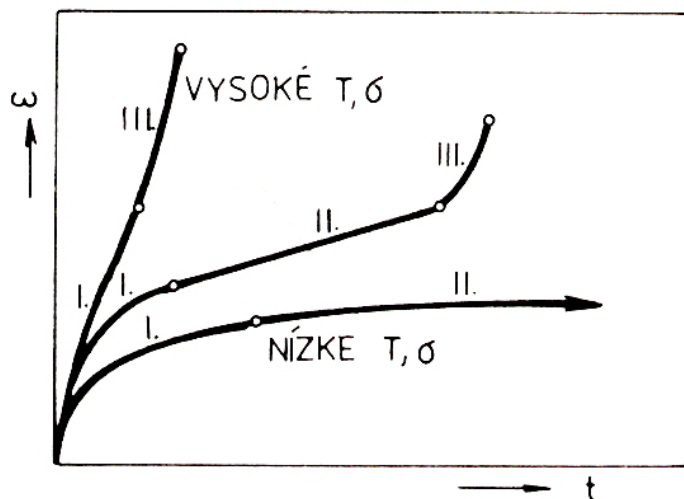
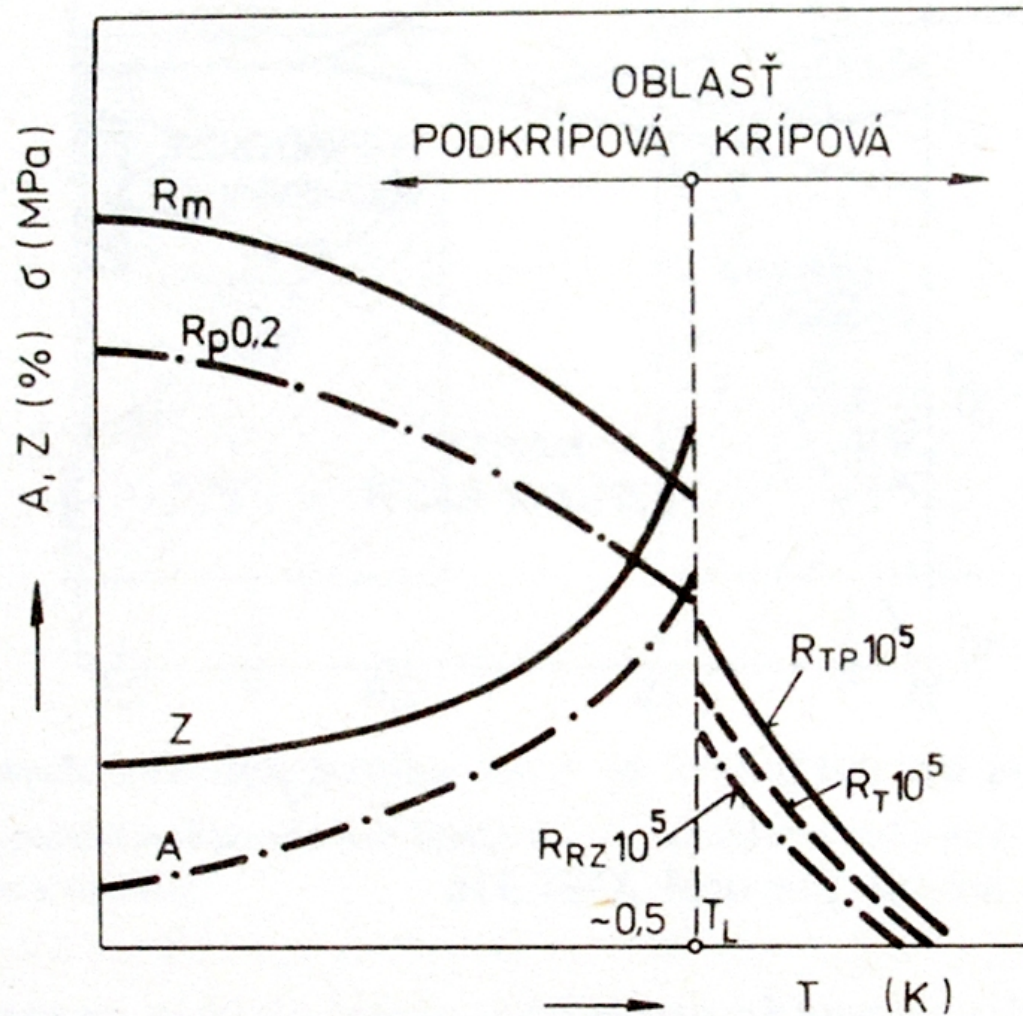


