



LOCAL MECHANICAL PROPERTIES – WHAT DOES IT MEAN?

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stress – strain

$$\sigma - \varepsilon$$

mechanisms:

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

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

uniform deformation

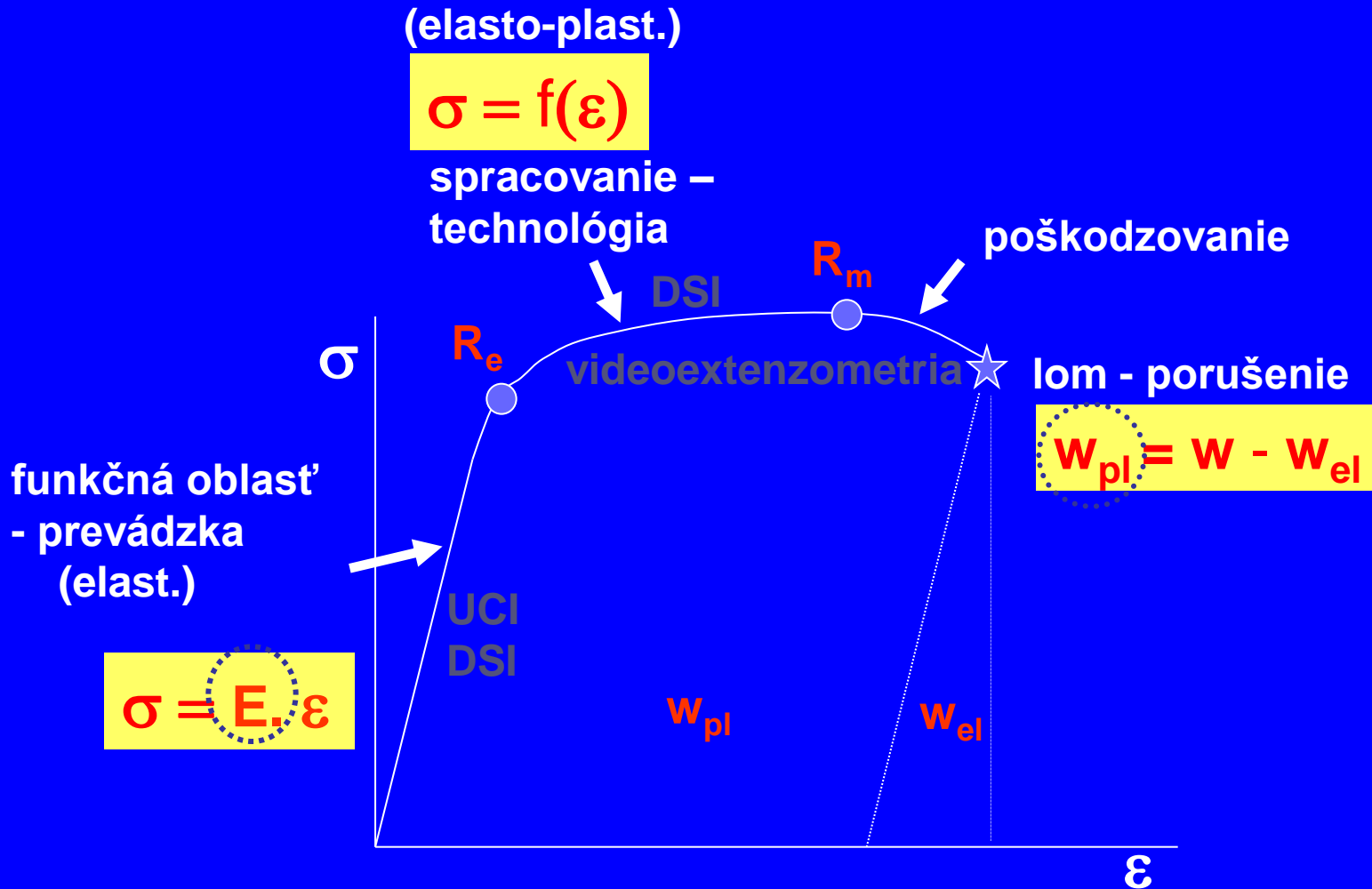
localised deformation

damage: voids initiation, growth, coalescence

fracturing: crack-initiation, -growth (stable, unstable), -arrest

thermal dilatation

Život (prevádzka) materiálu a jeho namáhanie





Veličiny charakterizujúce **medzný stav** (ťah, ohyb, tlak, krut, šmyk) (zmena mechanizmu, koniec, začiatok, rozhranie)

