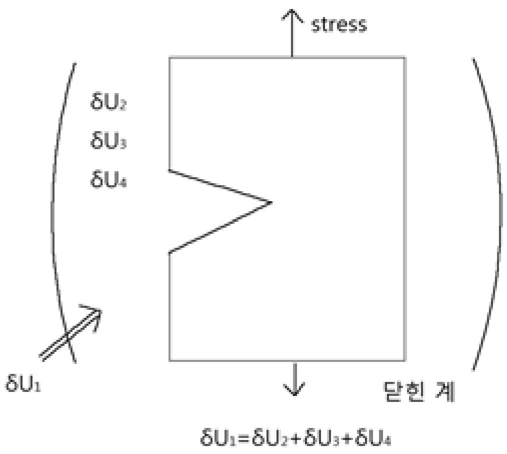
Ch.11 Mechanical behavior of Polymer

11. 1 An energy balance for deformation and fracture

notch

1) 1st law of thermodynamics



δU_1 = Input Energy

δU_2 = Dissipated E(분산E)

δU_3 = Stored E(저장E=내부E)

δU_4 = Kinetic E(운동E)

* 입력 E (= 파괴 E) = 분산E + 운동E + 저장E(내부E)

* 강체(단단한 물질, rigid body)일 경우 분산E = 저장E = 0

2) Spring과 Dashpots의 관계

U4 = 1/2MV^2 (Newton's 3법칙)

U3 = 1/2Eε^2 (Kinetic E for spring)

$$\sigma = E\epsilon + \eta\frac{d\epsilon}{dt} + M\frac{d^2\epsilon}{dt^2}$$

spring

dashpot

$$\Rightarrow \frac{\delta U_1}{\delta A} - \frac{\delta U_2}{\delta A} = \frac{\delta U_3}{\delta A} + \frac{\delta U_4}{\delta A}$$

(δA : 단면적)

* $\frac{\delta U_2}{\delta A} = \overline{R}$

(fracture resistance, 파괴저항:

단위면적당 분산 에너지)

$\overline{R}$↑⇒tough material(튼튼한 재료)

U2 = U1 – U3- U4(= 0)

* $\frac{dU_1}{dA} - \frac{dU_3}{dA} = g$ (strain energy release rate, 변형 에너지 방출율)

(단위면적당 입력에너지) - (단위면적당 저장에너지)

= 파괴일(work of fracture)

= 파괴에너지(fractured energy)

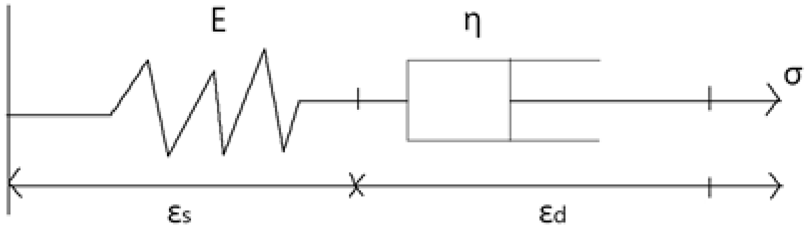
if> g >$\overline{R}$: $\overline{R}$보다 큰 힘을 주면 craze--->crack 속도↑⇒crack 성장 → fracture

균열

*spring・dashpot 모델

①Maxwell model

: Newton의 법칙을 따르는 점성 유체의 거동을 나타내는 dashpot(viscosity)과 Hooke의 법칙을 따르는 고체 탄성을 나타내는 spring (elasticity)이 직렬로 연결되어 점탄성을 나타내는 모델.

