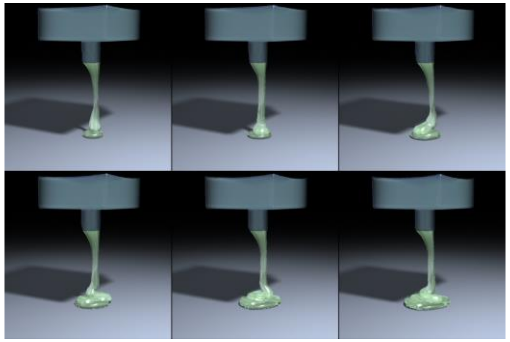


Physical basis of dental material science 9.

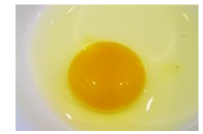
Mechanical properties 3.

Materials

elastic material

force results reversible change.

elastic or viscous?



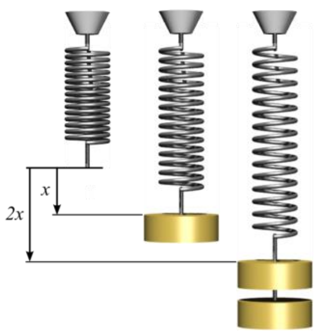
nor elastic and nor viscous.

viscoelastic material

viscous material

force results
flow,
irreversible change.

Ideal elastic material



Hooke's law:

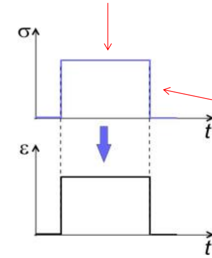
F = -D x

$$\sigma = E\varepsilon$$

The deformation is proportional to the external force. Removing the load it recovers the original size.

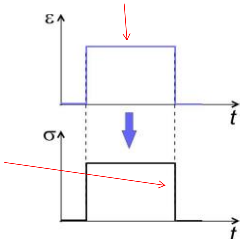
Ideal elastic body!

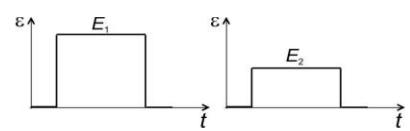
Constant force (stress)



no stress relaxation!

Constant deformation



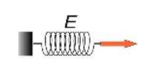


$$E_1 < E_2$$

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

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

Model:



Hookean elastic spring

Ideal viscous material

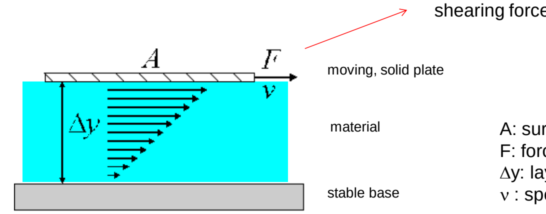
There is no any recovery.
The deformation is permanent.

Characteristic property:
Viscosity!

The measure of the resistance of a material that is deformed by either shear stress or tensile stress.

5

Viscosity (η):



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

The force is proportional to the speed, surface.

The resistance is due to the atomic interaction inside the material!

6

Description

Newton's friction law:

$$F_f = \eta \cdot A \cdot \frac{\Delta v}{\Delta y}$$

(rearrange)

$$\frac{F_f}{A} = \eta \cdot \frac{\Delta v}{\Delta y}$$

velocity gradient

= g -> gradient

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

viscosity (internal friction coefficient)

$[\eta]$ = Pa·s

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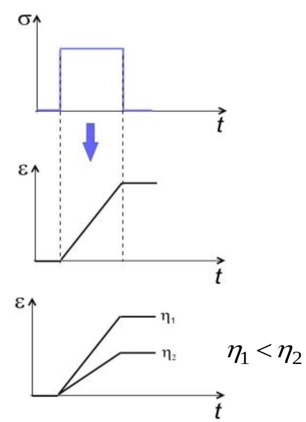
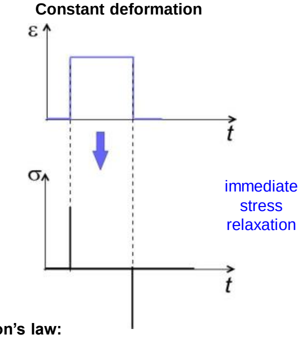
Ideal viscous body

Deformation in the case of constant force (stress).