napätie, deformácia, energia, čas, teplota

medza úmernosti	R_u	MPa
medza pružnosti fyzikálna	R_E	MPa
medza pružnosti technická (konvenčná)	$R_{p0,005}$	MPa
medza klzu: výrazná (horná, dolná)	R_e	MPa
nevýrazná	$R_{p0,2}$	MPa
medza pevnosti konvenčná (medza plastickej stability)	R_m	MPa
medza pevnosti skutočná = skutočné lomové napätie	σ_L	MPa
ťažnosť	A	%
rovnomerná ťažnosť	A_g	%
kontrakcia	Z	%



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húževnatosť	w_L (plast)	Jm^{-3}
vrubová húževnatosť	KCV, KCU	Jm^{-2}
lomová húževnatosť	K_{IC}	$\text{MPa m}^{1/2}$
lomová húževnatosť	J_{IC}	Jm^{-2}
kritické rozovretie trhliny	δ_c (CTOD)	mm
medza únavy	σ_C	MPa
časová medza únavy	σ_{CN}	MPa
životnosť	N_C	-
medza tečenia	R_{tT}	MPa
medza pevnosti pri tečení	R_{mT}	MPa
životnosť	t	h



Veličiny, ktoré necharakterizujú medzný stav, ale **vlastnosť** materiálu

Elastická oblasť

modul pružnosti
Poissonovo číslo

E, G, K
v alebo $\mu = - \varepsilon_{\text{priečna}} / \varepsilon_{\text{pozdĺžna}}$

MPa

tuhosť
poddajnosť

$k = F / \Delta L$
 $\lambda = 1/k = \Delta L / F$

N m^{-1}
 m N^{-1}

Tuhosť , poddajnosť = f(súčiastka)

$k = E S_0 / L_0$

Elasto-plastická oblasť

exponent deformačného spevnenia

n

$$\sigma = k \phi^n$$

ϕ = skutočná deformácia

tvrdosť \neq medzný stav

Rýchlosť šírenia únavovej trhliny dc/dN



stress - strain

$$\sigma - \epsilon$$

- material (E)
- construction (stiffness)

1. Temperature transition behaviour: brittle - tough
2. Stress state triaxiality: compressing (plastic) → tensile (brittle)
3. Strain rate creep → static → dynamic (brittle)
4. Testing conditions specimen size, shape,...
5. Environment

Relationships: $\sigma = f_1 (T, \epsilon, d\epsilon/dt, x, y, z)$

$$\epsilon = f_2 (T, \epsilon, d\epsilon/dt, x, y, z)$$

Mechanical properties = g(microstructure)

microscopy: optical, TEM, SEM, AFM, confocal,...



stress - strain

$$\sigma - \varepsilon$$

Bulk material ... „global“ properties

Standardized testing techniques tensile test, compression, toughness (Charpy, fracture t. K_{IC}), creep, bending, fatigue (S-N; $da/dN - \Delta K$), hardness (macro)