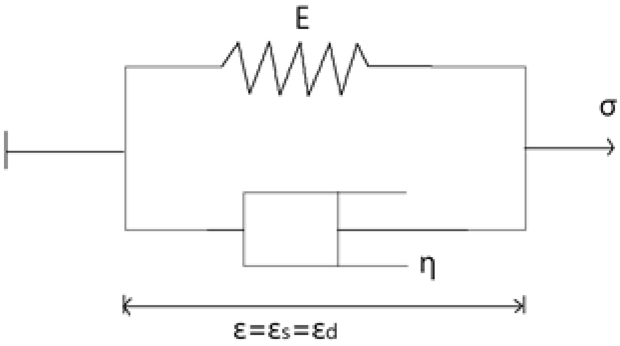


→$\varepsilon=\varepsilon_s+\varepsilon_d$ (spring(ε_s)과 dashpot(ε_d)의 변위의 합이 전체 변위)

$\sigma=\sigma_s=\sigma_d$ (spring(σ_s)과 dashpot(σ_d)이 받는 응력이 같음⇒직렬 연결)

② Kelvin - Voigt model

: dashpot(점성유체)과 spring(고체탄성)dl 병렬로 연결



→$\sigma=\sigma_s+\sigma_d$

(시스템에 가해지는 전체 응력을 분담)

→$\varepsilon=\varepsilon_s=\varepsilon_d$

(spring과 dashpot의 변형 길이가 같음)

→병렬관계

11. 2 Deformation and fracture in polymers

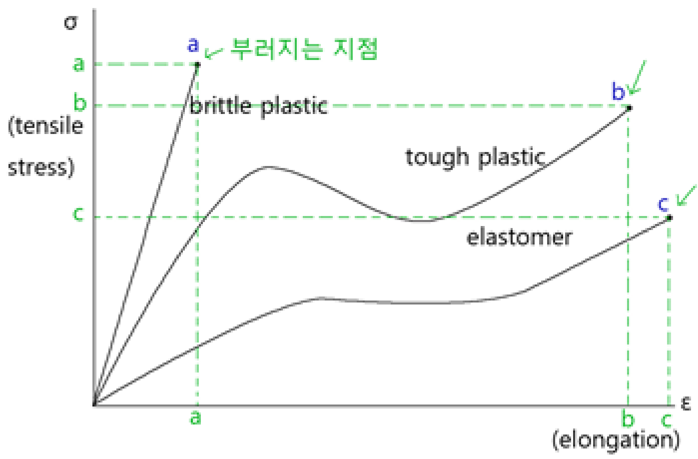
craze(작은 균열)

shear yielding →crack →fracture

(균열에 대한 저항으로 가는 실 같은 것이 생기는 현상) (큰 균열) (파괴)

1) Stress - Strain Behavior of Polymer

<stress - strain curve : s - s curve, 응력-변형 곡선>



a,b,c: tensile strength 인장강도

* x축→ε(elongation)

ε↓→brittle(취성, 잘 깨짐)

ε↑→ductile(연성,잘 늘어남)

* y축→σ(tensile strength)

σ↑→rigid(튼튼한)

σ↓→soft(무른)

a.b.c;

elongation at (to) break 파단신율

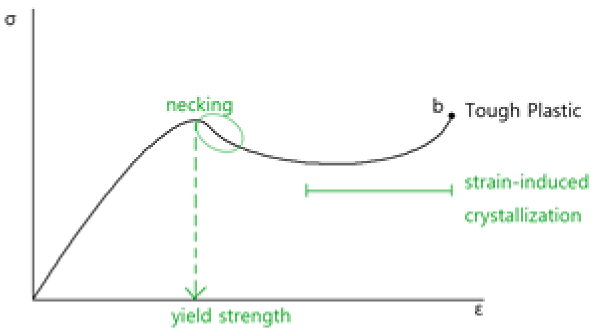
*면적→에너지(Energy) *기울기→tensile modulus(E)

면적↑→toughness (질긴)↑ 기울기↑→rigid (튼튼한);stiff

(기울기↓→soft (무른);flexible

<비교>

- brittle : a>b>c
- ductile : c>b>a
- strong : a>b>c
- toughness : b>c>a
- rigid : a>b>c



