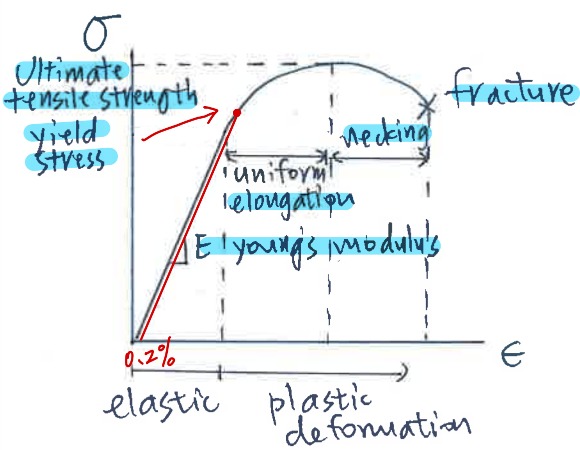
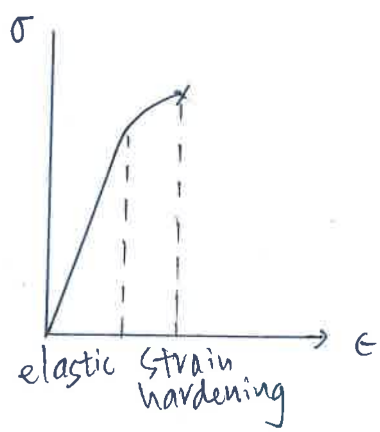
a)

1. Football helmet : polycarbonate , Injection (compression molding)
2. Coffee mug : ceramic casting (investment casting)
3. Lego : ABS, IM
4. Bottle : PET, blow molding
5. Dreamliner fuselage : Carbon fiber reinforced polymer (composite) extrusion
6. Turbine blade : Ni-alloy, casting (engine blade-die casting)
7. Toothbrush grip : rubber, IM (CO)
8. Bumper of car : polycarbonate, reaction-IM
9. Apple notebook case : Al, CNC

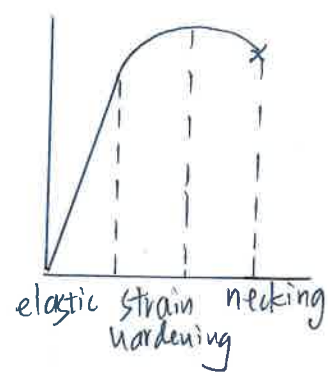
Stress-strain curve



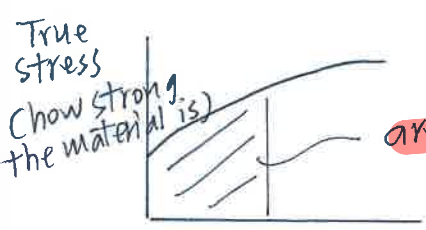
Brittle material



Ductile material



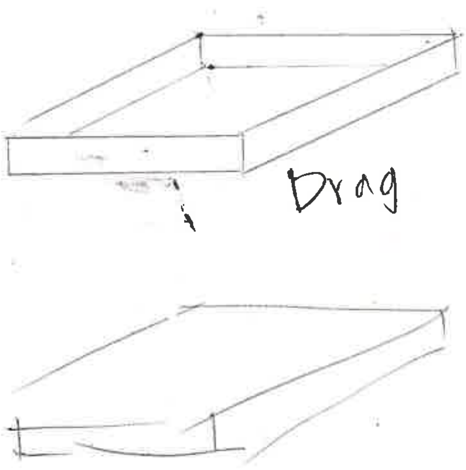
True stress - True strain curve



area = toughness : the amount of energy per unit volume the material can absorb

True strain (Ductility)

Sand Casting



(Drag)

Put pattern into the box.
then sand.
↓
(Cope)

Cope (box) → pattern → sand

insert gate, spures → pour metal into mold

Pros: - no limit in size
- almost all metals (variety of metals)
- low cost. reuse sand
- expendable mold, reusable pattern