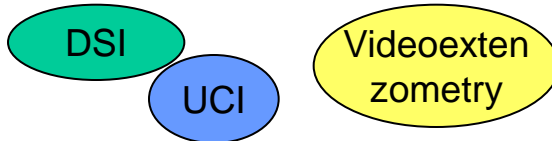
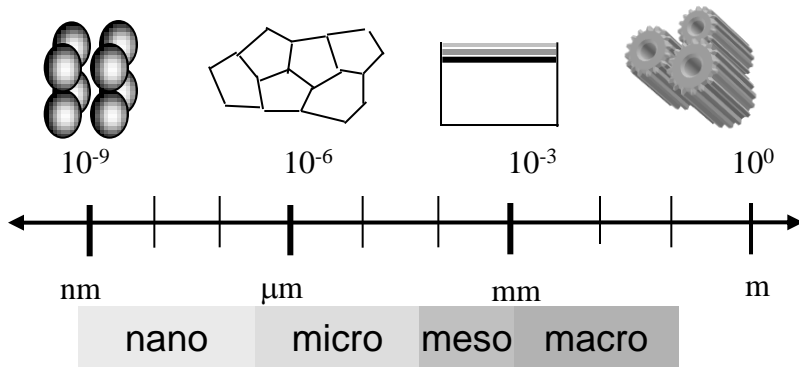
crack \leftrightarrow process zone

Microstructure objects ... „local“ properties

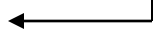
Experimental techniques in development



Local mechanical properties



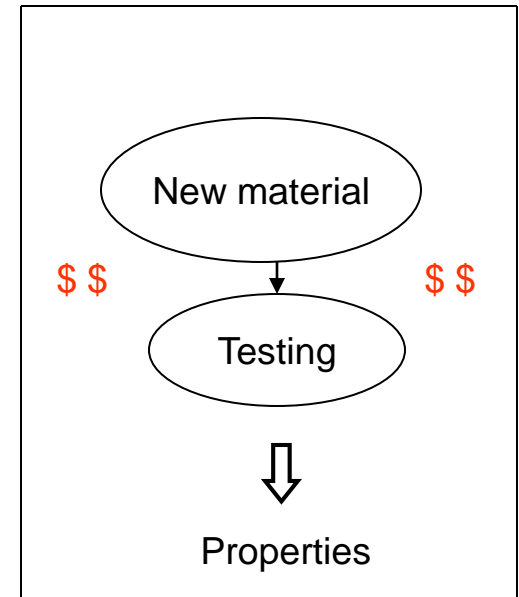
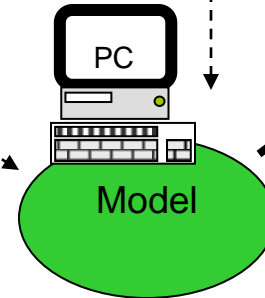
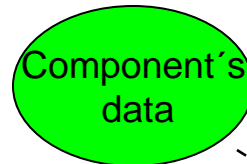
Local Mechanical Properties



Modeling

Importance:

- Identification
- Characterization
- Input data for modeling
- Testing technique

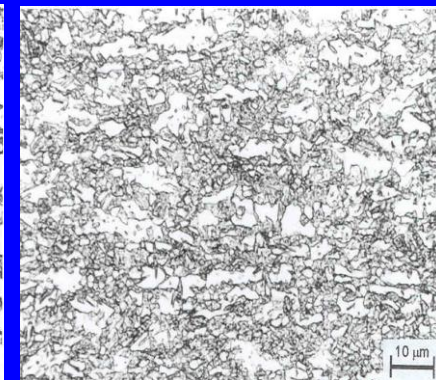
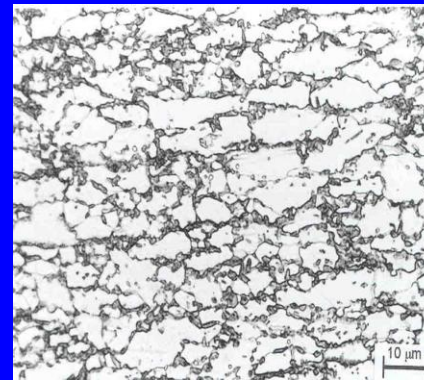
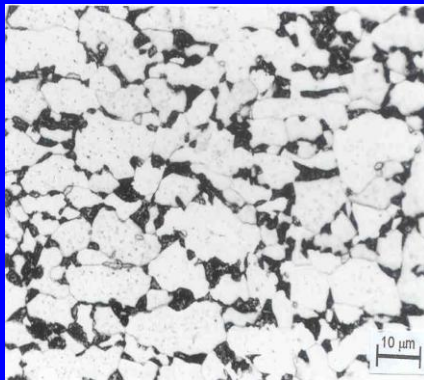