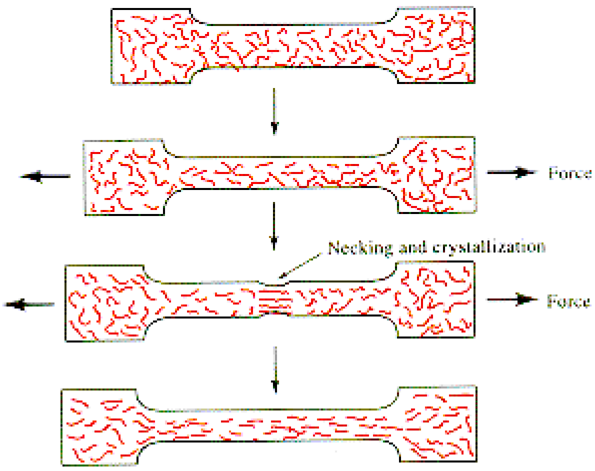
→대부분 polymer가 이런 행동, 매우 특이

- necking : 최대 stress이후 감소하는 부분, cold-drawing(냉연신)시 관찰되기도 함

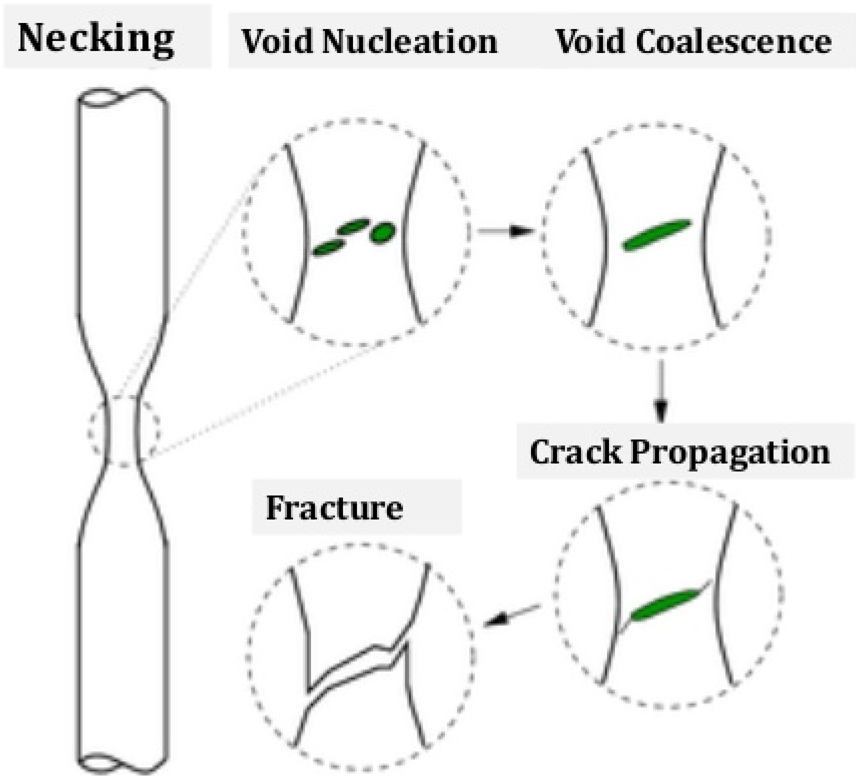
• yield strength(항복 강도) : necking 전 최대응력, 항복응력 이후 crack 성장

• stain-induced crystallization(변형에 의한 유도 결정화)

: 응력에 의해 다시 단단해짐(σ↓→σ↑) 이후 파괴



Necking and strain(혹은 stress) induced crystallization


Necking
Void Nucleation
Void Coalescence
Crack Propagation
Fracture

actual stress-strain (S-S) behavior

Description of Polymer	Characteristics of Stress-Strain Curve			
	Modulus	Yield Stress	Ultimate Strength	Elongation at Break
Soft, weak	Low	Low	Low	Moderate
Soft, tough	Low	Low	(Yield Stress)	High
Hard, strong	High	High	High	Moderate
Hard, tough	High	High	High	High
Hard, brittle	High	None	Moderate	Low

