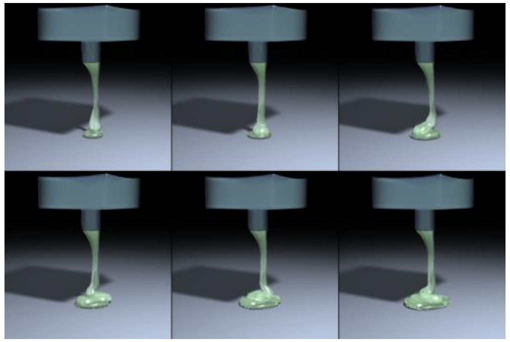


Physical basis of dental material science 9.

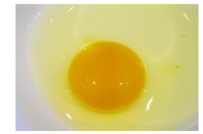
Mechanical properties 3.

Bodies

elastic material

force results reversible change.

elastic or viscous?



nor elastic and nor viscous.

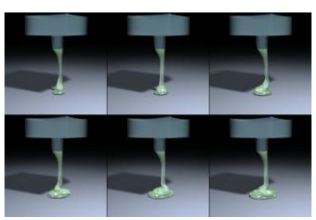
viscoelastic material

viscous material

force results flow, irreversible change.

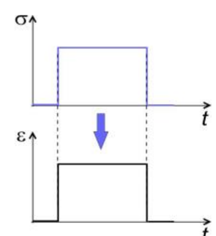
Viscoelasticity:

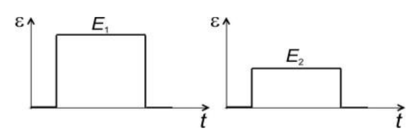
materials which exhibit both viscous and elastic characteristics when undergoing deformation.



Ideal elastic body!

Constant force (stress)

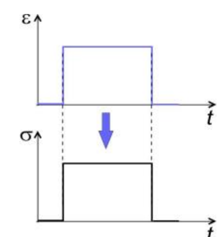




$E_1 < E_2$

no stress relaxation!

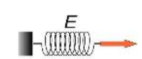
Constant deformation



Hooke's law: $\sigma = E\varepsilon$

$\sigma_{\text{shear}} = G\gamma$

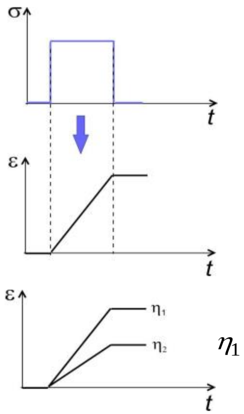
Model:



Hookean elastic spring

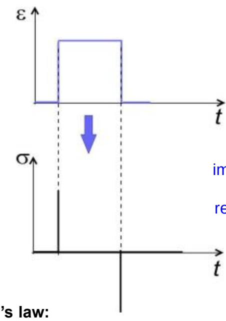
Ideal viscous body

Deformation in the case of constant force (stress).



$\eta_1 < \eta_2$

Constant deformation

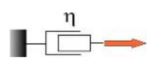


immediate stress relaxation

Newton's law:

$\sigma_{\text{shear}} = \eta\, g_{\text{speed}}$

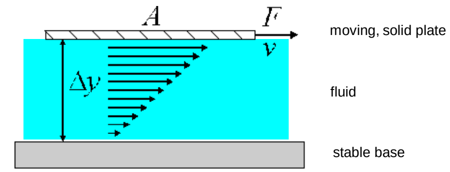
Model:



Newtonian dumper, dashpot

Viscosity (η):

measure of the resistance of a fluid which is deformed by either shear stress or tensile stress.



A: surface
F: force
Δy: layer thickness
v : speed

Newton's friction law:

$$F_s = \eta \cdot A \cdot \frac{\Delta v}{\Delta y} \quad \dashrightarrow \quad \frac{F_s}{A} = \eta \cdot \frac{\Delta v}{\Delta y}$$

velocity gradient

= g - gradient

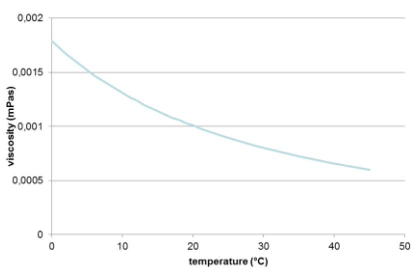
viscosity (internal friction coefficient)

$[\eta] = \text{Pa}\cdot\text{s}$

$\sigma_{\text{shear}} = \eta\, g_{\text{speed}}$

Dependence on the temperature

viscosity of the water



honey in fridge or room

oil in winter and summer

strongly depends on the temperature.

