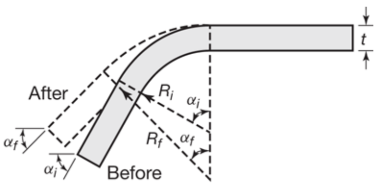
Springback



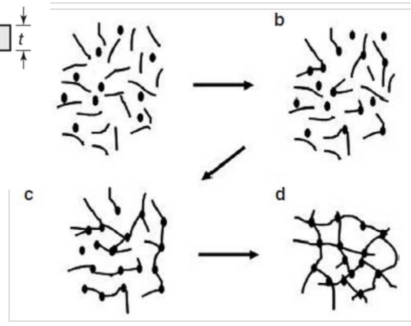


Figure 1 - Schematic diagram illustrating the steps involved in cross-linking: a) starting resin material with low-molecular-mass monomers (A-stage monomers); b) linear growth and branching (B-stage material or prepolymer); c) gelled, but still incomplete network; d) fully cured polymer (C-stage thermoset).

Look up Ks from table.

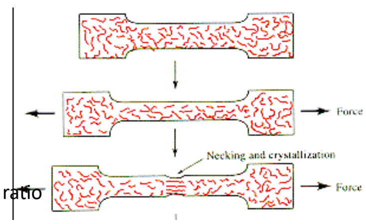
$$K_s = \frac{\alpha_f}{\alpha_i} = \frac{(2R_i/t)+1}{(2R_f/t)+1}$$

Can't look up Ks from table. Need material properties.

$$\frac{R_i}{R_f} = 4\left(\frac{R_i S_y}{Et}\right)^3 - 3\left(\frac{R_i S_y}{Et}\right) + 1$$

Limiting Drawing Ratio

$$LDR < \frac{D_o}{D_p}$$

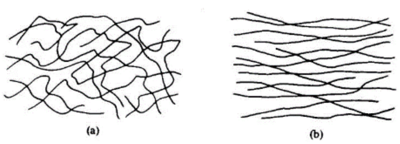


Normal anisotropy/plastic anisotropy/strain ratio

$$R = \frac{\epsilon_w}{\epsilon_t} = \frac{\ln\left(\frac{w_o}{w_f}\right)}{\ln\left(\frac{t_o}{t_f}\right)} \qquad R = \frac{\epsilon_w}{\epsilon_t} = \frac{\ln\left(\frac{w_o}{w_f}\right)}{\ln\left(\frac{t_o}{t_f}\right)}$$

Planar anisotropy

$$\overline{R} = \frac{R_0 + 2R_{45} + R_{90}}{4}$$



Want a high $\bar{R}$ for good LDR.

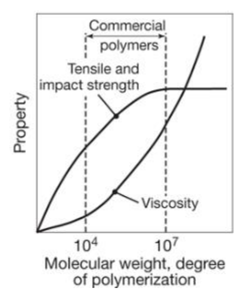
$$\Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2}$$

Low ΔR for good LDR

$\Delta R = 0 \rightarrow no\ earing(same\ in\ all\ directions)$

$\Delta R \uparrow = height\ of\ ears\ increases$

Desirable to have a larger die and punch radii.