Modeling

- Physical models

$0,73 \text{ HM(ferrite)} + 0,27 \text{ HM(martensite)} = \text{HM (mixed ferrite/martensite)}$



Microstructure of DP600, DP800 and DP1000 steels (from left to right)



Modeling

- Finite element method
- Representative volume element

Tensile test

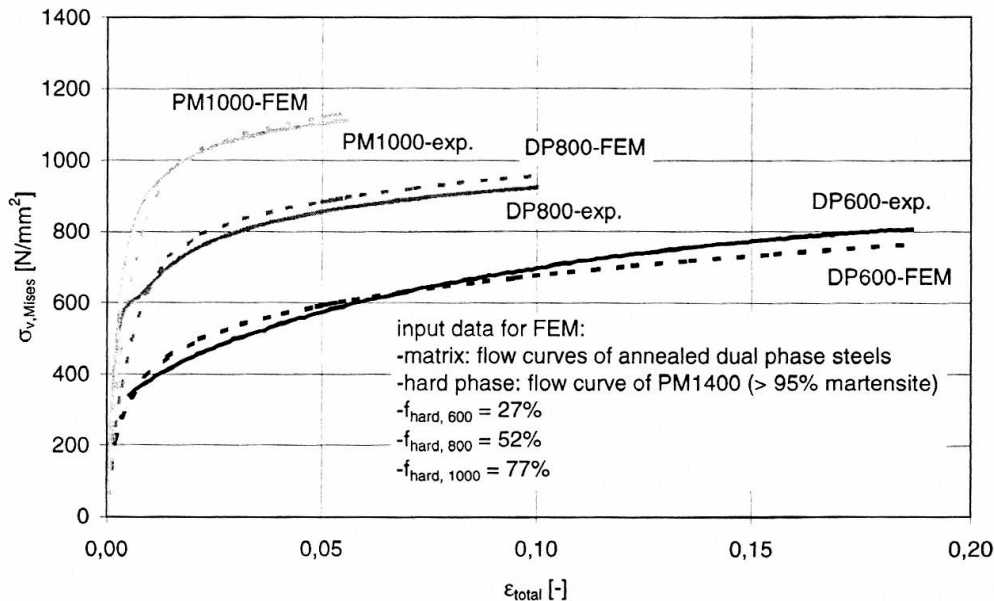
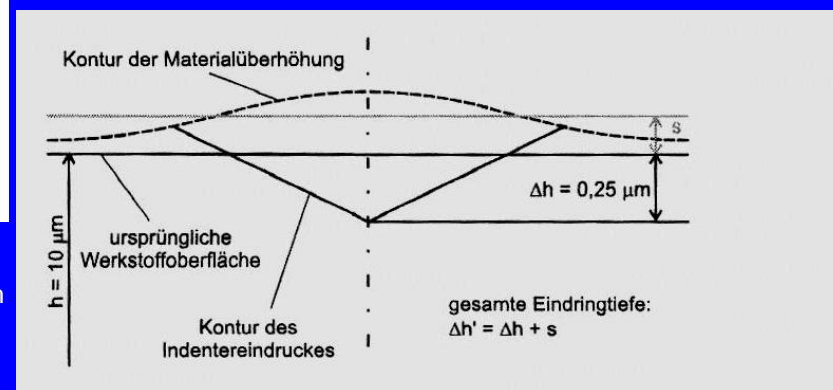
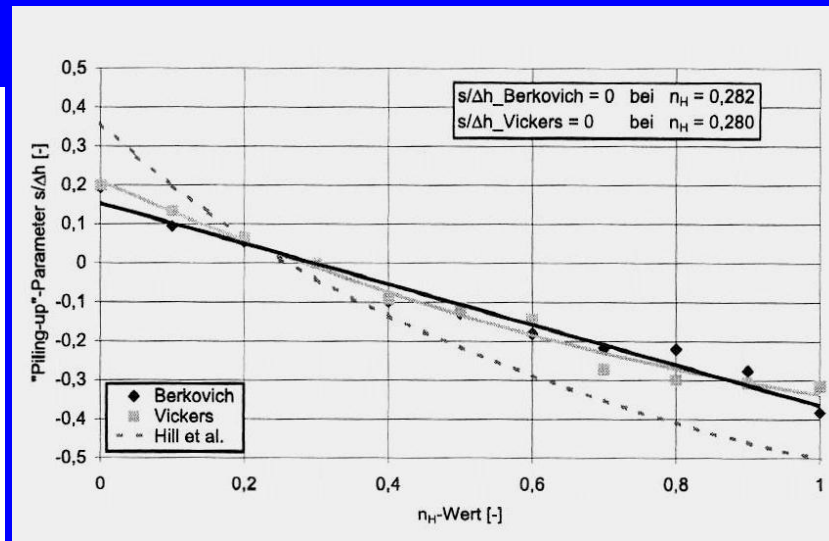


