P287 # Chap. 10 Optical properties

P296 (EX 10.1) Estimate the refractive index of PF

P303 (Ex10.2) Estimate the opticalstress coeff. For polycarbonate with Vw=144 cm^3/mol

P311 (Ex 10.3) Estimate the specific refractive index increment (dn/dc) of polystylene in 1, 4 – dioxane (n_d=1.422)

Chap. 11 Electrical poroperties

P324 (Ex11.1) Estimate the dielectric constant and the average dipole moment of polycarbonate

P325 correlation between dielectric constant and solubility parameter (see Table 11.4)

$$\delta = 7.0\,\epsilon \qquad (11.5)$$

p330 conductivity (see Fig 11.5)- p.332

p343 # Chap. 12 Magnetic properties.

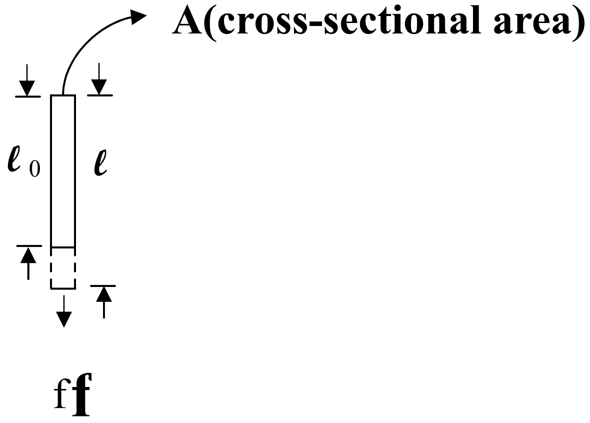
Chap. 13 Mechanical Properties of Solid Polymer

p.367 • Hook's Law

$\tau = Y\epsilon$, stress is proportional to the strain

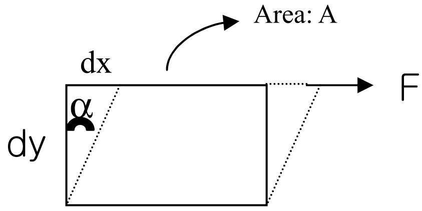
- τ : stress
- ϵ : strain
- Y : young's modulus

(a) Tensile deformation



- tensile strain : $\epsilon = \frac{\lambda - \lambda_0}{\lambda_0}$
- tensile stress : σ = f/A
- tensile modulus : Y = τ / ϵ
- tensile compliance : D = ϵ / τ

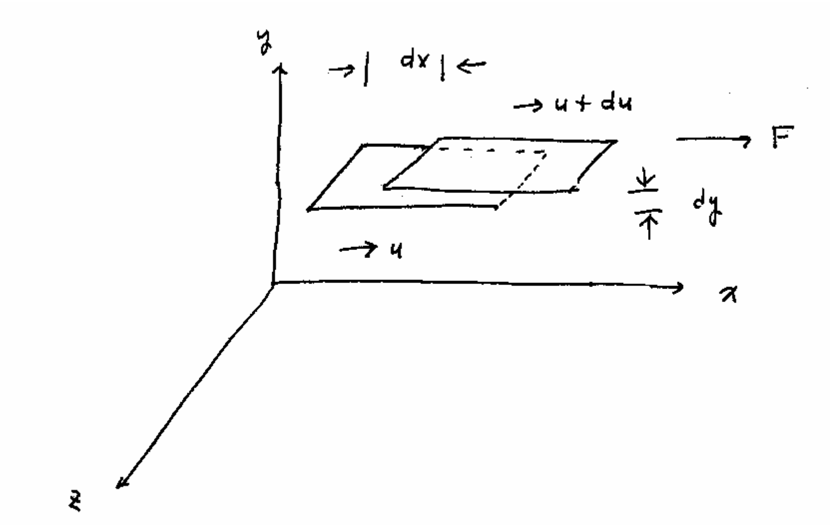
(b) shear deformation



- shear strain: γ = tan α $= \frac{dy}{dx}$
- shear stress: σ =f/A
- shear modulus :G=σ / γ
- shear compliance : J=γ / σ

(see Table 13.1)

- A modulus is the ratio between the applied stress and the corresponding deformation.



