Design using Material Selection (with side-note on Technical Writing)

24-370 - Spring 2011

Professor Steve Collins

Announcements

- Project 1 parts due… now :-D
- Project 1 report due Wednesday
- HW2 answer key online

Technical Writing

- Goal: Transfer knowledge efficiently
  - Unambiguous, unique, concise descriptions
  - Shorter, woloc, is better
  - Very difficult, requires iteration
  - Takes practice
- Project 1 application
  - Description (100 words)
  - Reasoning (200 words)
  - Failure mode prediction (15 words)

Technical Writing Exercises

- Edit this sample sentence (reasoning):

  "Steel is a good material for this design because it is not very expensive and it has good mass properties and is also simple for machinists to work with."
- One possible improved version:
  "We chose steel because it is dense, cheap, and easily machined."

Technical Writing Exercises

- Edit this sample topic sentence (description):

  "A cylinder, made of steel, with a hole along a radial line and located a small distance from one end of the cylinder, is the part that will be used as the testing mass."
- One possible improved version:
  "The testing mass comprises a steel cylinder with a radial hole through one end."

Technical Writing Exercises

- Edit this sample sentence (failure mode):

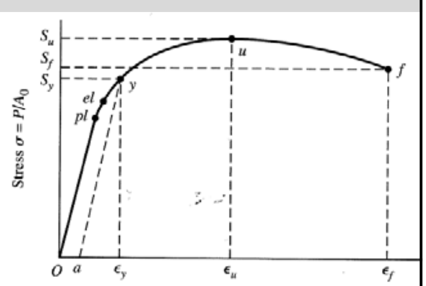
  "The part will yield."
- One possible improved version:
  "Yielding will occur at the contact between the wire rope and the hole."

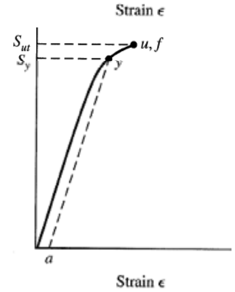
Design using Material Selection

- Designer's perspective…
- Review of material properties
  - A little on their modification
- Finding material properties
- Analytical approaches to material selection
- Common materials and uses
- Other considerations

Review of Material Properties

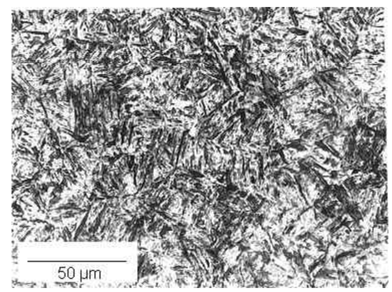
- Elastic modulus, E
- Yield strength, S_y
- Ultimate strength, S_u
- Ductility
- Resilience, u_R
- Toughness, u_T
- Hardness
- Density, ρ





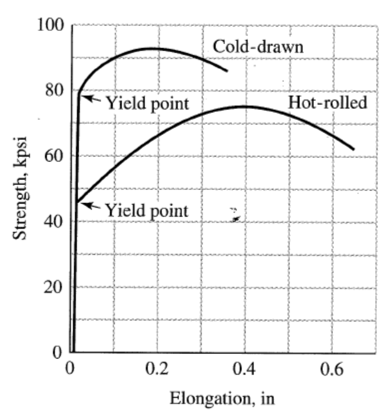
Processing that Affects Strength

- All about crystals
- Alloying (metallurgy)
- Cold working



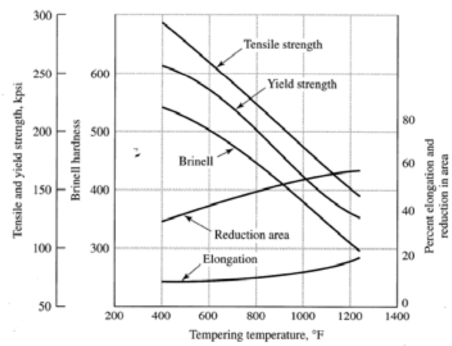
Processing that Affects Strength

- All about crystals
- Alloying (metallurgy)
- Cold working
- Annealing
- Quenching
- Tempering



Processing that Affects Strength

- All about crystals
- Alloying (metallurgy)
- Cold working
- Annealing
- Quenching
- Tempering
- Case Hardening
- E, ρ, unchanged



