

Physical basis of dental material science

9.

Mechanical properties 3.

1

Bodies

elastic material



force results
reversible change.

elastic or viscous?



nor elastic and nor viscous.

viscoelastic material

viscous material

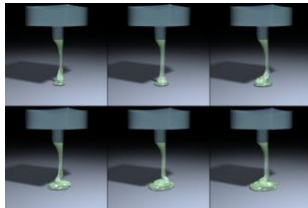


force results
flow,
irreversible change.

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Viscoelasticity:

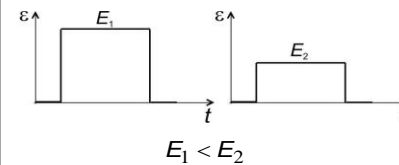
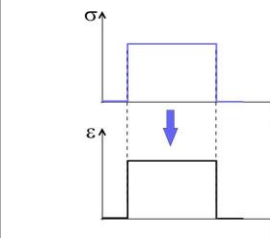
materials which exhibit both viscous and elastic characteristics when undergoing deformation.



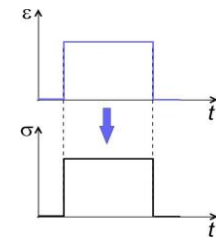
3

Ideal elastic body!

Constant force (stress)



Constant deformation



Hooke's law: $\sigma = E\varepsilon$
 $\sigma_{\text{shear}} = G\gamma$

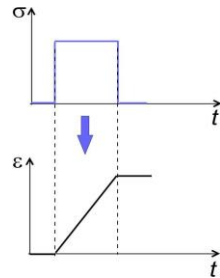
Model:



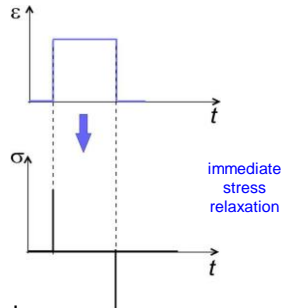
4

Ideal viscous body

Deformation in the case of constant force (stress).



Constant deformation

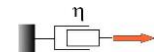


immediate stress relaxation

Newton's law:

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

Model:



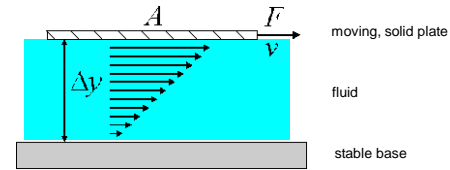
$$\eta_1 < \eta_2$$

Newtonian dumper, dashpot

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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:

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

viscosity (internal friction coefficient)
[η] = Pa·s

$$\frac{F_s}{A} = \eta \cdot \frac{\Delta v}{\Delta y} = g \cdot \text{gradient}$$

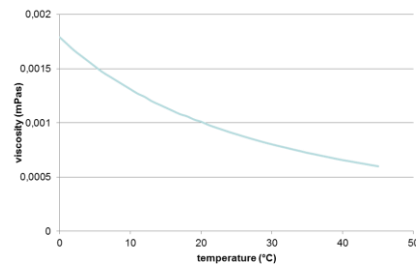
$$\sigma_{\text{shear}} = \eta \cdot g_{\text{speed}}$$

velocity gradient

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Dependence on the temperature

viscosity of the water



honey in fridge or room



oil in winter and summer



strongly depends on the temperature.

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

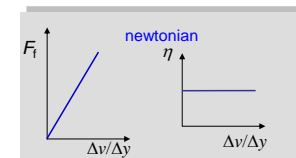
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e.g. at 20 °C:

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).



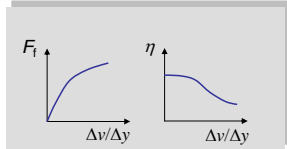
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Anomalous (or non-newtonian) fluids:

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

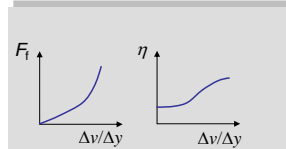
Pseudoplastic:

Viscosity decreases with the rate of shear.