- a fuid surface at y :

  velocity : y= $\frac{dX}{dt}$

- a fluid surface at y+dy :

  velocity : y+dy:

- shear strain : $\gamma = \frac{dX}{dy}$

- shear rate : ŕ = $\frac{d}{dt}(\gamma) = \frac{d}{dt}\left(\frac{dx}{dy}\right) = \frac{d}{dy}\left(\frac{dx}{dt}\right) = \frac{dx}{dt}$

an alternate definition of the shear rate is the velocity gradient du/dy

- shear stress : τ = $\frac{F(in\ x\ direction)}{A(in\ y\ direction)}\ \frac{(force)}{(length^2)}$

- viscosity : $\eta \equiv$ τ / ŕ

p369• Poisson Ration : $\upsilon \equiv \dfrac{change \quad in \quad width \quad per \quad unit \quad width}{change \quad in \quad length \quad per \quad unit \quad length}$

$$= \frac{lateral \quad contraction}{axial \quad strain}$$

- poisson ratio 비교,

Table 13.4 (p.374)로부터

PMMA,	υ =0.40
PS	0.38
Copper	0.34
Glass	0.23

p. 377

(Ex.13.1) Estimate the bulk modulus of a medium density polyethylene, density of 0.95 (degree of crystallinity = 70%)

(sol.)

(a) Estimation by Rao fuction:

식 (13.22)로부터 (p. 375)

$$K/\rho = \left(U_R/V\right)^6$$

molar volume, $V = \dfrac{M}{\rho} = \dfrac{28}{0.95} = 29.5\ (cm^3/mol)$

여기서 U (Molar elastic Wave Fuction)를 구하기 위하여 Table 14.2 참조 (p.447)

$U_R = 2 \times 880\ (cm^3/mol)\ (cm/sec)^{1/3}$

$= 1760$

그러므로 $\left(U_R/V\right)^6 = \left(1760/29.5\right)^6$

$= 4.5 \times 10^{10} (cm^2/sec^2)$

$\therefore\ K = 4.5 \times 10^{10} \times 0.95\ g/cm \cdot sec^2$

$= \underline{4.3 \times 10^9}\ (N/m^2)$

p378 (Ex 13.2) Estimate the moduli and Poisson ratio of polycarbonate,

(sol.) Poisson ratio ;

식 (13.10) (p. 370)으로부터

$$\upsilon = \frac{1-\frac{2G}{3K}}{2(1+\frac{G}{3K})} = \frac{1-0.15}{2(1+0.075)} = 0.39$$

υ (exp) = <u>0.39</u>

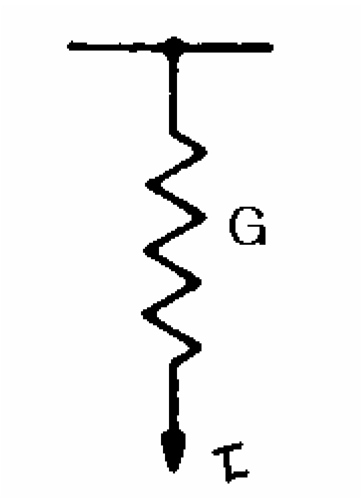
<u>p388.</u> • Linear Viscosity.

-Two linear model
- linear elastic
- linear viscous

ⅰ) Linear elastic model : OR Hookean Solid.