Condition	Tensile strength, kpsi	Yield strength, kpsi	Reduction in area, %	Elongation in 2 in, %	Brinell hardness, Bhn
Normalized	200	147	20	10	410
As rolled	190	144	18	9	380
Annealed	120	99	43	18	228

Finding Specific Material Properties

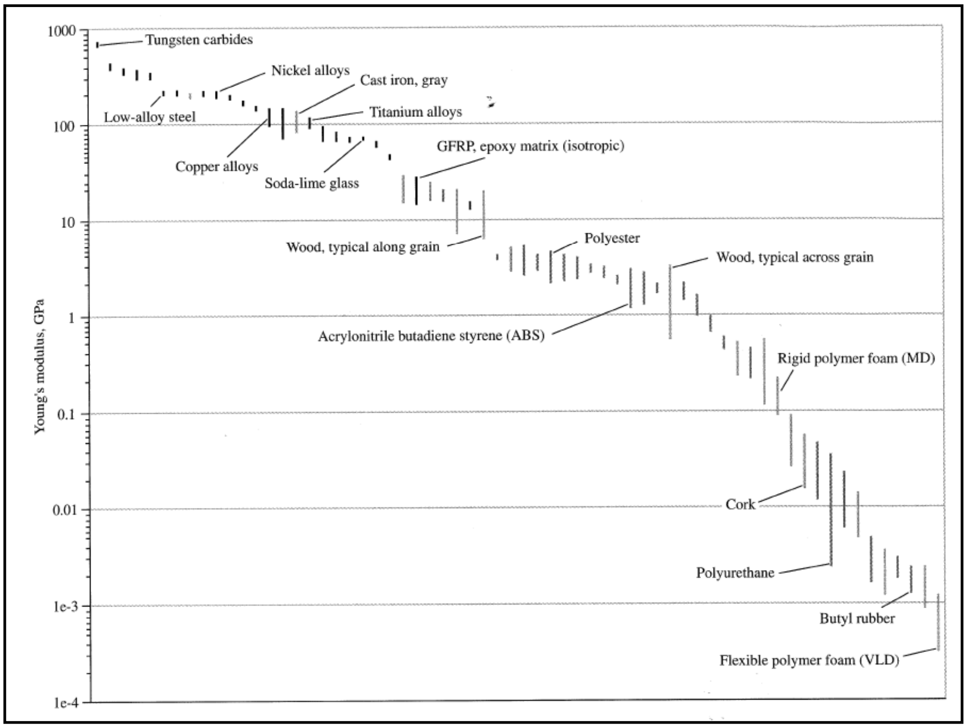
- Manufacturer specifications
- Standardization, e.g. AISI, ASTM, UNS
- Databases, e.g. MatWeb: www.matweb.com

Material Properties Exercise

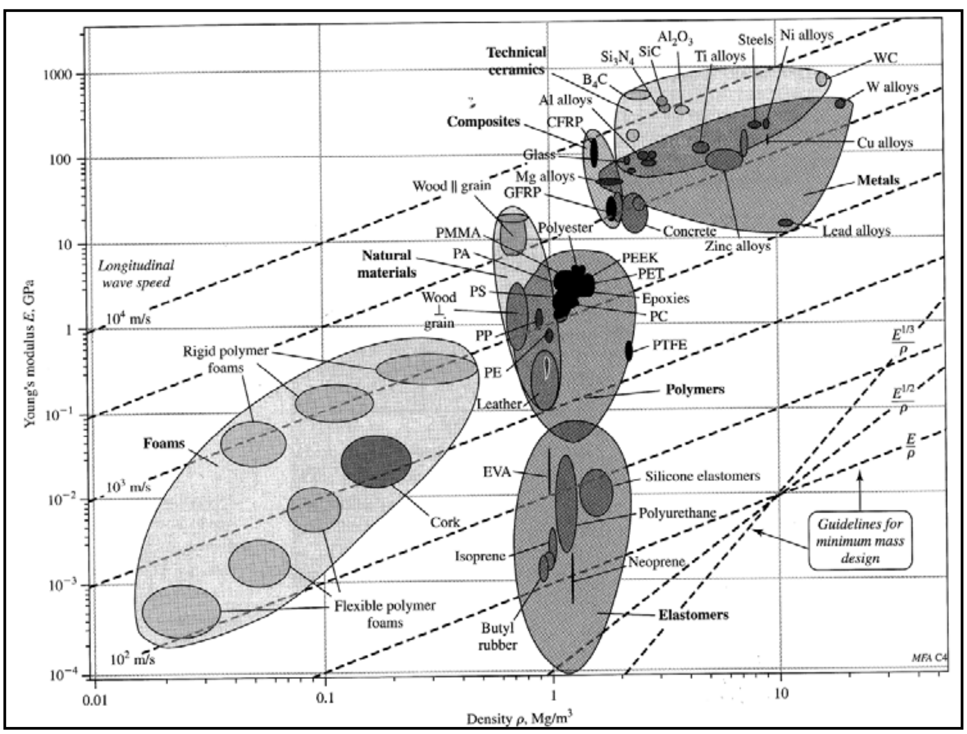
- What is the yield stress of 7075-T6 Aluminum?
- Elongation at failure of 6061-T6 Aluminum?
- Is Acrylic ductile or brittle?
- Elastic modulus of ABS?
- Ultimate strength of 440C stainless?
- Inverse look-up → selection
  - E.g., find material with high strength, low density
  - Harder problem…
  - Two solutions: chart analysis and intuition