FIG. 3.10 Creep is the slow deformation with time under load. It is characterised by the creep constants  $\dot{\epsilon}_0$ ,  $\sigma_0$  and  $Q$ .

$$\dot{\epsilon} = A \left[ \frac{\sigma}{\sigma_0} \right]^n \exp - \left[ \frac{Q}{RT} \right]$$

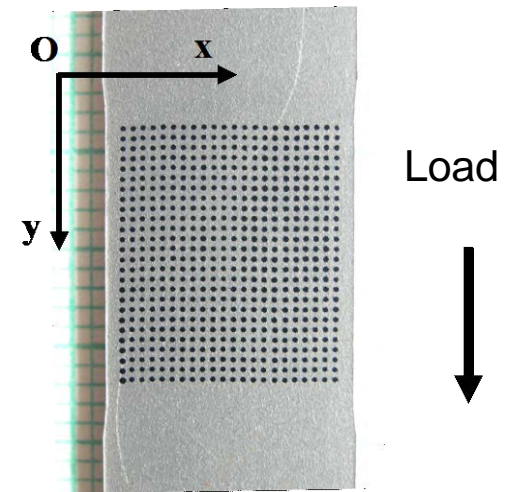
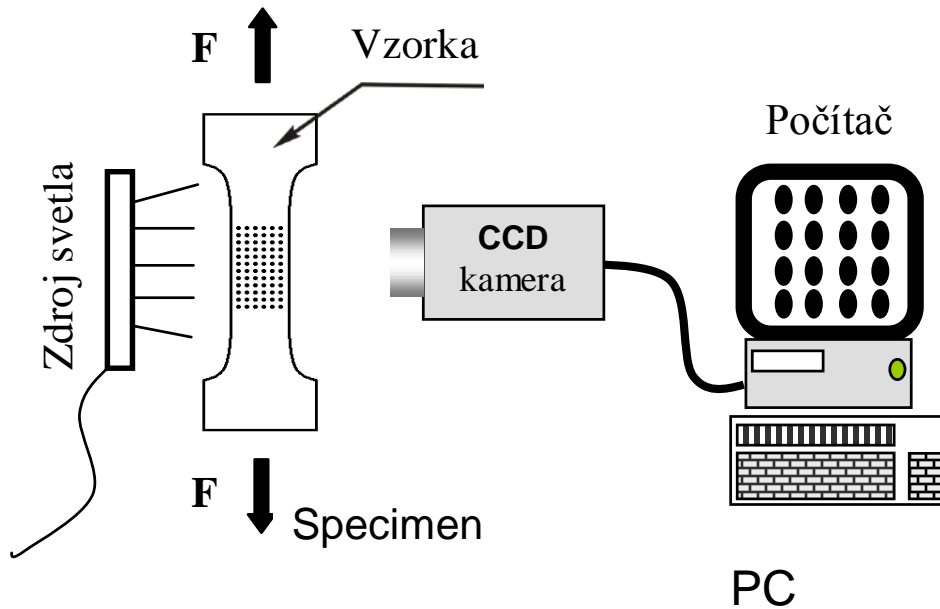


# Zvýšené teploty

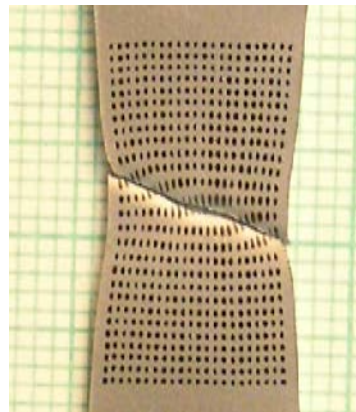
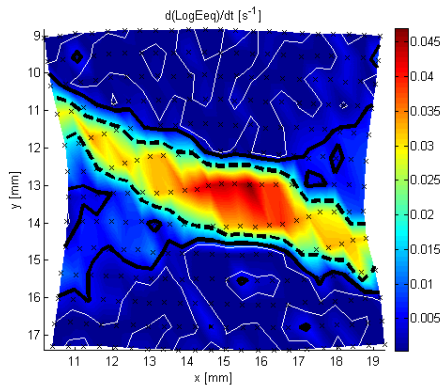