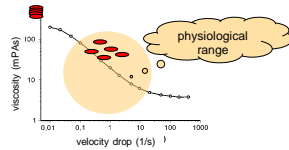


Dilatant:

Viscosity increases with the rate of shear.



blood

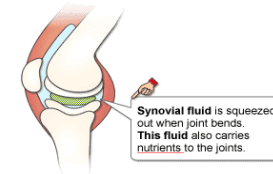
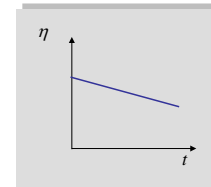


Silly Putty



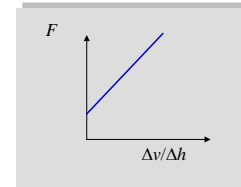
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Tixotropy: normally viscous, but becomes flow if stressed.



Synovial fluid is squeezed out when joint bends. This fluid also carries nutrients to the joints.

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



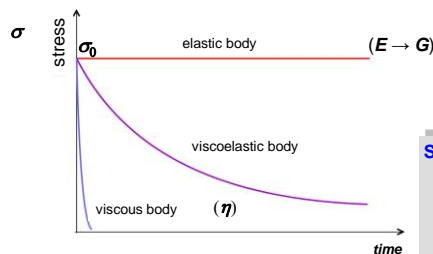
Tooth-paste



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Viscoelasticity:

After instant deformation:



Newton's law
 $\sigma_{shear} = \eta \dot{\gamma}_{speed}$

Hooke's law
 $\sigma = E \epsilon$
 $\sigma_{shear} = G \gamma$

Stress relaxation:

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

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

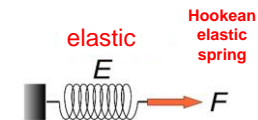
relaxation time

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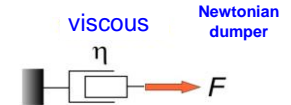
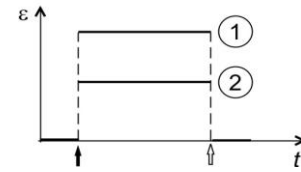
Changing deformation in the case of constant force

Models:

