Materials Selection Guidelines

Or how to avoid breakage, berylliosis and/or bankruptcy
Overview

- Important material properties
  - Design-centered
  - Environmental
  - Fabrication

- Material classes and common examples
  - Metals
  - Polymers
  - Ceramics
  - Composites
When in doubt, ask your machinist!
Material Properties - Overview

- **Design-Centered Properties**
  - Satisfy functional requirements

- **Environmental Properties**
  - Constraints based on operating environment of apparatus

- **Fabrication Properties**
  - Constraints based on cost, available processes, and manufacturing quantity
Material Properties - Overview

Resources

- MatWeb (www.matweb.com)
- Machinery’s Handbook
- McMaster-Carr (www.mcmaster.com)
Material Properties - Design

- Mechanical Properties
  - Young’s modulus, density, fracture toughness
- Electromagnetic Properties
  - Dielectric strength, transparency, permeability
- Thermal Properties
  - Thermal conductivity, heat capacity
Material Properties – Design
Mechanical Properties

- Young’s Modulus
- Density
- Yield Strength (???)
Material Properties – Design Mechanical Properties

- Failure is not as simple as yield stress!
- Yield stress
  - Processing sensitive, maybe anisotropic
- Creep
  - Stay below 1/3 of melting point (in K)
- Fatigue
  - Some materials fatigue even at low stress
- Fracture
  - Very common failure mode, but very complex
Material Properties – Design

Mechanical Properties

- Watch for tempers, fillers, and/or temperatures used for mechanical property measurements

- Britteness indicators
  - Low elongation (< ~10%)
  - UTS close to yield stress
  - Very different notched/unnotched impact energy (Izod or Charpy tests)
Material Properties – Design
Electromagnetic Properties

- **Dielectric Strength**
  - Watch out for short circuits!

- **Transparency / Color**
  - There are very few clear materials

- **Electrical Conductivity**

- **Magnetic Permeability / Hysteresis**
  - Special alloys with tailored properties are available
Material Properties – Design
Thermal Properties

- Thermal Conductivity
  - Good insulators are not strong materials
- Thermal Diffusivity
Material Properties – Environment

- Operating temperature range
  - Remember to watch the low end, too!
- Chemical resistance
  - If in doubt, buy a material sample and test it
  - Cleaners matter too!
- Radiation resistance
  - Includes solar UV radiation!
- Appearance
  - Does it need to be shiny and impressive?
Material Properties - Fabrication

- You are making one machine, not $10^6$
  - Casting, molding, forging, and stamping are not economical
  - Benefits of rapid prototyping may offset poor material properties
- Machinability directly impacts cost
- Hazardous materials more expensive to work
  - DON’T TRY THESE YOURSELF!
    - Beryllium, magnesium, glass-reinforced plastics, etc.
A Reminder:

When in doubt, ask your machinist!
Materials - Metals

- **Aluminum Properties**
  - High strength/weight ratio
  - No fatigue limit (vibration = trouble!)
  - Widely variable toughness
  - Most alloys resistant to air, humidity, solvents
    - Acids and bases very bad!
  - Inexpensive and easy to work
Materials - Metals

- Aluminum Alloys
  - Machining
    - 6061, 2024, 7075
  - Forming
    - 5052, 3003, 6063
  - Welding
    - 6061, 5052
Carbon and Alloy Steel Properties

- Heat treatment allows even a single alloy to have widely variable properties
- In general, toughness and yield strength inversely proportional
- Well-defined fatigue limit
- Poor corrosion resistance
- Inexpensive, but can be hard to machine
- Weldable
Steel Alloys
- 1018: General purpose, low strength
- 4140: Higher strength, heat treatable

Tool Steels
- Many proprietary varieties available
- Difficult to machine or form
- S7 good for high-impact structural applications

Maraging Steels
- Ultra-high strength and toughness, but very expensive
Materials - Metals

- **Stainless Steel Properties**
  - Wide range of corrosion resistance
    - Some little better than alloy steel!
  - Difficult to machine
  - Moderate cost
  - Most corrosion-resistant alloys not strong
    - Good at low temperatures
  - Can be easy to weld
Materials - Metals

- Stainless Steel Alloys
  - 304: Most common, resistant to common conditions
  - 316: Extreme corrosion resistance, very difficult to machine, low strength
  - 440C: High strength, relatively low corrosion resistance
Materials - Metals

- Copper Alloy Properties
  - High thermal and electrical conductivity
  - Widely variable strength and machinability
  - Moderate cost
  - Corrosion resistant, but can tarnish
  - Easy to join by brazing/soldering
Copper Alloys

- Brass
  - Alloy 360 is strong and extremely machinable
- Bronze
  - Alloy 630 is very hard and wear-resistant
- Beryllium Copper
  - Superb properties, but VERY TOXIC
  - Few shops will work it, and only for big $$$
Materials - Metals

- **Magnesium**
  - Lightest structural metal
  - Flammable during machining
  - Tarnishes and corrodes easily

- **Titanium**
  - Very high strength/weight ratio
  - More corrosion resistant than stainless steel
  - Very difficult to machine or form
Materials - Plastics

- Acrylic
  - Transparent and UV resistant
  - Stiff and strong
  - Very brittle
  - Easily solvent-welded
  - Easily laser cut
  - Difficult to drill or machine
Materials - Plastics

- Polycarbonate
  - Transparent, but not UV resistant
  - Impact resistant, but notch-sensitive
  - Easy to machine
Materials - Plastics

- Delrin
  - Very easy to machine
  - Somewhat brittle
  - Low friction
- Teflon
  - Very easy to machine
  - Very solvent resistant
  - Expensive
Materials - Ceramics

- Not machinable without special equipment/experience
  - Even “machinable” ceramics aren’t
- High strength with high dielectric strength
- High temperature capability
- Very brittle
- Very expensive
Materials - Composites

- FR-4 Fiberglass-Epoxy Composite
  - Circuit board material; inexpensive
  - Machining dust is hazardous
  - Strong, but somewhat brittle

- Carbon Fiber
  - Very expensive
  - Sheets, tubes available w/o custom tooling
  - Very strong, but a bit brittle