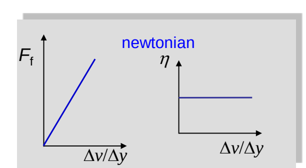
$$\eta \sim e^{-bT}$$

e.g. at 20 °C:

material	air	water	blood (37°)	glycerine
η (mPa·s)	0.019	1	2–8	1490

Normal (or newtonian) fluid:

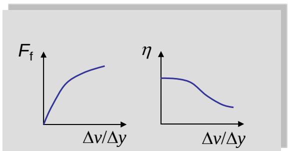
The viscosity depends only on the temperature (independent from e.g. velocity gradient or speed of flow).



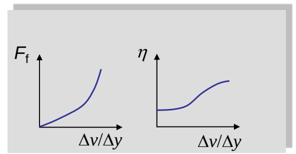
Anomalous (or non-newtonian) fluids:

The viscosity depends on the **velocity gradient**.

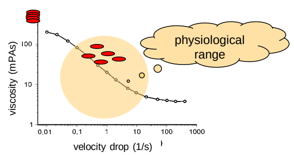
Pseudoplastic:
Viscosity decreases with the rate of shear.



Dilatant:
Viscosity increases with the rate of shear.

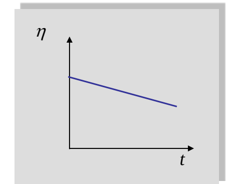


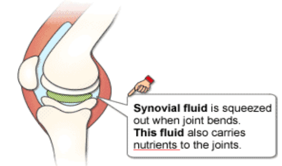
blood



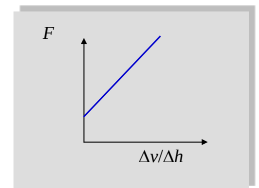
Silly Putty

Tixotropy: normally viscous, but becomes flow if stressed.





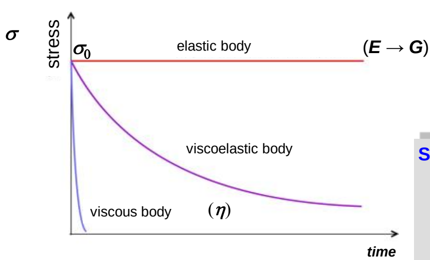
Bingham-fluid (plastics): behaves as a rigid body at low stresses but flows as a viscous fluid at high stress.



Tooth-paste

Viscoelasticity:

After instant deformation:



Hooke's law

$$\sigma = E\varepsilon$$

$$\sigma_{shear} = G\gamma$$

Stress relaxation:

$$\sigma = \sigma_0 e^{-\frac{t}{t_{rel}}}$$

$$t_{rel} = \frac{\eta}{G}$$

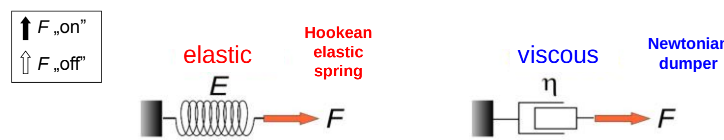
relaxation time

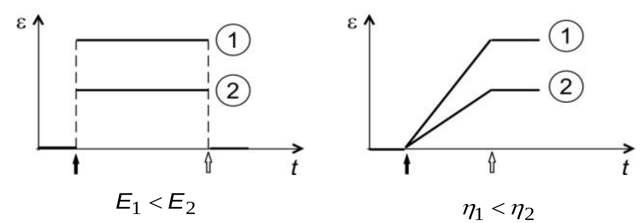
Newton's law

$$\sigma_{shear} = \eta\, g_{speed}$$

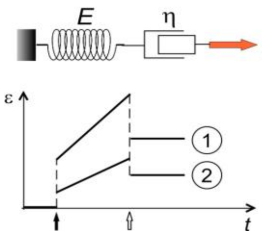
Changing deformation in the case of contant force

Models:





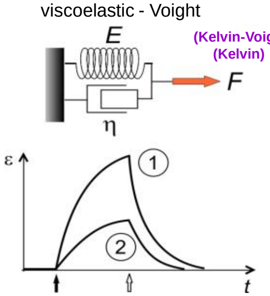
viscoelastic - Maxwell



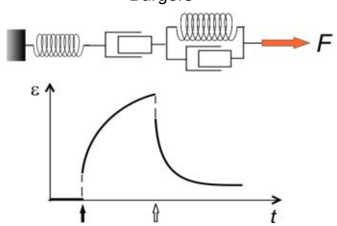
$E_1 < E_2$
$\eta_1 < \eta_2$

viscoelastic - Voight

(Kelvin-Voigt)
(Kelvin)



viscoelastic
- Burgers



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Long-term phenomena

Change in:

shape: → slow increase: **creep**
→ slow decrease: **shape recovery**

integrity: → fracture: **fatigue**
→ surface: **abrasion**

stress: → slow decrease: **stress relaxation**

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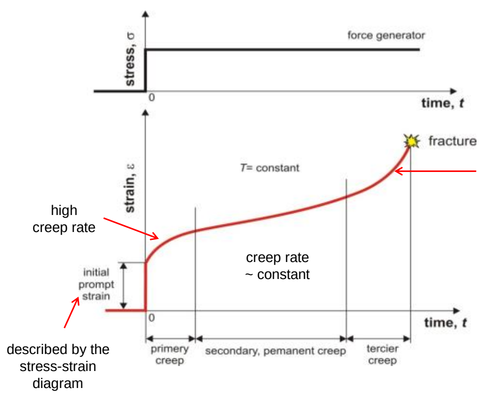
Creep:

is the slow change in the dimensions of a material due to prolonged stress.

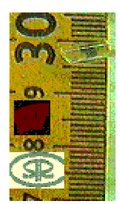
Stress is below the yield strength!



creep rate:

deformation during unit time

due to the necking!



$1\text{–}10^7$ s **!!**

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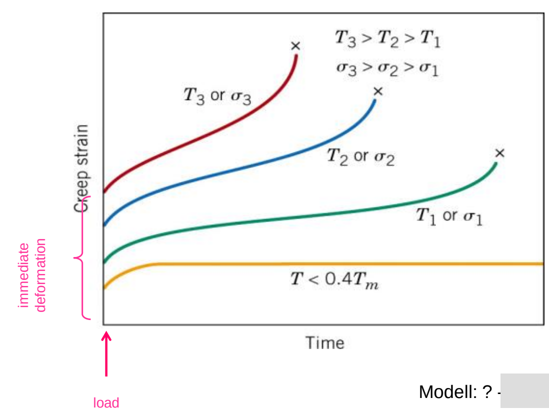
Effect of the stress and the temperature



temperature!
e.g. metals
$0.4T_m < T$

Modell: ? -

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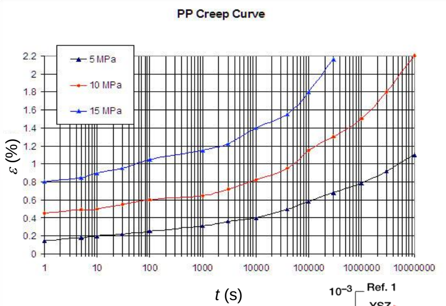
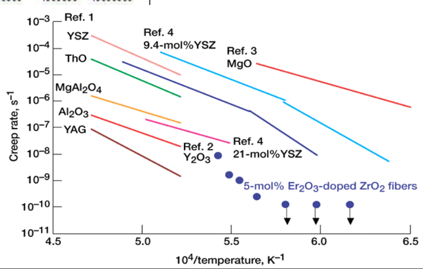


Polipropilene (PP)

ceramics



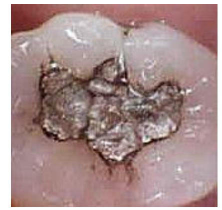
__creep rate__:

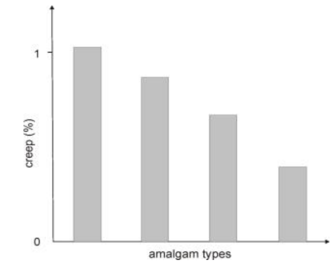
deformation during unit time

Example: amalgam

Creep influences the marginal integrity of the filling.

melting point: 100 – 180 °C!