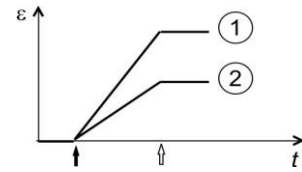
↑ F_{on}
↑ F_{off}



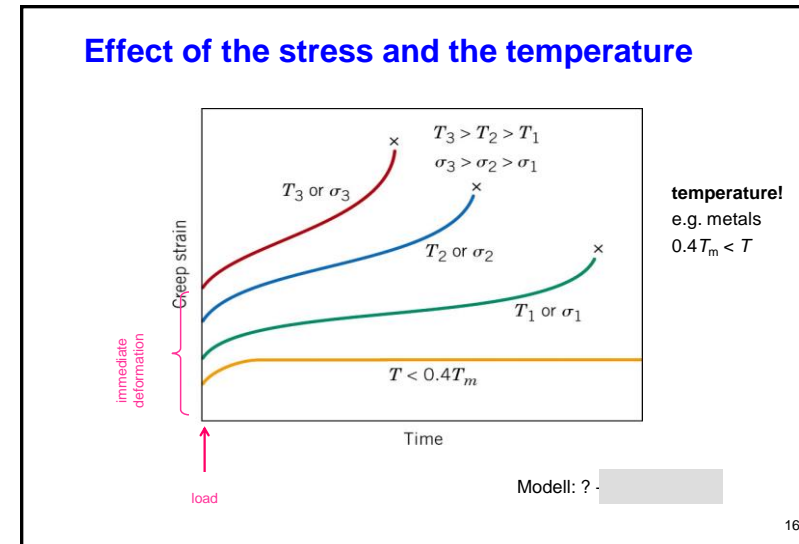
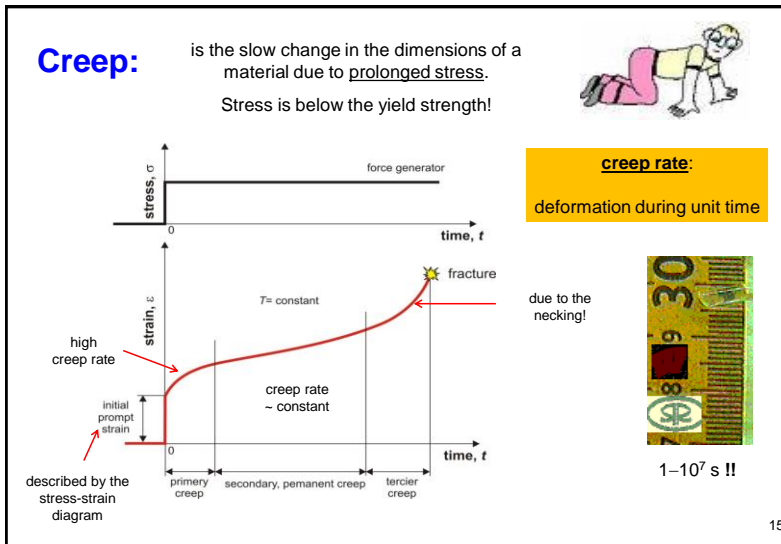
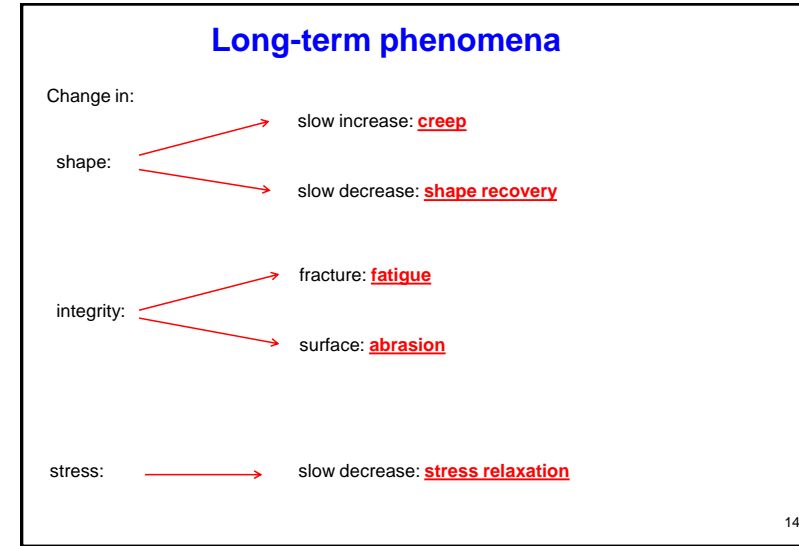
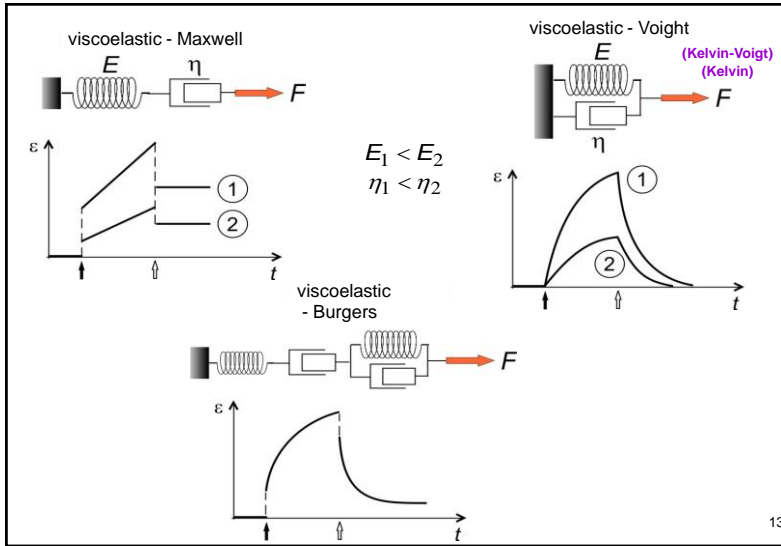
$$E_1 < E_2$$

