Mechanical Design I

Materials and Processes

General Properties of Metals

Outline

- General Properties of Metals
- Cast irons
- Cast steels
- Wrought steels
- Steel numbering system
- Steel alloys
- Aluminum alloys
- Other alloys
- Nonmetals general properties
- Materials Selection
- Product Analysis
- Case Study
- Materials Selection Charts
- Bigger Picture
- Case Study (2)

Learning Outcome

- Purpose : Material selection
- Resources:
  - Appendix A: Mechanical property data
  - Figure 2-17 :Young's module
  - Material manufacturers handbook

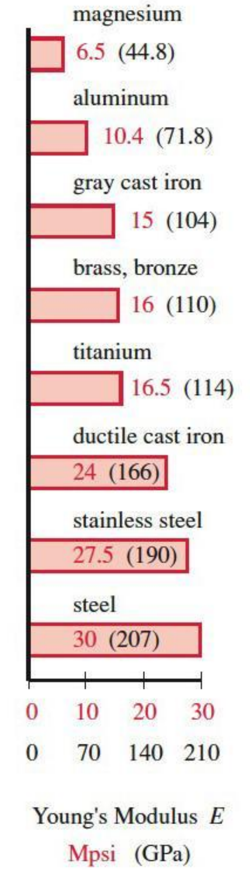


FIGURE 2-17
Young's Moduli for Various Metals

Cast irons

- Advantages: relatively low cost and ease of fabrication
- Density is slight higher than steel
- Week in tension, high compressive strength
- Carbon content 2-4.5% Not easily welded

- **White cast iron**
  - With no graphite.

- **Gray cast iron**
  - Most commonly used form of cast iron. (Graphite: helps machining and casting)

Cast steels

- Has much **less carbon** than cast iron
- Mechanical properties superior to cast iron but inferior to wrought steel
- Classes
  - Low carbon: <0.2%
  - Medium carbon: 0.2-0.5%
  - High carbon: >0.5%

Wrought steels

- "Wrought" refers to all processes that manipulate the shape of the material **without melting it**.
  - Hot-rolled steel
    - Change the shape at elevated temperature, rough surface
    - Good choice for steel members used for building and machine frame construction
  - Cold-rolled steel
    - Changing shape at room temperature
    - Very good polished surface
    - Sheets, strips, plates, round and rectangular bars, tubes, etc.

Steel numbering system

Table 2-5 AISI/SAE Designations of Steel Alloys

A partial list - other alloys are available - consult the manufacturers

Type	AISI/SAE Series	Principal Alloying Elements
Carbon Steels		
Plain	10xx	Carbon
Free-cutting	11xx	Carbon plus Sulphur (resulphurized)
Alloy Steels		
Manganese	13xx	1.75% Manganese
	15xx	1.00 to 1.65% Manganese
Nickel	23xx	3.50% Nickel
	25xx	5.00% Nickel
Nickel-Chrome	31xx	1.25% Nickel and 0.65 or 0.80% Chromium
	33xx	3.50% Nickel and 1.55% Chromium
Molybdenum	40xx	0.25% Molybdenum
	44xx	0.40 or 0.52% Molybdenum
Chrome-Moly	41xx	0.95% Chromium and 0.20% Molybdenum
Nickel-Chrome-Moly	43xx	1.82% Nickel, 0.50 or 0.80% Chromium, and 0.25% Molybdenum
	47xx	1.45% Nickel, 0.45% Chromium, and 0.20 or 0.35% Molybdenum
Nickel-Moly	46xx	0.82 or 1.82% Nickel and 0.25% Molybdenum
	48xx	3.50% Nickel and 0.25% Molybdenum
Chrome	50xx	0.27 to 0.65% Chromium
	51xx	0.80 to 1.05% Chromium
	52xx	1.45% Chromium
Chrome-Vanadium	61xx	0.60 to 0.95% Chromium and 0.10 to 0.15% Vanadium minimum