Obr. 5.133. Kritériá žiarupevnosti v oblastiach použitia

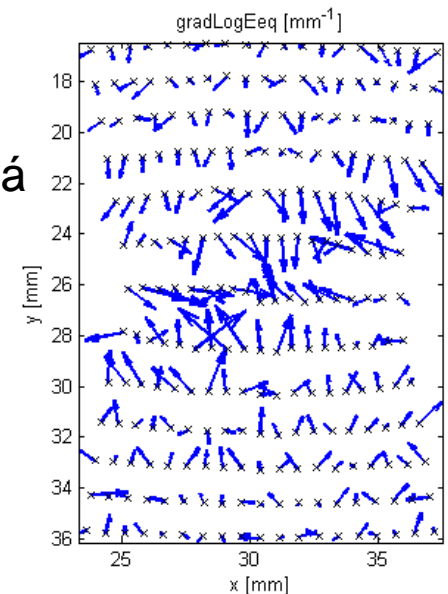
# Videoextenzometria - bezkontaktné meranie posunutí (deformácií) na povrchu súčiastky



Deformačná mapa

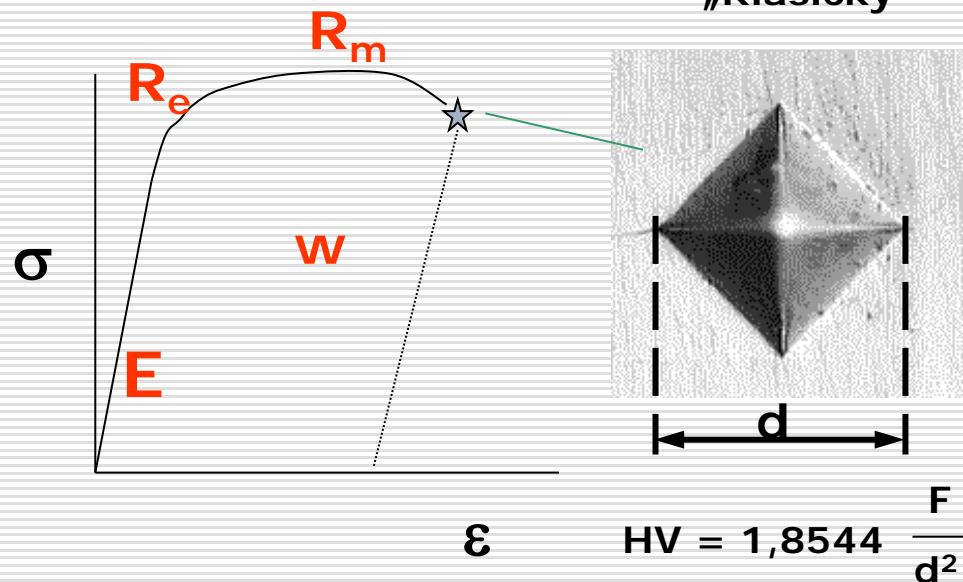


Vektorová mapa



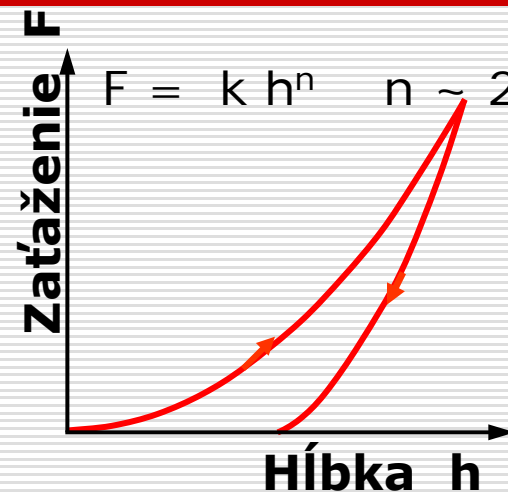
# Inštrumentovaná tvrdosť (DSI)