$\eta_1 < \eta_2$

Constant deformation

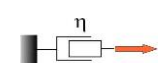


immediate stress relaxation

Newton's law:

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

Model:

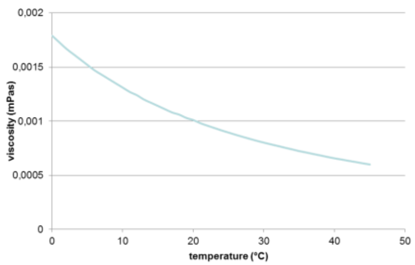


Newtonian dumper, dashpot

8

Dependence on the temperature

viscosity of the water



honey in fridge or room

oil in winter and summer

Strongly depends on the temperature!

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

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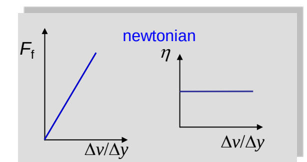
---

e.g. at 20 ºC:

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).



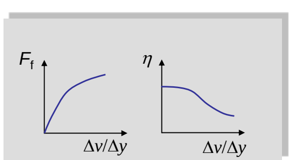
10

Anomalous (or non-newtonian) fluids:

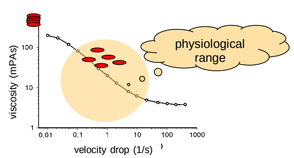
The viscosity depends on the **velocity gradient**.

Pseudoplastic materials:

Viscosity decreases with the rate of shear.



blood



It is also a common property of polymer solutions and molten polymers.

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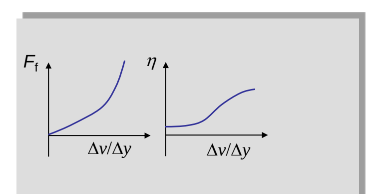
Dilatant material

Viscosity increases with the rate of shear.

Walking on wet sand, a dry area appears underneath your foot.



Silly Putty

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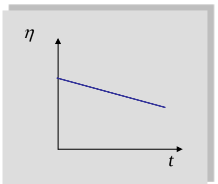
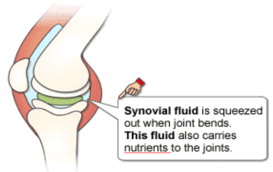
Thixotropic material

Normally viscous, but becomes flow if stressed.



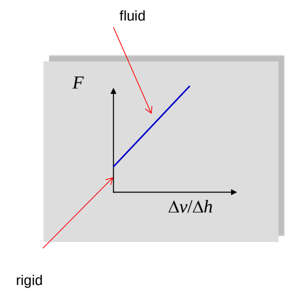


Another examples:

cytoplasm, semen.

Bingham-fluid (plastics)

Behaves as a rigid body at low stresses
but flows as a viscous fluid at high stress.

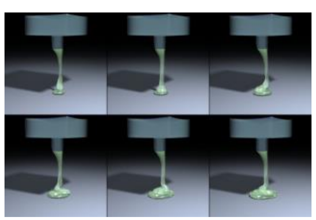


Mayonnaise

Tooth-paste

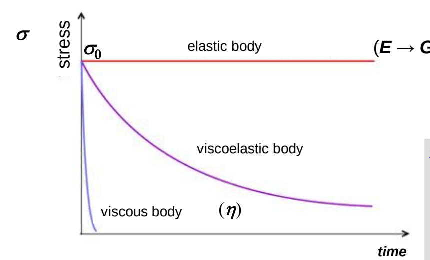
Viscoelasticity:

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



Viscoelasticity:

After instant deformation:



$(E \rightarrow G)$

Hooke's law

$\sigma = E\varepsilon$

$\sigma_{shear} = G\gamma$

Newton's law

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

Stress relaxation:

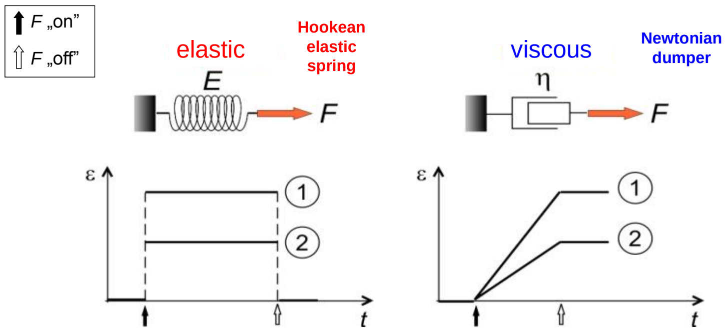
$$\sigma = \sigma_0 e^{-\frac{t}{t_{rel}}}$$