Steel alloys

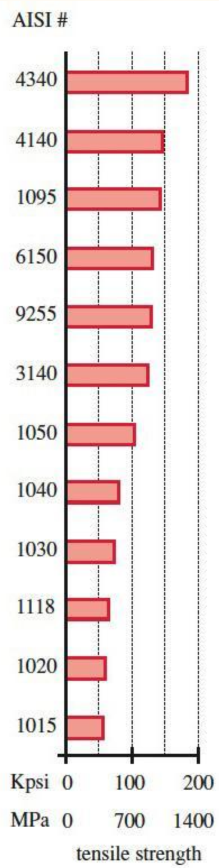


FIGURE 2-18

Approximate Ultimate Tensile Strengths of Some Normalized Steels

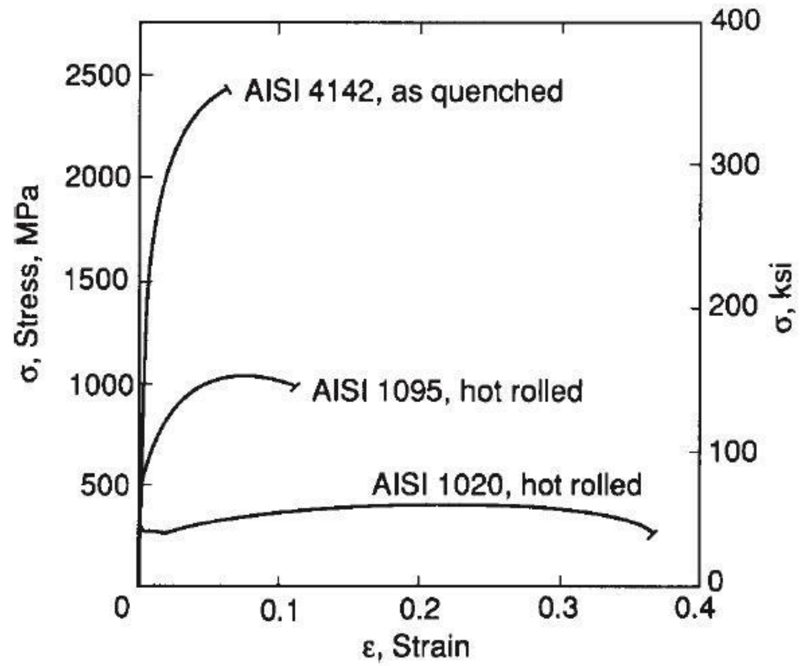


FIGURE 2-19

Tensile Test Stress-Strain Curves of Three Steel Alloys (From Fig. 5.16, p. 160, in N. E. Dowling, *Mechanical Behavior of Materials*, Prentice-Hall, Englewood Cliffs, N.J., 1993, with permission)

Aluminum alloys

- Aluminum is the most widely used nonferrous metal.
- Low density, good strength-to-weight ratio, ductility, high conductivity, corrosion resistance and reasonable price are its main properties.
- Alloys have significantly greater strength, and extensively used in aircraft and automotive industries.

Aluminum alloys

Table 2-6 Aluminum Association Designations of Aluminum Alloys
A partial list - other alloys are available - consult the manufacturers

Series	Major Alloying Elements	Secondary Alloys
1xxx	Commercially pure (99%)	None
2xxx	Copper (Cu)	Mg, Mn, Si
3xxx	Manganese (Mn)	Mg, Cu
4xxx	Silicon (Si)	None
5xxx	Magnesium (Mg)	Mn, Cr
6xxx	Magnesium and Silicon	Cu, Mn
7xxx	Zinc (Zn)	Mg, Cu, Cr
Hardness Designations		
xxxx-F	As fabricated	
xxxx-O	Annealed	
xxxx-Hyyy	Work hardened	
xxxx-Tyyy	Thermal/age hardened	

Other alloys

- Titanium alloys are among the newest of engineering materials.
- Magnesium alloys are lightest of the commercial metals but is relatively weak.
- Pure copper is soft, weak and malleable and is used primarily for piping, flashing, electrical conductors and motors.

Nonmetals general properties

- Polymers
  - Thermoplastic and thermosets
- Ceramics
  - Compounds of metallic and non-metallic elements.
- Composites
  - Combination of strong, fibrous material such as glass or carbon fibers glued in a matrix of resin such as epoxy or polyester.

Materials Selection: Decisions, decisions!

So many materials, so much information.

How do we decide?

How do we begin to choose?

First we need to look at the function of the product – product analysis

Product Analysis

- Just what it says – analyse the product!
- What does it do?
- How does it do it?
- Where does it do it?
- Who uses it?
- What should it cost?

Case Study – a bike

- What is the function of a bike – obvious?
- How does the function depend on the type of bike?
  - Racing
  - Touring
  - Mountain bike
  - Commuter
  - Childs

Bike Frame

Frame Design Detail

Case Study – a bike

- How is it made to be easily maintained?
- What should it look like (colours etc.)?
- What should it cost?
- How has it been made comfortable to ride?
- How do the mechanical parts work and interact?

System Analysis – the bike

When we analyse a system we need to break the system down into individual components and then analyse each one.

The bike breaks down into various parts:

- Frame
- Forks
- Wheels
- Saddle
- Etc.

System Analysis – the bike

We now need to look at the following for each part:

- Requirements (mechanical, ergonomic, aesthetic etc.)
- Function
- How many are going to be made?
- What manufacturing methods are we going to use?

Manufacturing

Oh No!

We have to actually make it!

This is a key question which has a massive influence on materials selection.

e.g. The frame, what materials could we use?

Frame Materials

- Steel –

Strong, stiff, heavy, but cheap

- Aluminium –

weaker, lighter, more expensive than steel

- Composite–

strong, stiff, very light, but expensive to buy and to fabricate

What Properties?