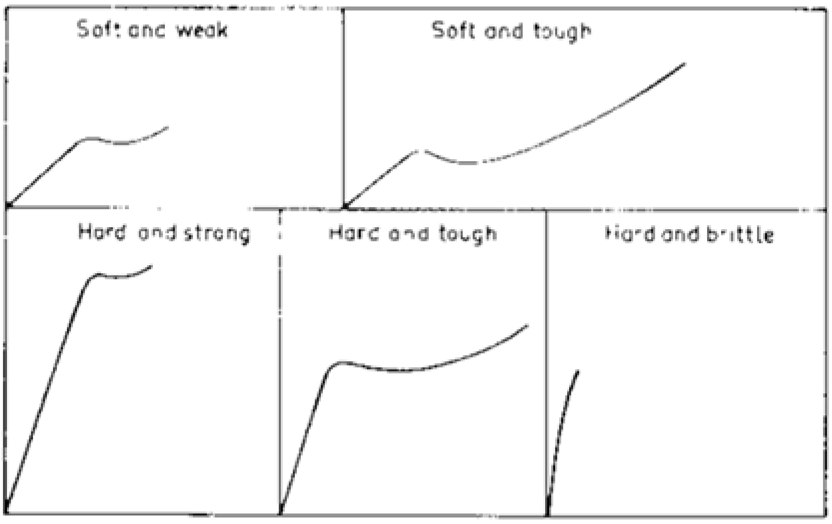


Fig. 13.27. Tensile stress–strain curves for several types of polymeric materials (Winding and Hiatt, 1961).

tensile strength of plastics

ex1)	amorphous polymer	semi-crystalline plastics	thermoset
tensile strength(σ)	σ↑ strong	σ↓ weak	σ↑ strong
elongation to break(ε)	ε↓ brittle	ε↑ ductile	ε↓ brittle

ex2)	Modulus	tensile strength	elongation
Polyethylene ultradrawn	172(rigid)	3.5(strong)	5(brittle)
Kevlar	100	3.0	6
Polyethylene	1(soft)	0.05(weak)	50(ductile)

Effects of time and temperature;

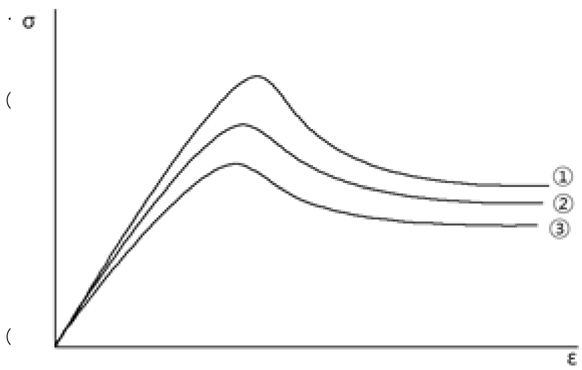
↳stress, strain이 같다면, 조건(t, T)이 다르면 modulus가 달라짐

(national standards국가 표준규격에 따라야)