$\tau = G\gamma$

G= shear modulus



Linear elastic model
Or Hookean solid

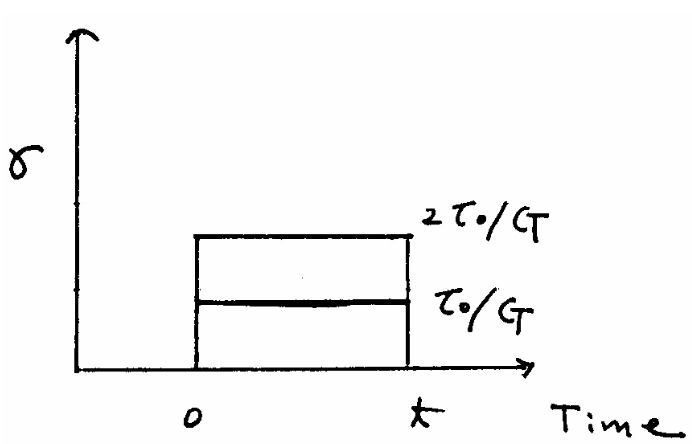


Fig. Response of spring

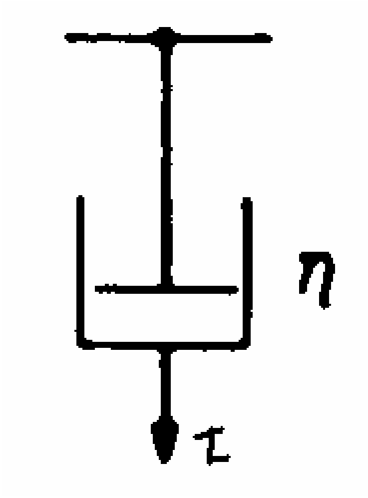
• The overall modulus is a function of time only, no the magnitude of Stress or strain.

τ : $G\gamma$

G: shear modulus

$$G \equiv \tau/\gamma = G$$

(t only for linear response)



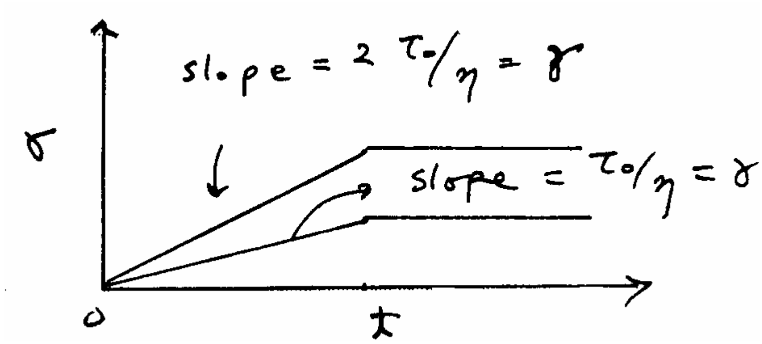


Fig. Response of dashpot

Linear viscous model

Or Newtonian fluid

$\tau = \eta \dot{\gamma}$

η :viscosity

- **Mechanical Models for linear viscoelasic response**

(1) The Maxwell Element.

- a simple series combination of a linear viscous element (dashpot) and a linear elastic element (spring)

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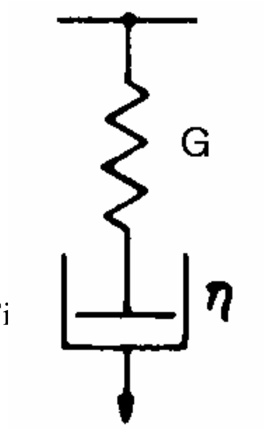


Fig. Maxwell element

-the spring and dashpot support the same stress:

$\tau = \tau_{spring} = \tau_{dashpot}$

-the overall strain of the element :