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

relaxation time

Changing deformation in the case of contant force

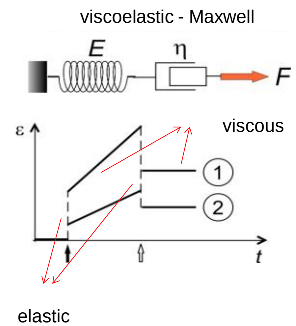
Base models:



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

Viscoelastic materials

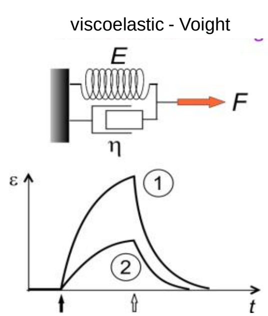
F „on”
F „off”



2 different material

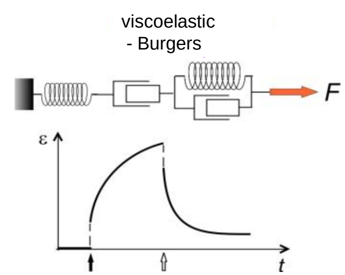
$E_1 < E_2$
$\eta_1 < \eta_2$

Viscoelastic materials



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

Viscoelastic materials



$E_1 < E_2$

$\eta_1 < \eta_2$

Long-term phenomena

Change in:

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

integrity:
- fracture: **fatigue**
- surface: **abrasion**

stress:
- slow decrease: **stress relaxation**

Creep

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

Time interval

Stress is below the yield strength!

Definition

creep rate: deformation during unit time.

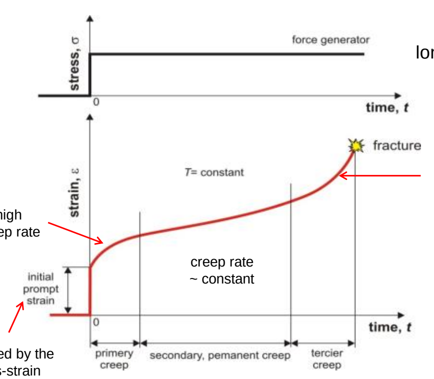
1–10^7 s **!!**

Creep components

long-term constant force

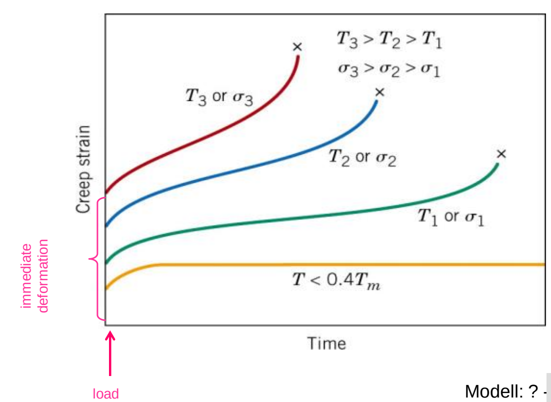
high creep rate

due to the necking!



described by the stress-strain diagram

Effect of the stress and the temperature



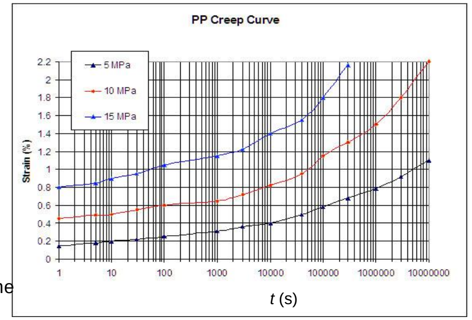
temperature!
e.g. metals
$0.4T_m < T$

T_m: melting point

Modell: ? -

Effect of the stress

Polipropilene (PP)

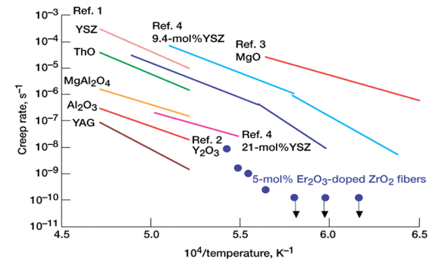


creep rate:

deformation during unit time

Effect of the temperature

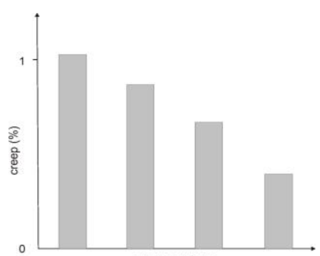
ceramics



Example: amalgam

Creep influences the marginal integrity of the filling.

melting point: 100 – 180 °C!