Cons: not precise

Die casting

- Permanent mold (no pattern) usually metal mold

- mold cost high, but can be reuse
- rapid high production for simple or complex, thin wall, precision parts
- usually small to moderate in size
- non-ferrous metals (Fe ×)
- Can produce multiple parts

Hot chamber - low melting temp. materials - plunger
Cold chamber - higher melting materials - feed system

Cons: × large part
high die cost

× for very high melting metals and alloy

Investment Casting - expendable mold, expendable pattern

- mold : ceramic
  pattern: wax (made by IM)
- takes time. expensive process

Part molded in wax → attach runner → dip in wet ceramic slurry
→ drying → heat → molten metal → break ceramic mold

Pros: complex shape, close tolerance, thin wall, smooth finishes

CNC

precise, speed, repeatable

Pros: 1. continuous use (no need to shut down)
2. consistency
3. less staff
4. update software can improve machine performance
5. Training, no degrees needed

Cons: 1. cost more
2. expensive
3. maintainence

IM

Pros: fast production
low labor cost
multiple materials
low production cost

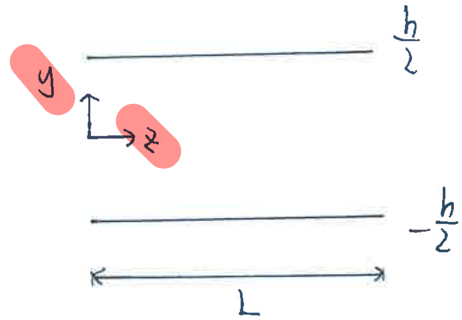
Cons: expensive mold
Some design restriction

AM

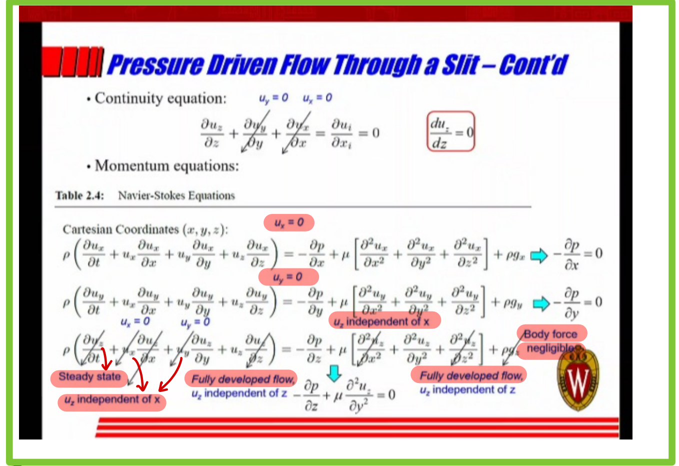
Pros: - not only rapid prototyping, but have good mechanical properties
- can be post processed
- moving assemblies

Cons: resolution
support structure
small voids

Slit



$$\mu \frac{\partial^2 u_z}{\partial y^2}$$



$$\frac{\partial \cancel{u_x}}{\partial \cancel{x}} + \frac{\partial \cancel{u_y}}{\partial y} + \frac{\partial u_z}{\partial z} = 0 \longrightarrow u_z(z) = 0$$

$$0 = -\frac{\partial P}{\partial z} + \mu\left(\frac{\partial^2 u_z}{\partial y^2}\right) \longrightarrow \frac{\partial P}{\partial z} = \mu\left(\frac{\partial^2 u_z}{\partial y^2}\right)$$

$$\frac{\partial^2 u_z}{\partial y^2} = \frac{1}{\mu}\cdot\frac{\partial P}{\partial z}$$

$$\frac{\partial u_z}{\partial y} = \frac{1}{\mu}\cdot\frac{\partial P}{\partial z}\cdot y + C_1$$

$$u_z(y) = \frac{1}{\mu}\cdot\frac{\Delta P}{L}\cdot\frac{1}{2}y^2 + C_1 y + C_2$$