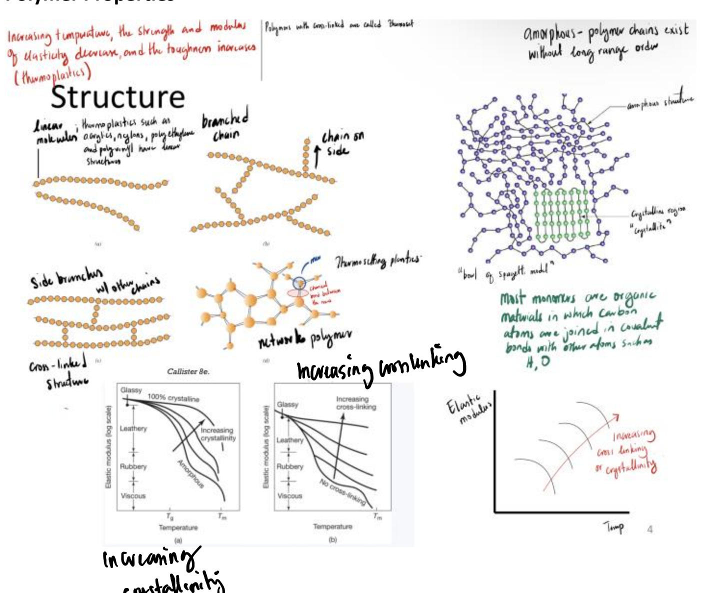
Maximum punch force

$$F_{\max} = \pi D_p t_o S_{ut}\left(\frac{D_o}{D_p} - 0.7\right)$$

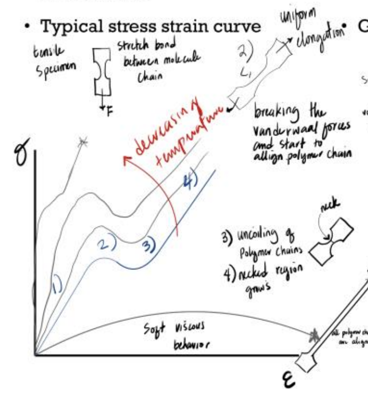
Thermoset - irreversible

Thermoplastic - reversible

Polymer Properties



Behavior



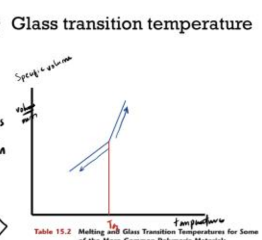


Table 15.2 Melting and Glass Transition Temperatures for Some of the More Common Polymeric Materials

Material	Glass Transition Temperature [°C (°F)]	Melting Temperature [°C (°F)]
Polyethylene (low density)	−110 (−165)	115 (240)
Polytetrafluoroethylene	−97 (−140)	327 (620)
Polyethylene (high density)	−90 (−130)	137 (279)
Polypropylene	−18 (0)	175 (347)
Nylon 6,6	57 (135)	265 (510)
Poly(ethylene terephthalate) (PET)	69 (155)	265 (510)
Poly(vinyl chloride)	87 (190)	212 (415)
Polystyrene	100 (212)	240 (465)
Polycarbonate	150 (300)	265 (510)

Adapted from *Callister 8e.*

Failure of Polymers

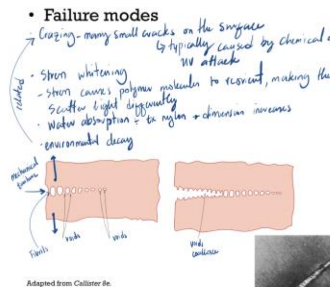
Table 8.1 Room-Temperature Yield Strength and Plane Strain Fracture Toughness Data for Selected Engineering Materials

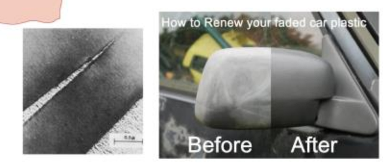
Material	Yield Strength MPa	Yield Strength ksi	K_{Ic} MPa$\sqrt{m}$	K_{Ic} ksi$\sqrt{in.}$
Metals				
Aluminum alloy[a] (7075-T651)	495	72	24	22
Aluminum alloy[a] (2024-T3)	345	50	44	40
Titanium alloy[a] (Ti-6Al-4V)	910	132	55	50
Alloy steel[a] (4340 tempered @ 260°C)	1640	238	50.0	45.8
Alloy steel[a] (4340 tempered @ 425°C)	1420	206	87.4	80.0
Ceramics				
Concrete	—	—	0.2–1.4	0.18–1.27
Soda-lime glass	—	—	0.7–0.8	0.64–0.73
Aluminum oxide	—	—	2.7–5.0	2.5–4.6
Polymers				
Polystyrene (PS)	25.0–69.0	3.63–10.0	0.7–1.1	0.64–1.0
Poly(methyl methacrylate) (PMMA)	53.8–73.1	7.8–10.6	0.7–1.6	0.64–1.5
Polycarbonate (PC)	62.1	9.0	2.2	2.0

[a] Source: Reprinted with permission, *Advanced Materials and Processes*, ASM International, © 1990.

Adapted from *Callister 8e.*

- Failure modes





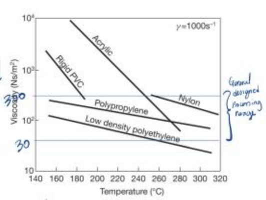
Polymer Processing

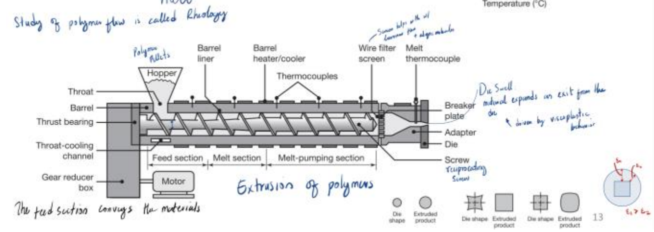
Processing Basics

- Viscosity/Temperature

to shape thermoplastics, they must be heated so they soften to the consistency of a liquid → liquid form is called "polymer melt"