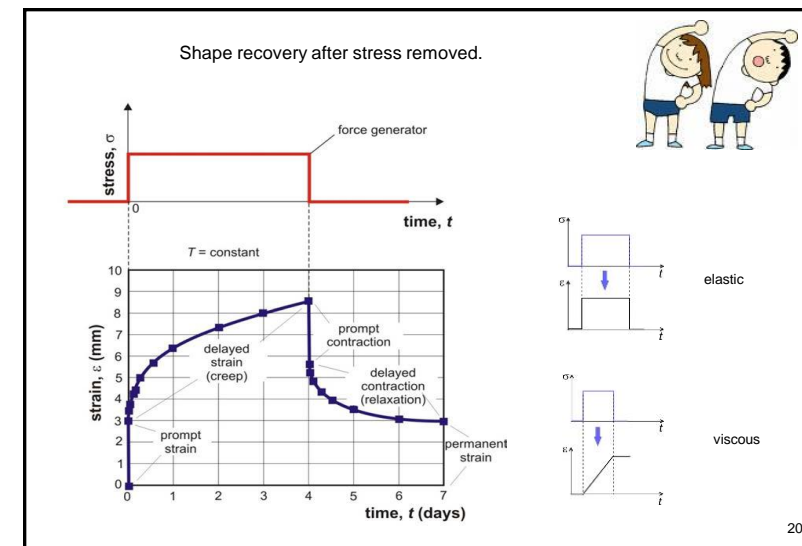
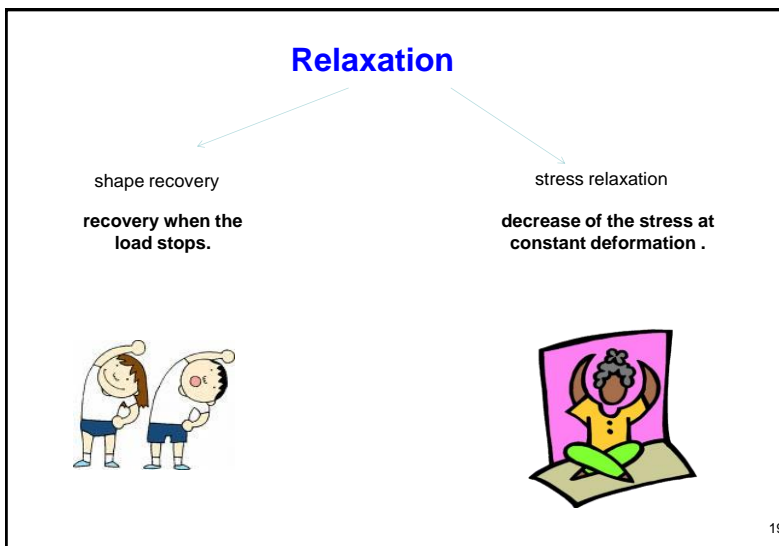
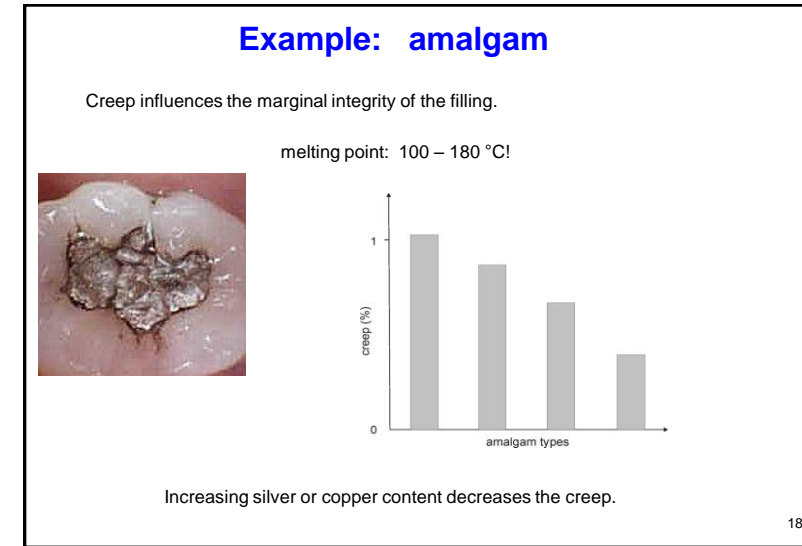
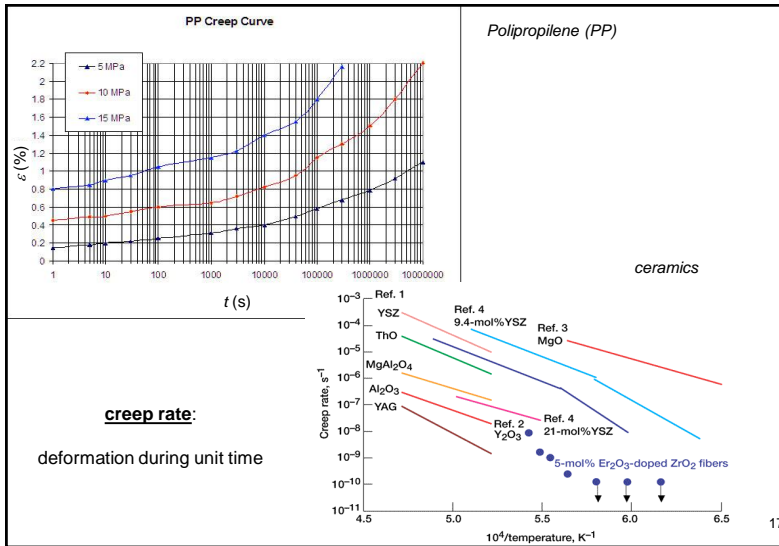