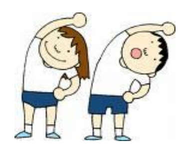


Increasing silver or copper content decreases the creep.

Relaxation

shape recovery

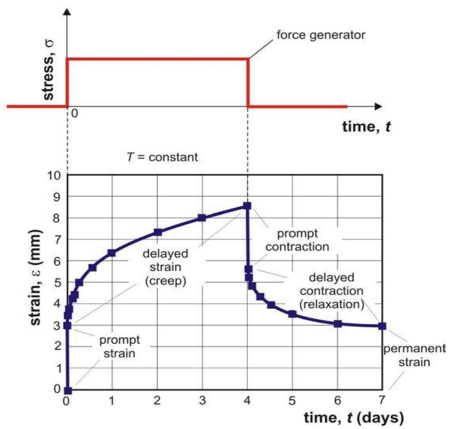
recovery when the load stops.

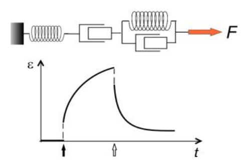


stress relaxation

decrease of the stress at constant deformation .

Shape recovery then stress is removed.

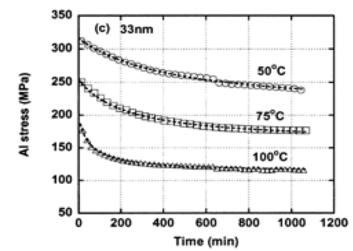




Stress relaxation

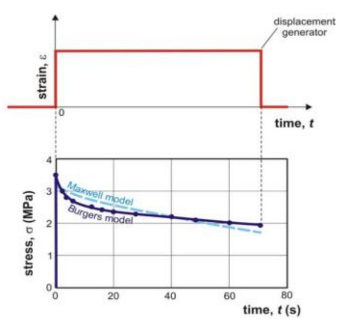
Decreasing of the stress in the case of constant deformation.

aluminum (Al)

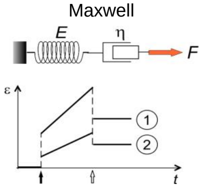


Models

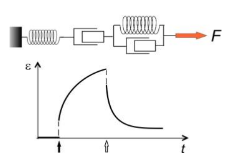
film made of myofibrillar proteins

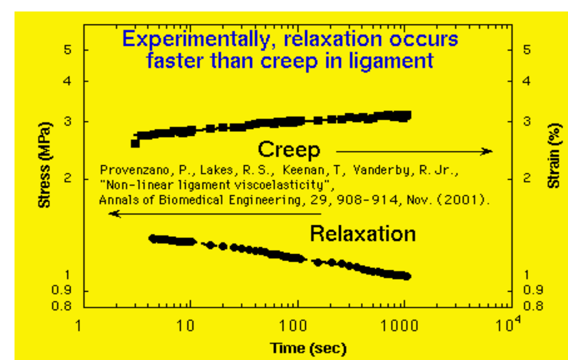


Maxwell



Burgersl





Fatigue

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

Stress is below the strength!
There is no immediate fracture.

Fatigue is a **stochastic process.**

Damage is cumulative.

Fatigue is usually associated with tensile stresses.

Long, repeated load
→ structural changes
→ strength decreases

cracks!

Short-term strength > long-term strength.

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Type of loads

Static fatigue:

Long-term stress results decrease in strength finally fracture.

A test equipment

testing a dental implants

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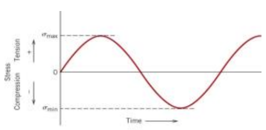
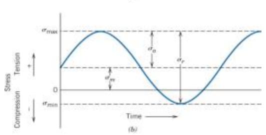
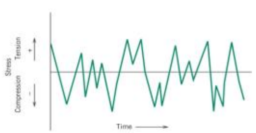
Type of loads



symmetric



asymmetric



random

Dynamic fatigue

Dynamically changing force.

Asymmetric tension and compression behavior of materials due to the asymmetric atomic forces.