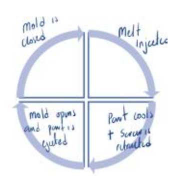
Study of polymer flow is called Rheology

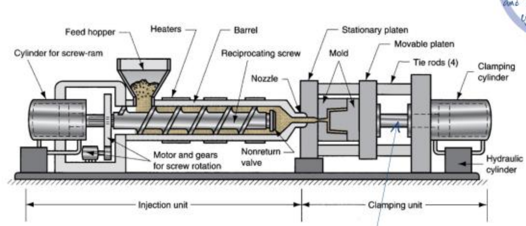




https://youtu.be/RMjtmsr3CqA

Injection Molding Press





Injection molding is very similar to hot chamber die casting. The pellets or granules are fed into a heated cylinder, where they are melted, then forced into a split-die chamber, either by a hydraulic plunger or by the rotating screw of an extruder. Most modern equipment is of the *reciprocating-screw* type. As the pressure builds up at the mold entrance, the screw starts to move backward and under pressure, to a predetermined distance, thus controlling the volume of material to be injected. The screw then stops rotating and is pushed forward hydraulically, forcing the molten plastic into the mold cavity. Injection-molding pressures usually range from 70 to 200 MPa (10–30 ksi).

In *extrusion*, raw thermoplastic materials, in the form of pellets, granules, or powder, are placed into a hopper and fed into the extruder barrel. The barrel is equipped with a *screw* that blends and conveys the pellets down the barrel. The internal friction and shear stresses developed from the mechanical action of the screw, along with heaters around the extruder's barrel, heats the pellets and liquefies them. The screw action also builds up pressure in the barrel.

Blow molding is a modified combination of extrusion and injection-molding processes. In **injection blow molding**, a short tubular preform (**parison**) is first injection molded. The parison can be stored for future molding, or it can be used immediately. If used immediately, the parison molds are opened, and the parison is transferred to a blow-molding die. Hot air is injected into the parison, which expands and fills the mold cavity. Typical products made include plastic beverage bottles and hollow containers.

Shrink Rate

Polymers have high thermal expansion coefficients, so significant shrinkage occurs during solidification.

$D_C = D_p + D_pS + D_pS^2$

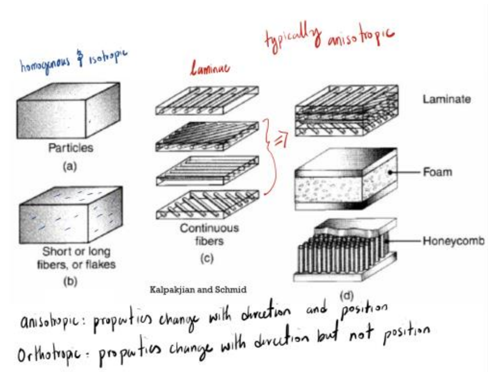
$D_c - dimension\ of\ cavity\ machined\ into\ mold$

$D_p - desired\ part\ dimension$

$D_p - desired\ part\ dimension$

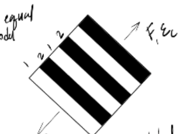
Composites

A material system that is composed of two or more physically distinct phases that have



different properties and constituents.

a) Constant equal stress model



$\sigma = E\varepsilon$

$\varepsilon = \frac{\sigma}{E}$

$\varepsilon_c = x_1\varepsilon_1 + x_2\varepsilon_2$

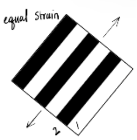
$\frac{\sigma_c}{E_c} = x_1\frac{\sigma_1}{E_1} + x_2\frac{\sigma_2}{E_2}$

divide by $\sigma_c = \sigma_1 = \sigma_2$

$\frac{1}{E_c} = \frac{x_1}{E_1} + \frac{x_2}{E_2}$

$\boxed{E_c = \frac{E_1E_2}{x_1E_1 + x_2E_2}}$ rule of mixture

Constant equal Strain model



$F_c = F_1 + F_2$ $\sigma = E\varepsilon$

$\sigma_c = x_1\sigma_1 + x_2\sigma_2$

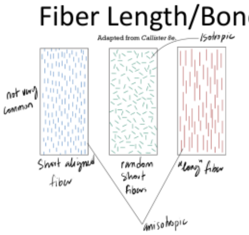
divide by $\varepsilon_c = \varepsilon_1 = \varepsilon_2$