$\gamma = \gamma_{spring} + \gamma_{dashpot}$

differentitation with time, t

$\dot{\gamma} = \dot{\gamma}_{spring} + \dot{\gamma}_{dashpot}$

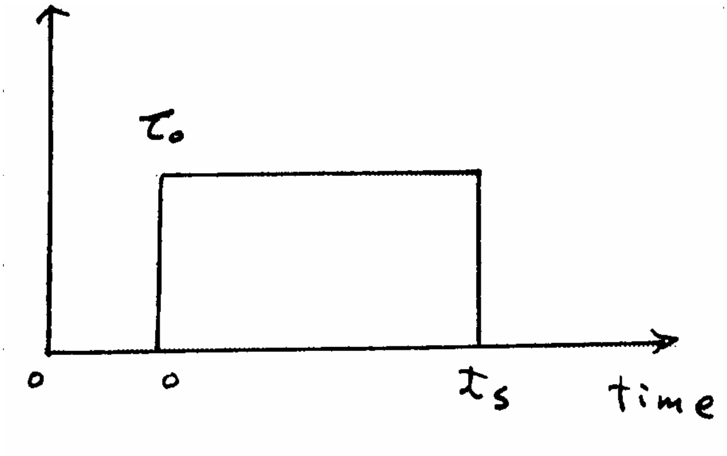
$\dot{\gamma} = \dot{\tau}/G + \tau / \eta$

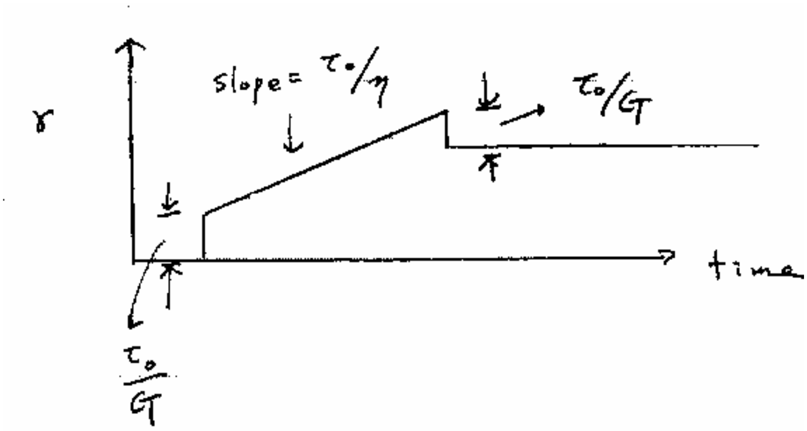
$\tau = \eta \dot{\gamma} - (\eta/G)\ \dot{\tau}$

$= \eta \dot{\gamma} - \lambda \dot{\tau}$

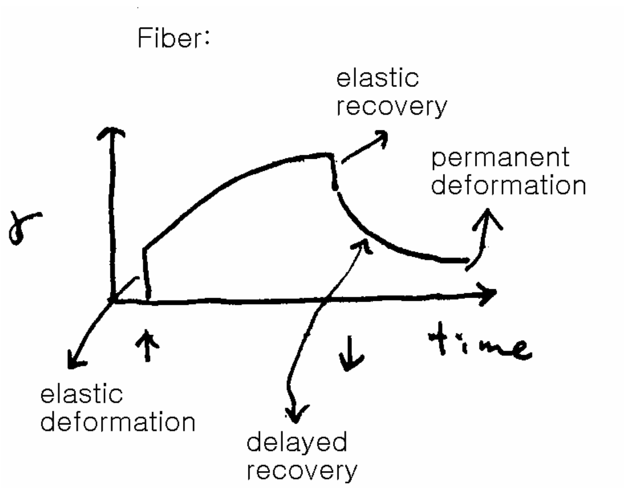
where ($\lambda = \eta/G$: relaxation time)

• <u>creep test</u> – a constant stress is instantaneously applied to the material, and the resulting strain is followed as a function of time