Using Material Charts

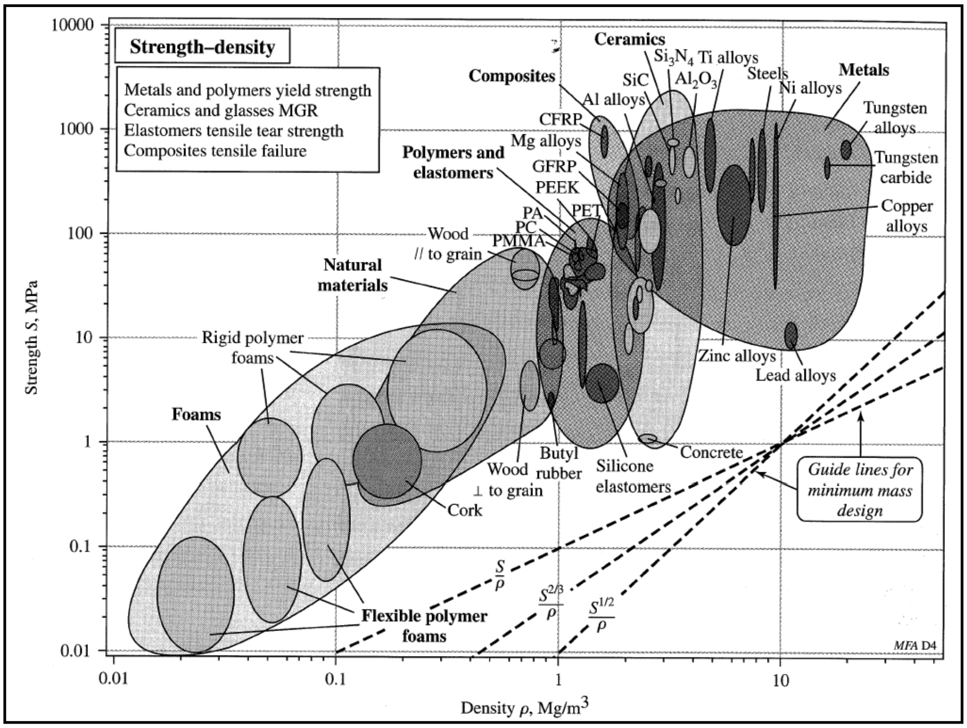
- First, analytically determine desired property
  - E.g., high elastic modulus, E
  - Or, high root strength to weight ratio, $S_y^{1/2} \rho^{-1}$
- Then, use a material chart
  - E.g. Ashby (some reproduced in Shigley)
- Other considerations…



Tungsten carbides
Nickel alloys
Cast iron, gray
Low-alloy steel
Titanium alloys
Copper alloys
Soda-lime glass
GFRP, epoxy matrix (isotropic)
Wood, typical along grain
Polyester
Wood, typical across grain
Acrylonitrile butadiene styrene (ABS)
Rigid polymer foam (MD)
Cork
Polyurethane
Butyl rubber
Flexible polymer foam (VLD)
Young's modulus, GPa
1000
100
10
1
0.1
0.01
1e-3
1e-4