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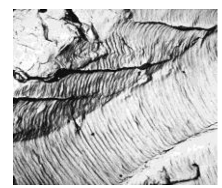
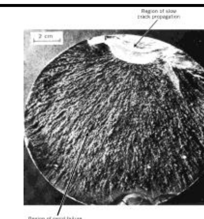
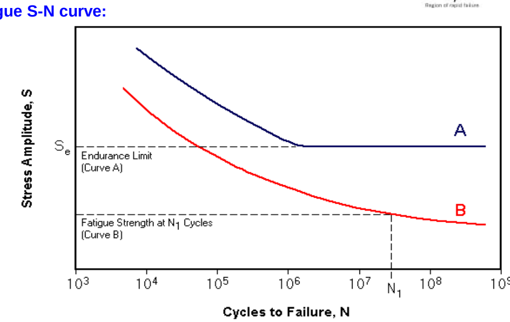




Fatigue S-N curve:



e.g. steel, titanium, …

e.g. aluminium, copper, ...

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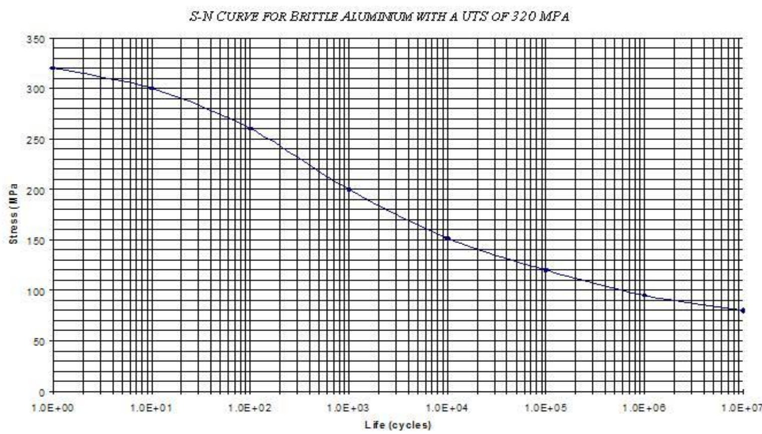
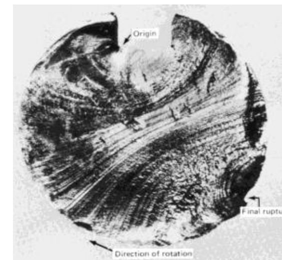


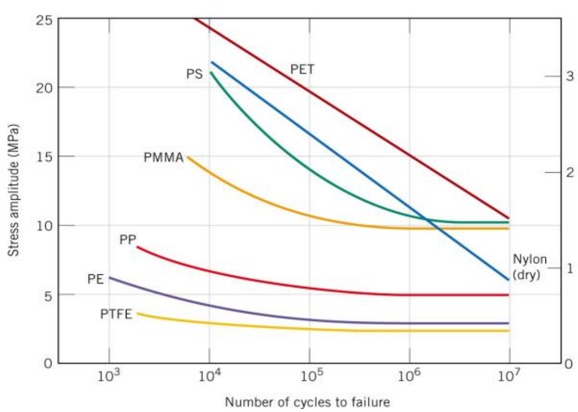


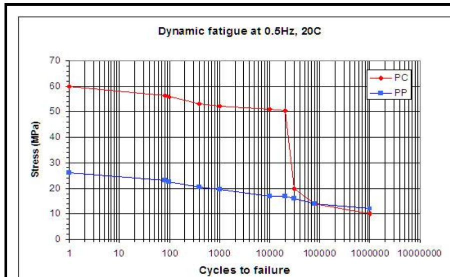
a test equipment

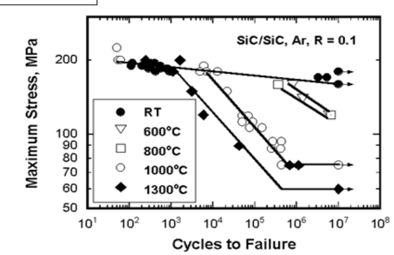
S-N curves of different polymers

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

PP: Polyethylene terephthalate
PE: Polyethylene
PTFE: Polytetrafluoroethylene







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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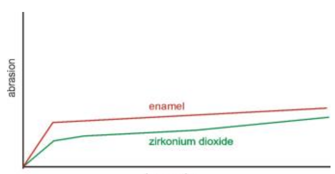
Role of hardness

Most commonly affected: premolars and canines.
(position)

Cementoenamel junction
(very thin enamel)
is very 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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