„Klasický“

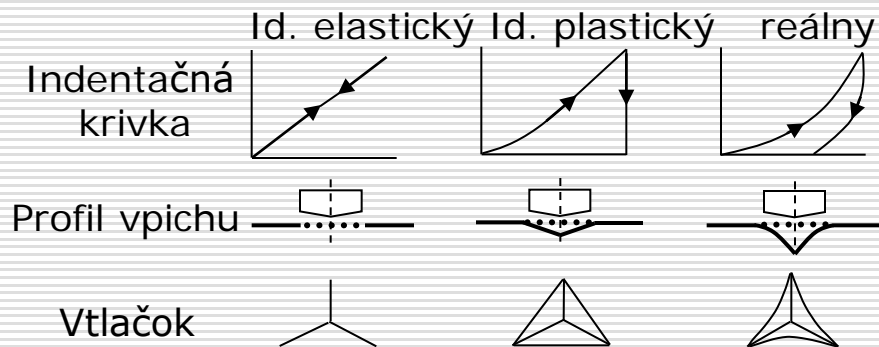
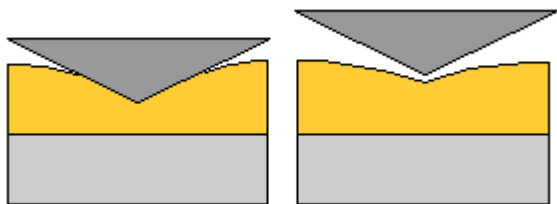


Zaťažovanie: statické  
dynamické (kmitanie, rázy)

elastické a plastické vlastnosti  
vzorky určujú tvar  
indentačnej krivky



zaťaženie      odľahčenie



# Inštrumentovaná tvrdost' - veličiny

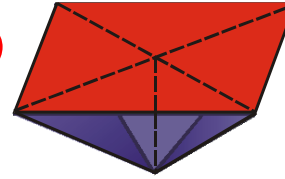
**Tvrdost' Martensova**

$$HM = \frac{F}{A_s(h)} = \frac{F}{k \cdot h^2}$$

**Indentačná**

$$H_{IT} = \frac{F_{\max}}{A_P(h_r)}$$

$$A_P(h)$$
$$A_s(h)$$



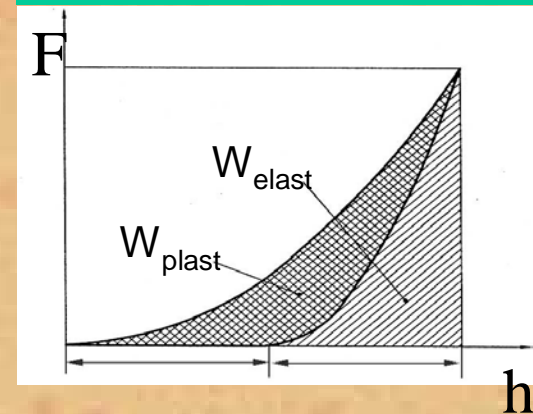
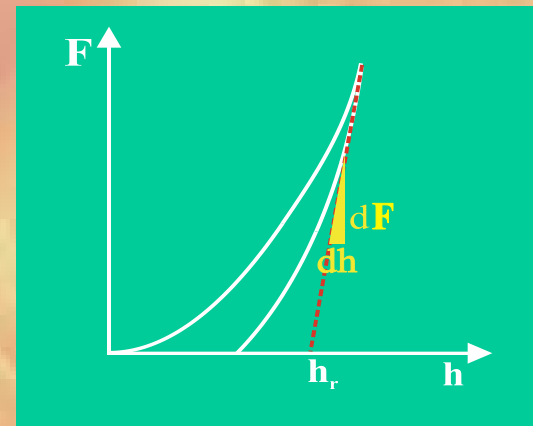
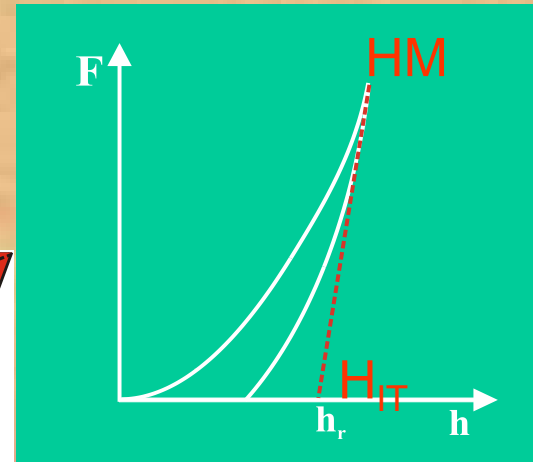
**Modul pružnosti**