$$\eta_1 < \eta_2$$



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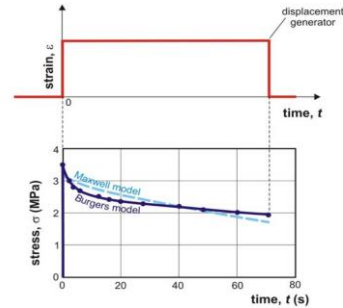
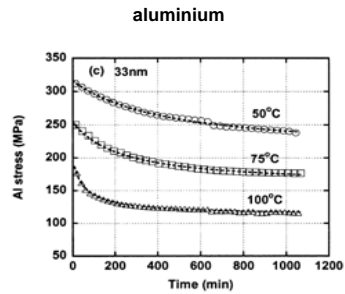




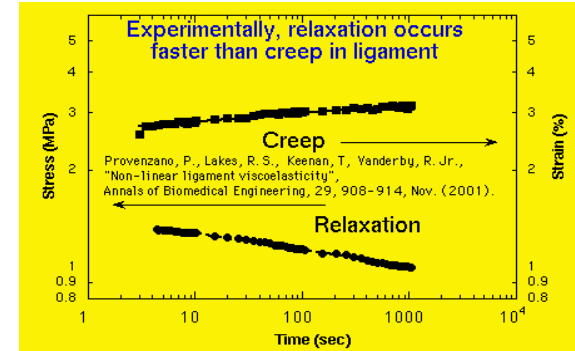
Stress relaxation

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

film made of myofibrillar proteins



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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!

Long, repeated load

→ structural changes

→ strength decreases

cracks!



Fatigue is a **stochastic process**.

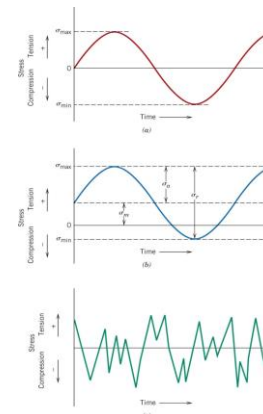
Damage is cumulative.

Fatigue is usually associated with tensile stresses.

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Type of loads

Dynamic fatigue



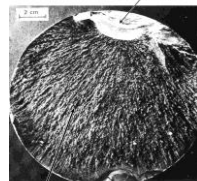
Static fatigue:

Long-term stress results decrease in strength.

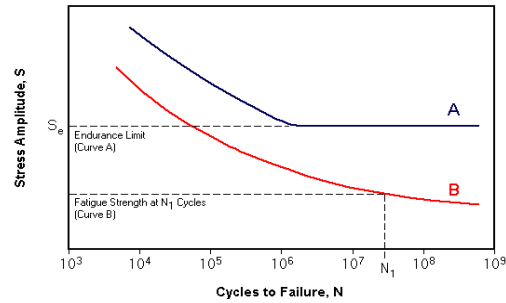
a test equipment



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Fatigue S-N curve:

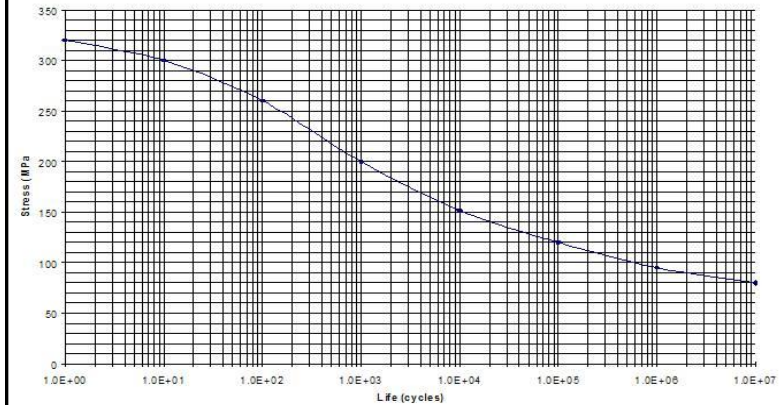


e.g. steel, titanium, ...

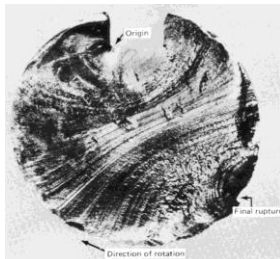
e.g. aluminium, copper, ...

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S-N CURVE FOR BRITTLE ALUMINUM WITH A UTS OF 320 MPa



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a test equipment

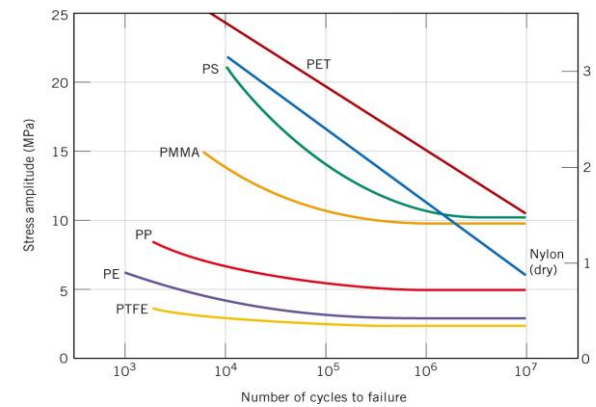


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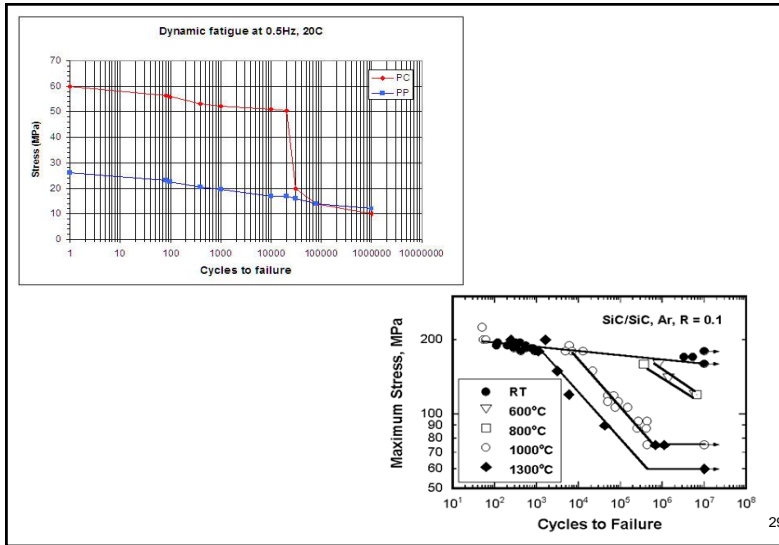
S-N curves of different polymers

PET: Polyethylene terephthalate
PS: Polystyrene
PMMA: Poly(methyl metacrylate)

PP: Polyethylene terephthalate
PE: Polyethylene
PTFE: Polytetrafluoroethylene



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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

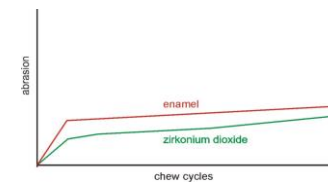
(Erosion a chemical event!)

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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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