Increasing silver or copper content decreases the creep.

Relaxation

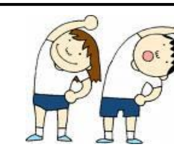
shape recovery

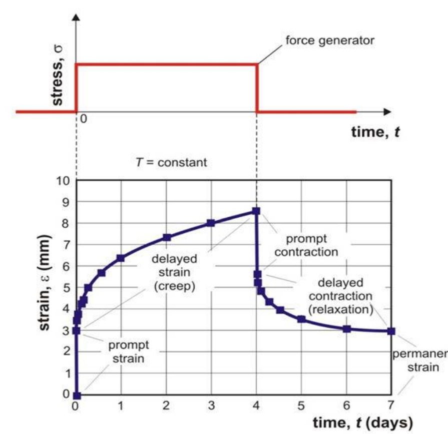
recovery when the load stops.

stress relaxation

decrease of the stress at constant deformation .

Shape recovery after stress removed.

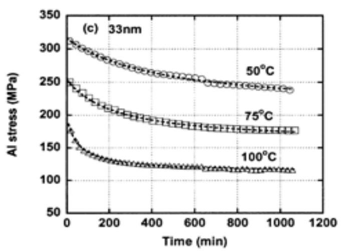




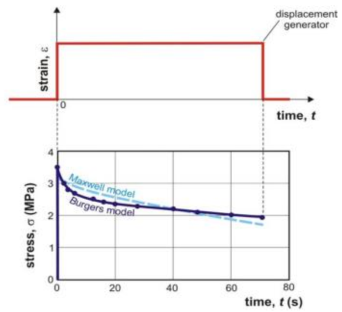
Stress relaxation

Decreasing of the inner stress in the case of constant deformation.

aluminium



film made of myofibrillar proteins



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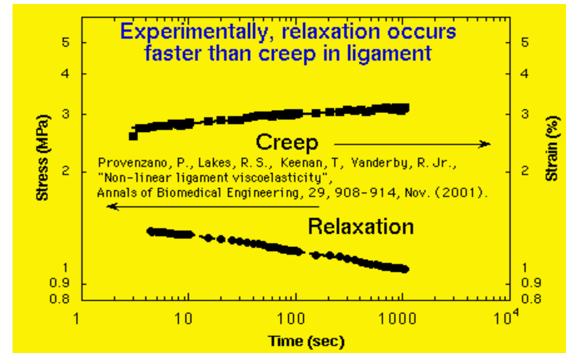

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Fatigue

is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading.

Stress is below the strength!

Fatigue is a **stochastic process.**

Long, repeated load

→ structural changes

→ strength decreases

↓

cracks!

Damage is cumulative.

Fatigue is usually associated with tensile stresses.

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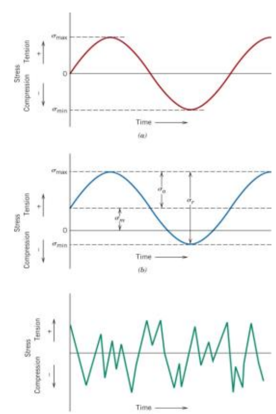
Type of loads

Dynamic fatigue



symmetric

assymmetric

random

Static fatigue:

Long-term stress results decrease in strength.

a test equipment

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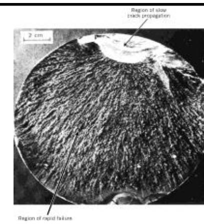
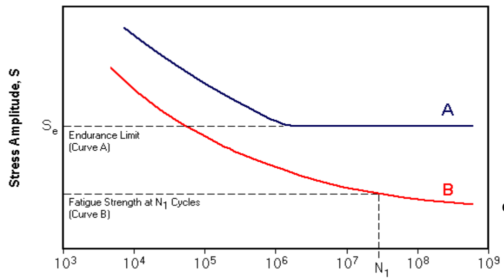


Fatigue S-N curve:



e.g. steel, titanium, …

e.g. aluminium, copper, ...