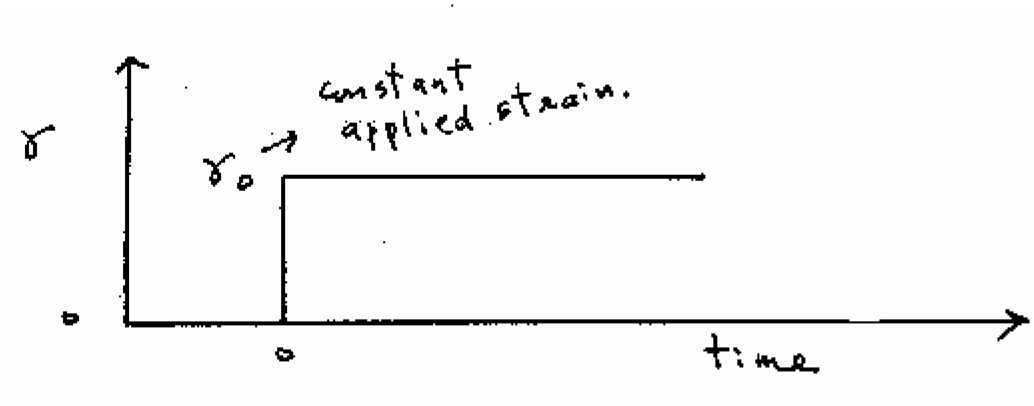


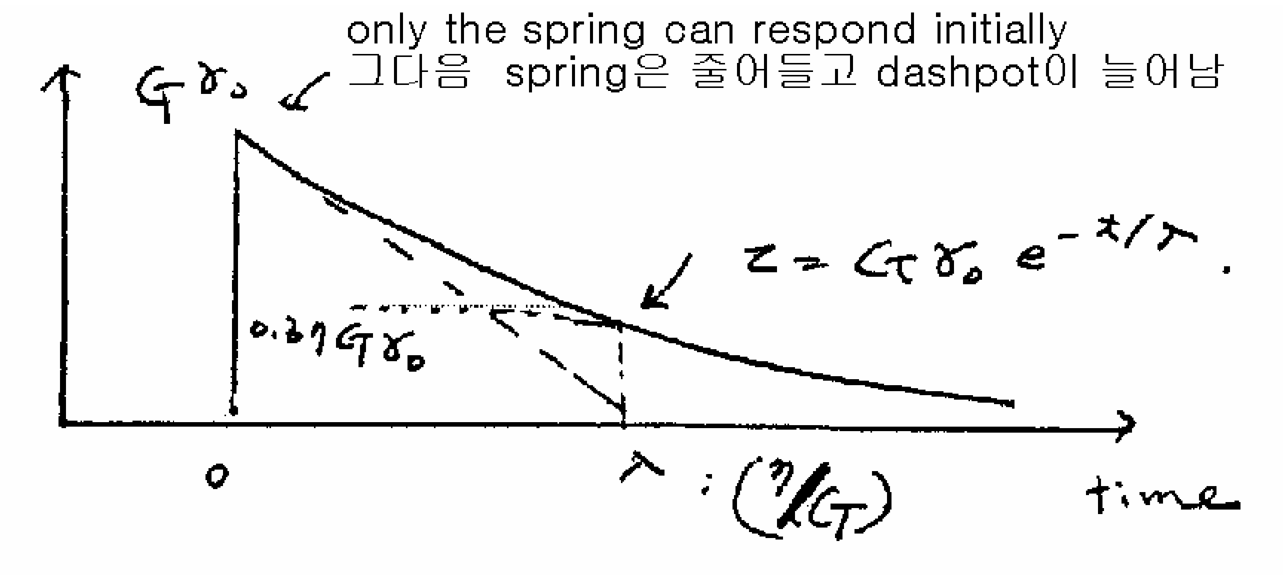
ex)



- creep recovery : deformation after removal of the stress.
- τ_0/G : instantaneous stretching of the spring to an equilibrium value with the sudden application of stress (τ_0)
- Elastic Recovery : when the stress is release the spring immediately contracts by an amount equal to its original extension

- **<u>Stress relaxation test :</u>** Suddenly applying a strain to the sample and following the stress as a function of time as the strain is held constant.