$$\frac{1}{E_r} = \frac{(1-\nu^2)}{E} + \frac{(1-\nu_i^2)}{E_i}$$

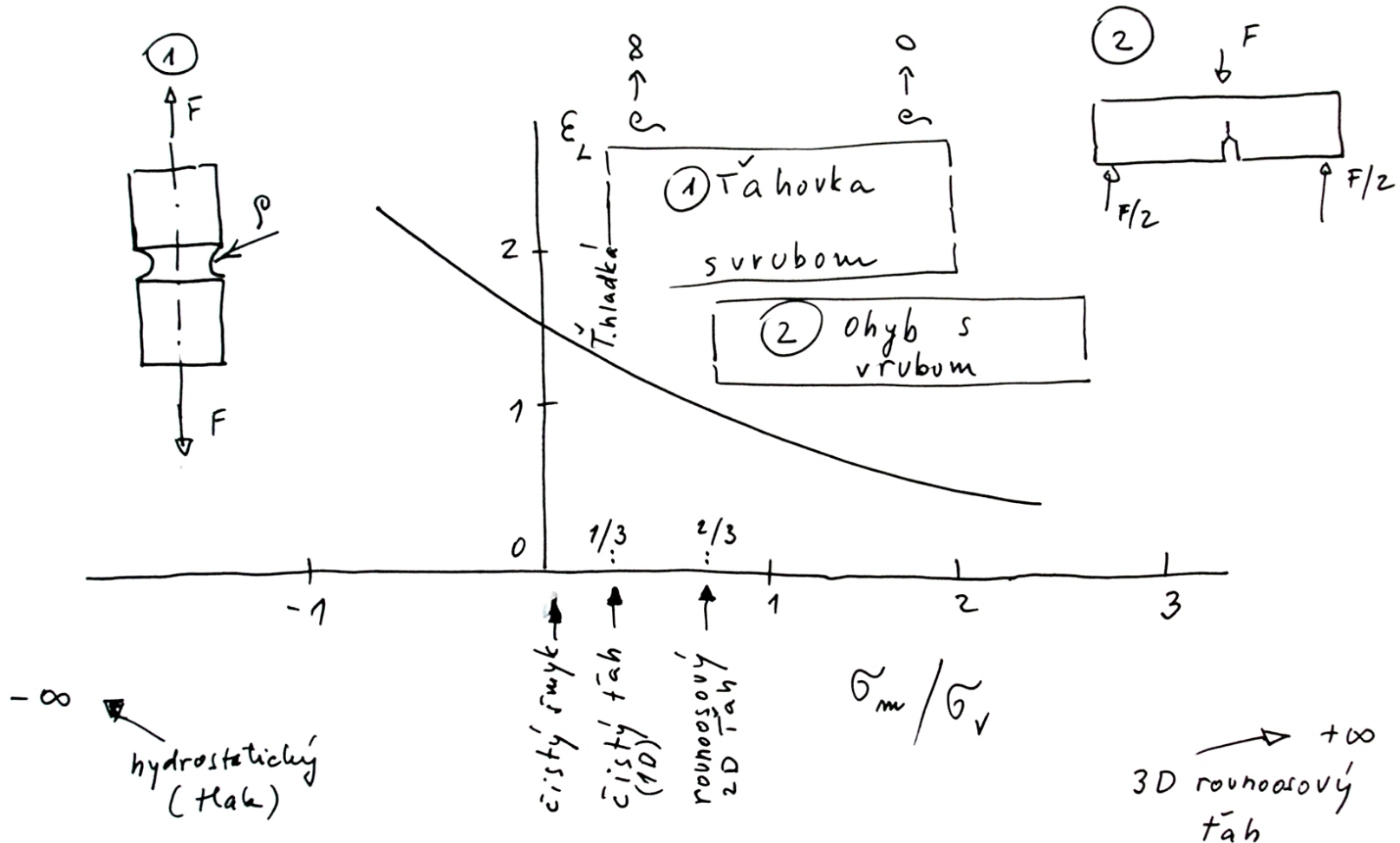
**Indentačná práca W**

$$W_{\text{total}} = W_{\text{elast}} + W_{\text{plast}}$$

$$\eta_{IT} = \frac{W_{\text{elast}}}{W_{\text{total}}} 100\%$$



# Medzná deformácia - triaxialita



$$\sigma_m = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$$

$$\sigma_v = \frac{\sqrt{2}}{2} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$