Technical ceramics
Si_3N_4 SiC Al_2O_3 Steels Ni alloys
Ti alloys
WC
B_4C
W alloys
Al alloys
Composites
CFRP
Cu alloys
Glass
Mg alloys
Metals
Wood || grain
GFRP
PMMA
Polyester
Concrete
Lead alloys
Zinc alloys
Longitudinal wave speed
Natural materials
PA
PEEK
PET
PS
Epoxies
Wood ⊥ grain
PC
10^4 m/s
PP
PTFE
Rigid polymer foams
PE
Leather
Polymers
Foams
EVA
Silicone elastomers
10^3 m/s
Cork
Polyurethane
Isoprene
Neoprene
Guidelines for minimum mass design
Flexible polymer foams
Butyl rubber
Elastomers
10^2 m/s
MFA C4
$\frac{E^{1/3}}{\rho}$
$\frac{E^{1/2}}{\rho}$
$\frac{E}{\rho}$
Young's modulus E, GPa
Density ρ, Mg/m^3
0.01
0.1
1
10



Example: Optimal Beam Material

- Gut check (to test our intuition)
- Symbolic derivation
  - Equation for peak stress
  - Rearrange to see material property effects
- What is ideal form of Unobtainium?
- Compare to chart
- First cross-section: I-Beam
- Second cross-section: Cylinder
- Other considerations?

Selection vs. Continuum Design

- E.g., material selection vs. geometric variation
- Discrete set of options
- Messy, discontinuous space
- Rote knowledge, not generalizable principles
- Finding sources a non-trivial task

Intuition and Knowledge

- Materials that are good for common designs
- Gets you started
- Let me pass on my experience to you…
  - Reflects my biases:
  - Robotics
  - Human-scale forces
  - High-cost prototypes

Common Engineering Materials: Aluminum

- Properties overview
  - Good machinability
  - Mid-to-high-strength, ductility, stiffness
  - Good density ratios
  - Good corrosion resistance, anodize-able
- When to use:
  - Multifeatured, medium-high load parts (manifolds)
  - Bending loads
- Common grades:
  - 6061 -- General purpose
  - 7075-T6 -- High strength

Common Engineering Materials: Steel

- Properties overview
  - Good machinability (unless heat treated, stainless)
  - Mid-to-high strength, ductility, stiffness
  - Infinite fatigue life possible
- When to use:
  - Compact, high-load parts (e.g. shafts)
  - Contact stresses (e.g. ball bearings)
  - High FOS, high ductility, fatigue (e.g. bridge truss)
- Common grades: too many to list
  - Carbon steel -- general purpose
  - 302 or 18-8 stainless steel -- general purpose

Common Engineering Materials: Plastics

- Properties overview: high variety
  - Good machinability, moldability
  - Low-to-medium strength and stiffness
  - Low cost, low friction possible
- When to use:
  - Rapid prototyping
  - Plain bearings
  - Cheap mass-produced parts
- Common types: too many to list
  - ABS - good strength, heat formable
  - Acrylic - decent strength, laser cuttable ;)

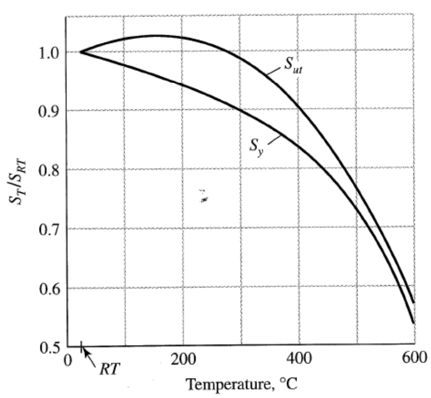
Other Common Engineering Materials

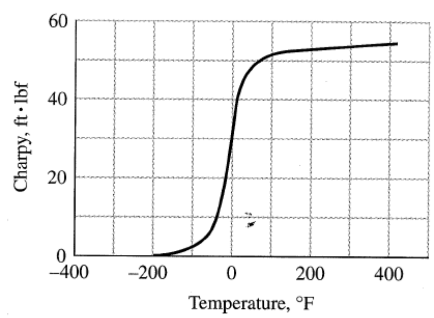
- Composites
  - Great properties, though hard to estimate
  - Hard to work with (layup, machining)
  - S-Glass (fiberglass) makes good springs
  - Carbon fiber is light & strong
  - When to use: simple, high-strength, low-mass parts
- Titanium
  - Good strength to weight
  - High cost, poor machinability
  - When to use: complex, costly, high-stregth, low-mass

Other Considerations

- Temperature
- Strain rate
- Manufacturing processes available
- Surface treatments available
  - Paint adherence
  - Tactile properties
- Cost

Temperature Dependence





Strain Dependence