BCs: ① $y = +\frac{1}{2}h$, $u_z = 0 \longrightarrow 0 = \frac{1}{\mu}\cdot\frac{\Delta P}{L}\cdot\frac{h^2}{8} + C_2 \longrightarrow C_2 = -\frac{1}{\mu}\frac{\Delta P}{L}\cdot\frac{h^2}{8}$

② $y = 0$, $\frac{\partial u_z}{\partial y} = 0 \longrightarrow C_1 = 0$

$$\therefore\ u_z(y) = \frac{1}{\mu}\cdot\frac{\Delta P}{L}\left(\frac{y^2}{2} - \frac{h^2}{8}\right)$$

$$\frac{1}{h/2}\int_0^{h/2} u_z(y)\,dy$$

$$\overline{u_z} = \frac{1}{h/2}\int_0^{h/2} u_z(y)\,dy$$

$$= \frac{2}{h}\left(\frac{1}{6\mu}\cdot\frac{\Delta P}{L}\cdot y^3 - \frac{\Delta P}{8\mu L}\cdot y h^2\right)\Big|_{y=0}^{\frac{h}{2}}$$

$$= \frac{2}{h}\left(\frac{\Delta P}{6\mu L}\cdot\frac{h^3}{8} - \frac{\Delta P}{8\mu L}\cdot\frac{h^3}{2}\right) = \frac{h^2\Delta P}{12\mu L}\ \frac{dP}{dz}$$

$$Q = L\cdot h\cdot\overline{u_z} = \cancel{L} h\cdot\frac{h^2\Delta P}{12\mu \cancel{L}} = \frac{h^3\Delta P}{12\mu}$$

Tube

4. Tube flow is encountered in several material manufacturing processes. Let's assume that the flow inside the tube is steady, fully developed, and is axis-symmetric. Furthermore, it has no entrance effects, the gravitational force is negligible, and the fluid is a Newtonian fluid. Based on the momentum equation in the z direction, simplify it and then solve for the velocity profile, $u_z(r)$ and the volumetric flow rate, Q.

$u_r = u_\theta = 0$

Steady State

fully developed

$$\rho\left(\cancel{\frac{\partial u_z}{\partial t}} + u_r\cancel{\frac{\partial u_z}{\partial r}} + \frac{u_\theta}{r}\cancel{\frac{\partial u_z}{\partial \theta}} + u_z\cancel{\frac{\partial u_z}{\partial z}}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u_z}{\partial r}\right) + \frac{1}{r^2}\cancel{\frac{\partial^2 u_z}{\partial \theta^2}} + \cancel{\frac{\partial^2 u_z}{\partial z^2}}\right] + \cancel{\rho g_z}$$

axis-symmetry

g force negligible

fully developed

$$\partial P/\partial z = \mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\,\partial u_z/\partial r\right)\right]$$

$$\partial/\partial r\left(r\,\partial u_z/\partial r\right) = r/\mu\;\partial P/\partial z$$

$$r\,\partial u_z/\partial r = \tfrac{1}{2}r^2/\mu\;\partial P/\partial z + C_1 \quad ①$$

$$\partial u_z/\partial r = \tfrac{1}{2}r/\mu\;\partial P/\partial z + C_1/r$$

$$u_z = \tfrac{1}{4}r^2/\mu\;\partial P/\partial z + C_1\ln r + C_2 \quad ②$$

① $r = R,\ u_z = 0$ $\quad C_2 = R^2/4\mu\;\partial P/\partial z$

② $r = 0,\ u_z = 0$ $\quad C_1 = 0$

$$u_z = \partial P/\partial z\;1/4\mu\,(R^2 - r^2)$$

$$Q = \int_0^R 2\pi r\left(\partial P/\partial z \cdot 1/4\mu\,(R^2 - r^2)\right)dr$$

$$= \partial P/\partial z\;\pi R^4/8\mu$$

$$= \pi R^4/8\mu\;\Delta P/L$$