Fig. 4: Comparison between FEM results and experimental tensile tests

DSI





Experimental techniques

IIT = Instrumented Indentation Testing

DSI = Depth Sensing Indentation

H, σ

IIT Instrumented Indentation Testing - instrumentovaná indentační zkouška (skúška tvrdosti so záznamom, skúška tvrdosti s registráciou sily)

ISO 14577 – Metallic materials – Instrumented indentation test for hardness and materials parameters, 2002

nano - mikro

UCI – Ultrasonic Contact Impedance

micro - meso

Frequency change due to mechanical contact

E, H

Videoextenzometry (non contact strain measurement)

meso - macro

ϵ



Indentation curve

Hardness

H

Modulus of elasticity

E

Indentation work

W W_{el} W_{pl}

Relaxation parameter

R_{IT}

Creep parameter

C_{IT}

Derived:

stress – strain curve, $\sigma - \varepsilon$

Yield strength, tensile strength

Fracture toughness K_{IC}

Thermal shock resistance (ceramics)

Adhesion strength, wear

Phase boundary strength

Fatigue properties

Residual stresses σ_{rez}



OBJECTS

Grains and boundaries
Coatings and layers
Phases and microstructure components
Weld parts
Particles
„Bulk“

PROPERTY

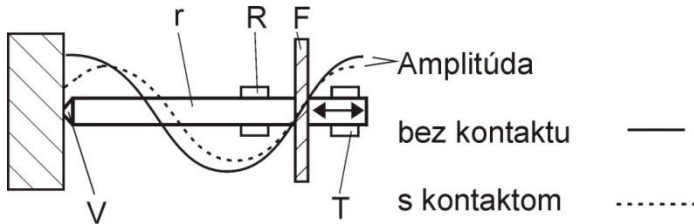
Hardness H
Young's modulus E
strength R_e, R_m
Indentation work (energy) W, W_{el}, W_{pl}
Fracture toughness K_{IC}
Relaxation and creep
Stress – strain curve $\sigma - \epsilon$
Thermal shocks
Adhesion, wear
Phase boundary strength
Fatigue
Residual stresses σ_{rez}

MATERIALS

Metals
Ceramics
Gradient materials
Plastics (rheological)
Porous materials
Composites
Biomaterials (tissues)
Concrete



UCI – Ultrasonic Contact Impedance



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

Principle: ultrasonic frequency change due to contact with specimen surface

$$\Delta f = f(A_S, E_P, \nu_P, E_d, \nu_d, f_0)$$

specimen

$$A_S = g(E_d, \nu_d, E_P, \nu_P) \cdot h(\Delta f/f_0)$$

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

$$HV = F / A_S$$

contact

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

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