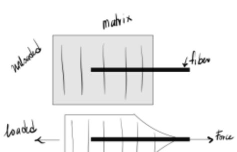
$\boxed{E_c = x_1E_1 + x_2E_2}$

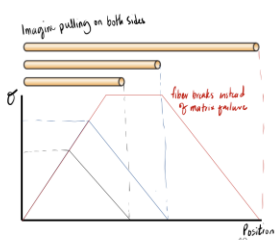
or $\boxed{E_c = x_1E_1 + (1-x_1)E_2}$

Effect of Fiber length & Strength

Fiber Length/Bonding







$L_c = \frac{\sigma_f \cdot d}{2\tau}$

critical length; fiber strength; fiber diameter; τ - fiber matrix bond strength

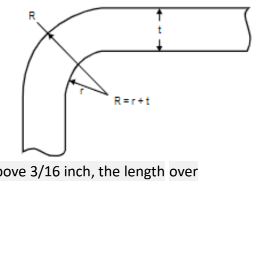
$L_c = 20d - 150d$

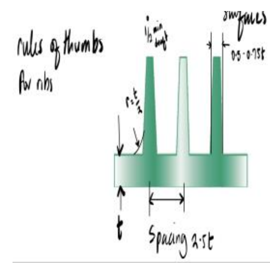
fraction (ratio) of load taken by the fibers

$$\frac{F_f}{F_c} = \frac{1}{\frac{(1-x_f)E_m}{x_fE_f} + 1}$$

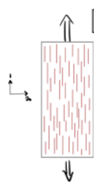
Polymer Design

- Wall Thickness
  - The basic wall of the part should be kept uniform.
  - Less than 5mm
  - Avoid variations in thickness to simplify flow patterns.
  - Avoid abrupt changes in wall thickness in wall thickness- use gradual transitions if necessary.
- Parting Lines
  - Specify mismatch on the parting line.
- Ejection
- No undercuts
- Draft
  - Minimum draft - 1 degree
  - 1/2 degree on short surface or critical section
  - 5-12 degree for textured surfaces
- Appearance Parts Ribs/Gussets
  - The thickness of the rib at the intersection with the nominal wall should be 50 to 60% of the nominal wall.
  -
- Bosses
  - Typically, the boss OD = 2 ID.
  - The wall thickness at the base of the boss should remain less than 60% of the nominal wall thickness.
  - The boss height should be less than 3 × OD.
  - Draft on the OD is 1/2̊ minimum.
- Holes
  - For blind holes, the length over diameter ratio should remain below 2. As the diameter of the hole increases above 3/16 inch, the length over diameter ratio can increase to 3.
- Depressions
- Radii, Fillets and Corners
  - The outside corner radius should be equal to the inside radii plus the wall thickness (R = r + t).





Elastic Modulus for Long Fiber Composites



Rule of mixture

$\boxed{E_1 = x_{matrix} \cdot E_{matrix} + x_{fiber}E_{fiber}}$

eq For fraction of load carried by fiber

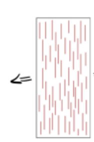
$\boxed{\frac{P_{fiber}}{P_{composite}} = \left(1 + \frac{x_mE_m}{x_fE_f}\right)^{-1}}$

$\sigma_{cu} = \sigma_{fu}x_f + \sigma_{mu}x_m$ — ultimate

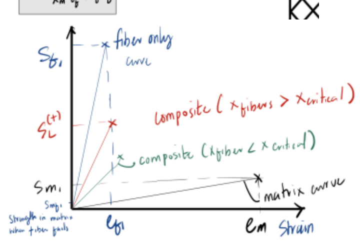
$\boxed{\sigma_{cu} = \sigma_{fu}x_f + \sigma_m' x_m}$

σ_m' - Stress in the matrix at the strain equal to the fracture strain of the fibers

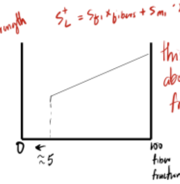
Material
T300/934 graphite/epoxy
AS/3501 graphite/epoxy
p-100/ERL 1962 pitch graphite/epoxy
Kevlar® 49/934 aramid/epoxy
Scotchply® 1002 E-glass/epoxy
Boron/5505 boron/epoxy
Spectra® 900/826 polyethylene/epoxy
E-glass/470-36 E-glass/vinylester



$\boxed{E_2 = \frac{E_mE_f}{x_m \cdot E_f + x_fE_f}}$



Strength $S_L^+ = S_{f1} x_{fibers} + S_{m1} \cdot X_{matrix}$



this model only applies above the critical fiber fraction

Failure of Fiber Composites

- **Failure modes**