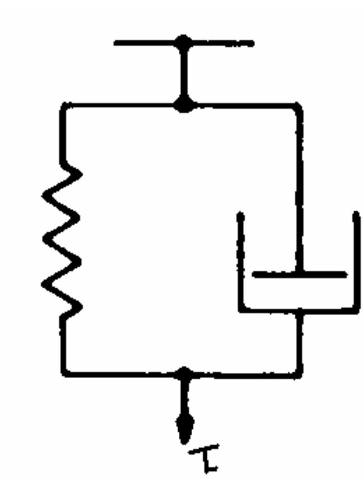




λ : (relaxation time)- time required for the stress to decay to a factor of 1/e or 37% of its initial value.

- 실제 linear polymer 의 stress-relaxation curve 와 비슷함

(ii) The Voigt-kelvin Element : for crosslinked polymer



- strain in each element is same

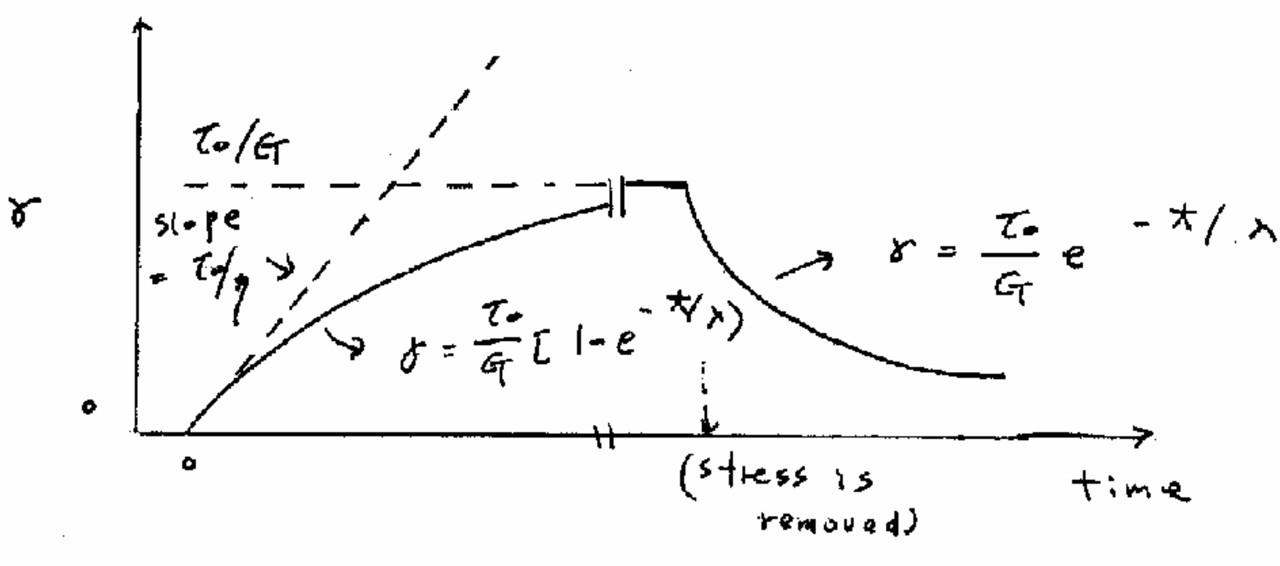
$\gamma = \gamma_{spring} = \gamma_{dashpot}$

- The stress is the sum of the stresses:

$\tau = \tau_{spring} = \tau_{dashpot}$

$\tau = G\gamma + \eta\dot{\gamma}$

- **Creep response of a Voigt-kelvin Element : stress is constant**



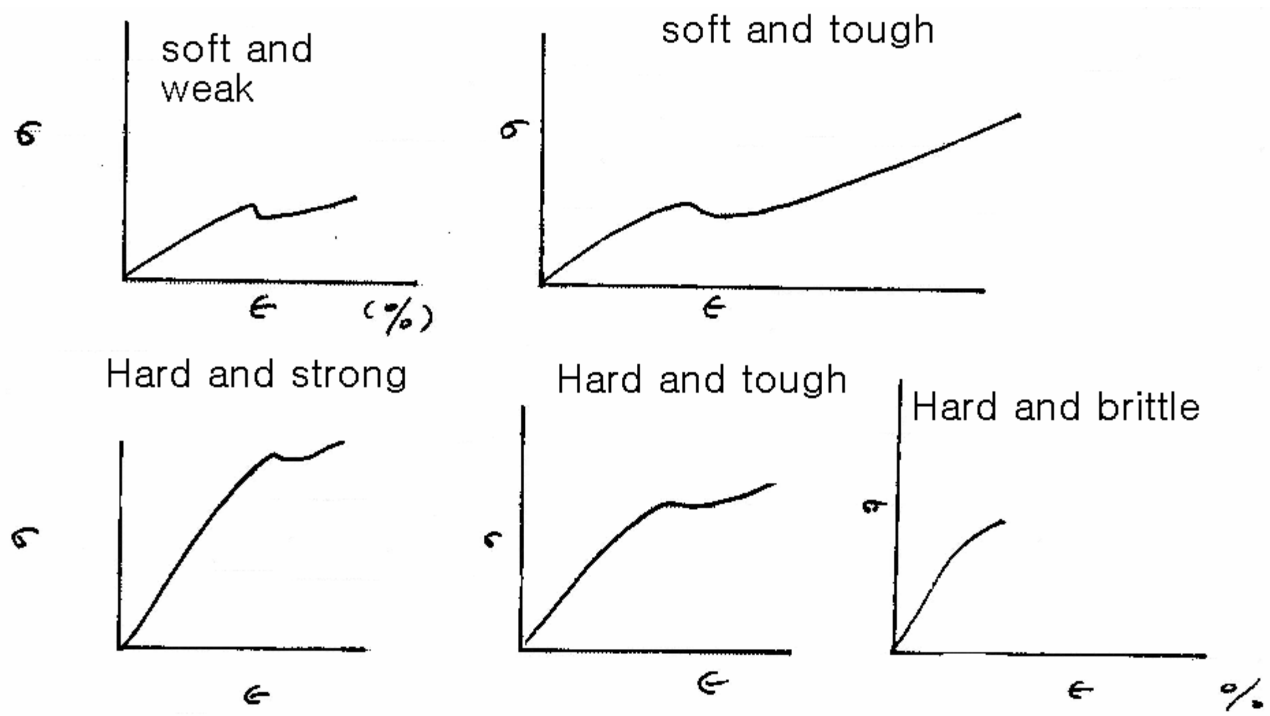
-initial slope of the strain vs time curve is

- as the element is extend, the spring provides an increasingly greater resistance to further extension, and so the rate of creep decreases.

- Eventually, the system curves to equilibrium with the spring alone supporting the stress. (rate of strain = 0 , resistance of the dashpot=0)
- The equilibrium strain = τ_0/G
- Voigt-kelvin model : a fair qualitative picture of the creep respose of some crosslinked polymers.