s-s curve 는 인장 속도, 측정 온도에 관련

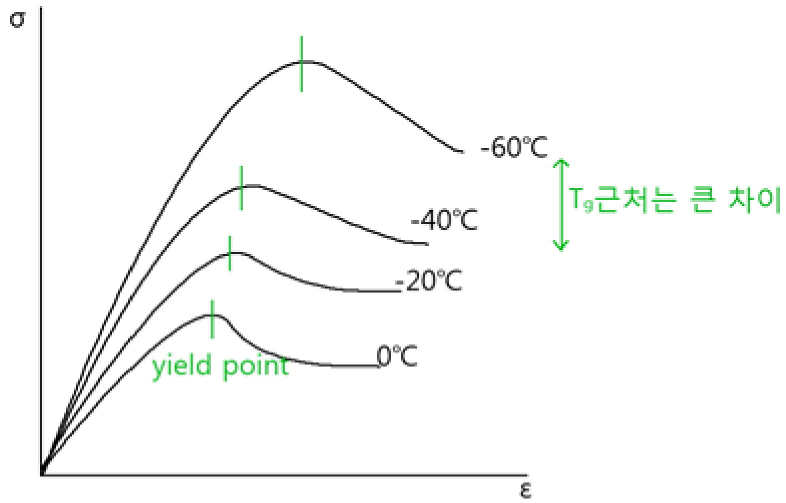
⇒ 빠른 측정 시간, 낮은 온도 ⇒ modulus↑

i) 인장속도



ㄷ↑ → modulus↑ (시간↓)

ii) 온도



⇒온도↓ → 기울기↑

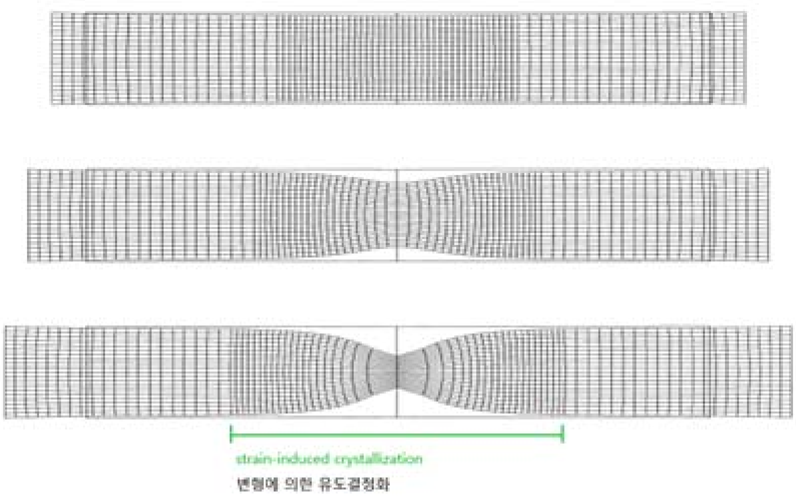
→ modulus↑

→yield point가 증가

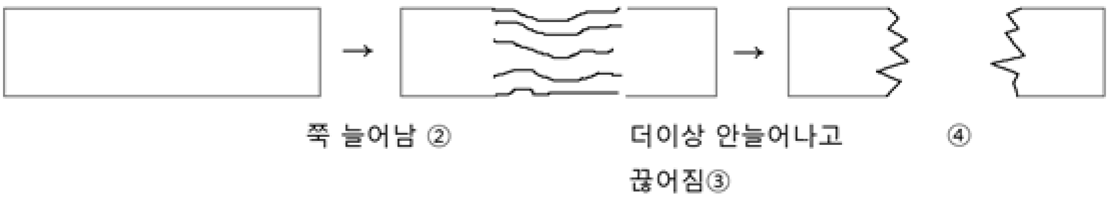
(elongation 증가)

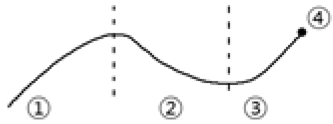
2) Cold Drawing in Crystalline polymer

⇒necking



→necking동안의 결정구조

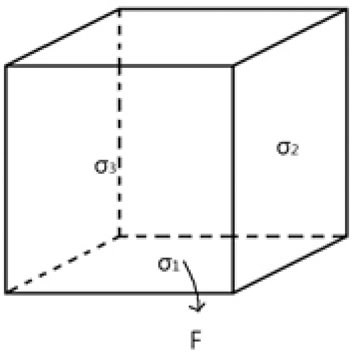




ex) 젓가락 비닐 껍질

3) The brittle - ductile transition

<von Mises criterion>



ex)

σ_1, σ_2, σ_3 : triaxial stresses

$$(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2=6c^2$$

If) $(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)<6c^2$

craze 발생, shear yielding 발생 X

If) $(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2>6c^2$

shear yielding 발생

종이는 $6c^2$보다 큰 값→shear yielding 발생