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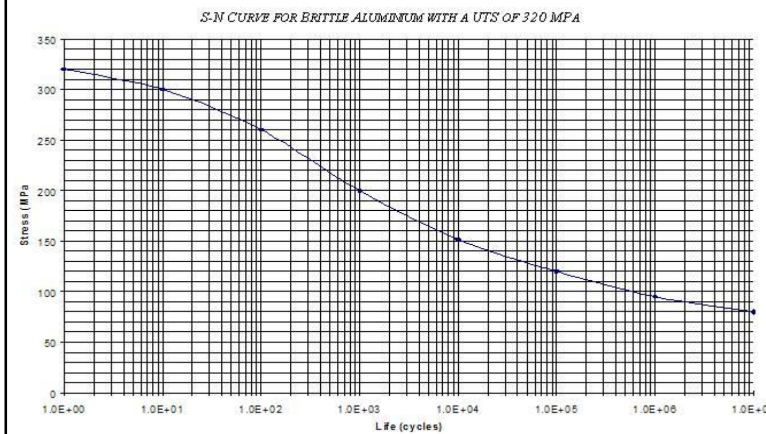

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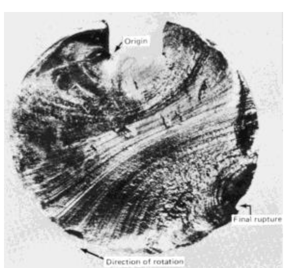

a test equipment

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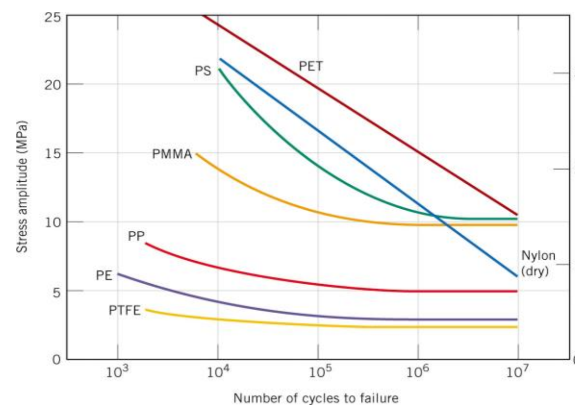
S-N curves of different polymers

PET: Polyethylene terephthalate
PS: Polystyrene
PMMA: Poli(methil metacrylate)

PP: Polyethylene terephthalate
PE: Polyethylene
PTFE: Polytetrafluoroethylene



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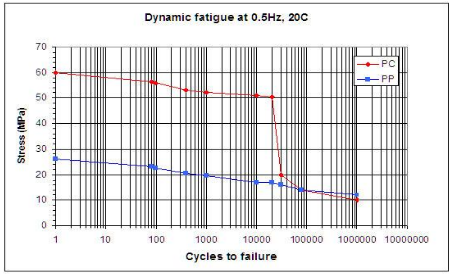

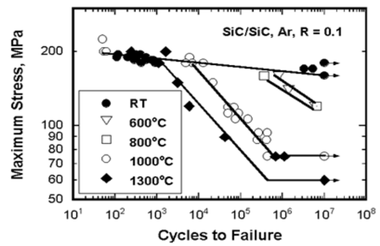

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Some factors

Geometry: Notches and variation in cross section.

Surface quality: Surface roughness.

Material type: E.g. composites and polymers differ markedly from metals.

Grain size: For most metals, smaller grains yield longer fatigue lives.

Temperature: Extreme high or low temperatures can decrease fatigue strength.

Prevention: E.g. stress should be below threshold of fatigue limit.

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Abrasion

Loss of the structure by mechanical forces.

E.g.: toothbrush abrasion causes
V-shaped notches

(Erosion a chemical event!)

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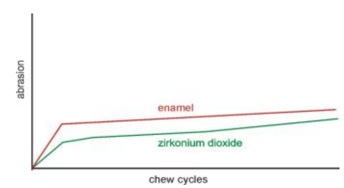
Role of hardness

Most commonly affected: premolars and canines.
(position)

Cementoenamel junction
(very thin enamel)
is sensitive.



material	*HV* (MPa)	*HK* (MPa)
Enamel	≈ 3400	3400-4000
Dentin	≈ 600	≈ 700
Amalgam	≈ 1000	

(cementum a little bit less hard than the dentine.)

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