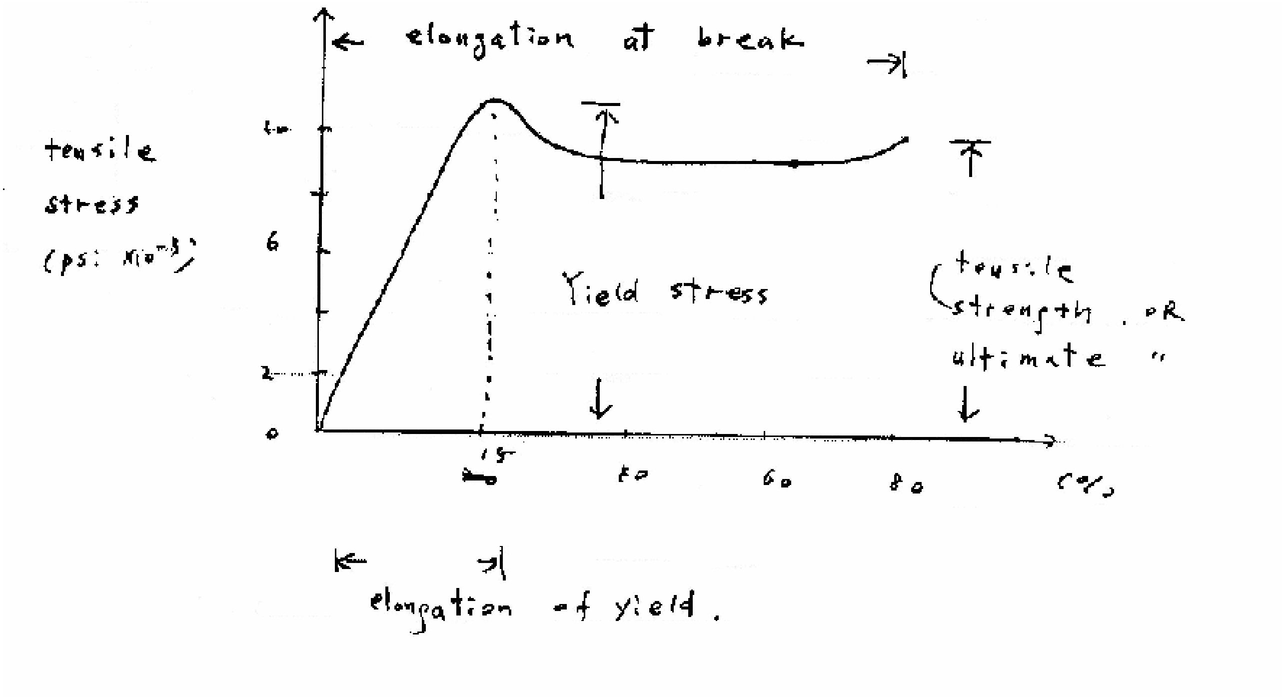
• characteristics of tensile stress-strain curves of polymer samples.

See page 413 in V. K.



• polymer 사이에 dipole-dipole interaction 이 없기 때문에 soft 하다.

• strongly polar polymer: Nylon, PC, acetal (Engineering plastics) see P.426



- yield stress : 11000psi
- strain at yield : 15%
- ultimate elongation : 80%
- Filled thermosetting polymers:

일반 engineering 고분자와 비교했을 때 stiffness 가 4-5 배

• high modulus, high strength polymer – Aramid Fiber (Kevlar) – aromatic polyamid. Thermosetting resin, carbon Fiber 등의 액정고분자

p402 <u>C5. The time-temperature superposition principle</u> (TTSP)

- Above Tg, the stress relaxation and the creep behavior of amorphous polymers obey the " time-temperature superposition principle"
- In viscoelastic maters, time and temperature are equivalent to the extent that data at one temp. can be superimposed upon data taken at a different temperature
- The amount each reduced modulus has to be shifted along the logarithmic time axis in making the master curve, the socalled shift factor, is a function of temp.

$$Log\ a_T = \log {t}/{t(T_g)} = \frac{-17.44(T-T_g)}{51.6+(T-T_g)}$$

W.L. Ferry Eq.

P. 405 <u>Ex 13.3</u>

25℃, measuring time 1h 에서 polyisobutylene 의 stress relaxation modulus 는 3×10^5 N/m^2 이다.

(a) time 1h, 80℃에서 modulus 는?

(b) 식(13.70)에서 그리고 PIB 의 T_g =197k

$$\log a(273+25) = \frac{-17.44(298-197)}{51.6+101}$$

$$= \frac{-1760}{152.6} = -11.5$$

$$\log a\frac{273-80}{193} = \frac{17.44\times 4}{51.6-4} = \frac{70}{47.6} = 1.5$$

$$\log\frac{a(193)}{a(298)} = 1.5+11.5 = 13.0 \quad \left(\log\frac{a(298)}{a(193)} = -13\right)$$

the master curve at t≈10-13 에서의 modulus 는 약 $\underline{2\times 10^9 \text{ N/m}^2}$