- Mechanical –
  Strength, modulus etc.
- Physical –
  Density, melting point.
- Electrical –
  Conductivity, resistivity.
- Aesthetic –
  Appearance, texture, colour
- Process ability –
  Ductility, mould ability
- And last, but not least………important.
  Cost, cost, cost!

Where do I find the data?

- Textbooks
- Databooks
- Manufacturer's literature
- Internet Sites

Textbooks

- Good for general information.
- Some have tables of properties.
- Not good for detailed specifications and properties.
- A useful first point of call.

Databooks

- One of the quickest sources of detailed information.
- Usually contain grades and specifications as well as properties.
- Small and perfectly formed – pocketbooks
- Easy to navigate around.

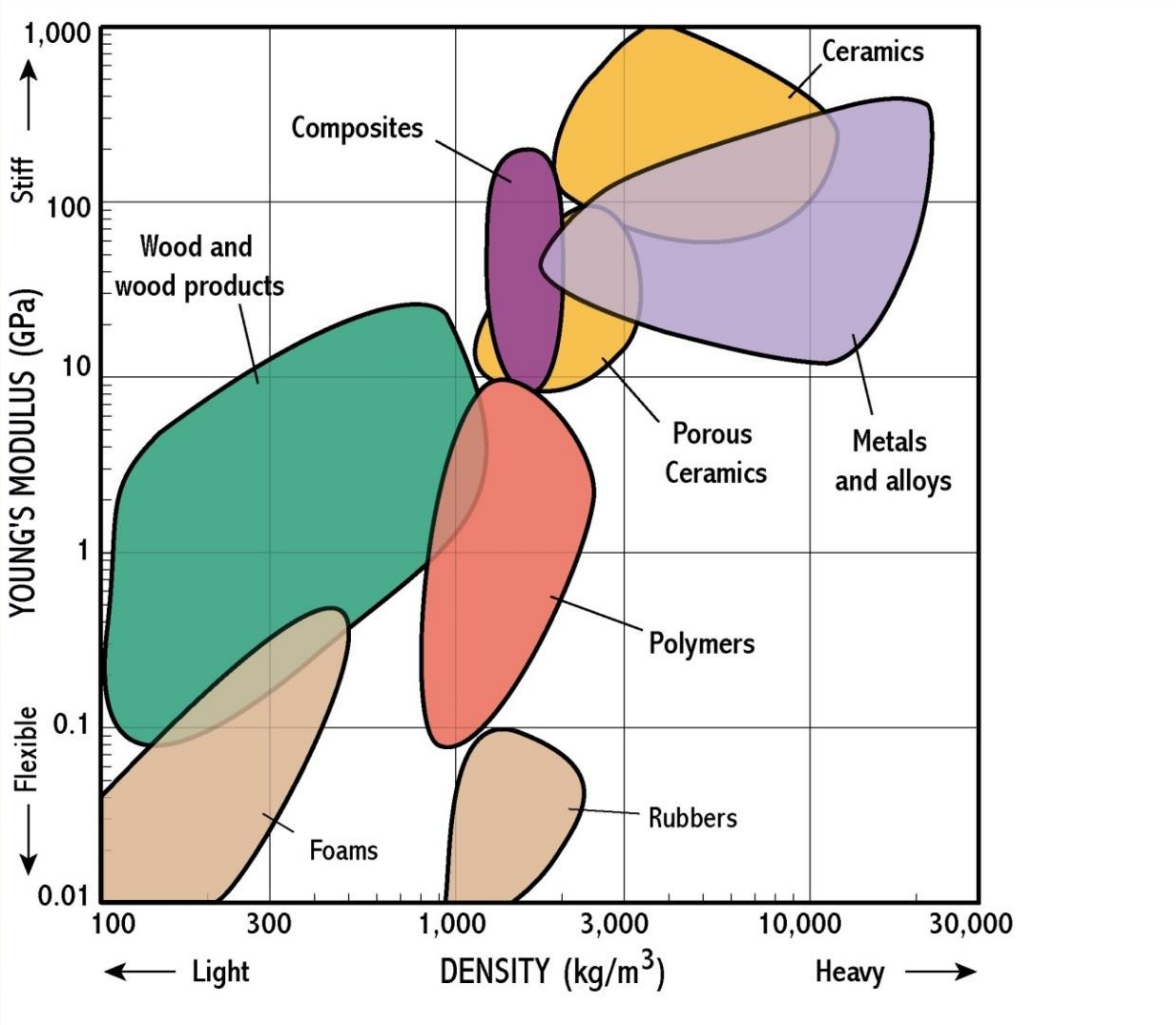
Manufacturer’s literature

- Variable in quality and usefulness.
- Often only cover their products.
- Usually do not compare materials.
- Can be subjective.
- Good for final selection before ordering.

Internet Sites

- Lots of poorly presented information.
- Google searches bring up lots of rubbish.
- Hard to find technical information.
- Best to use non-commercial sites.

Materials Selection Charts



Materials Selection Charts

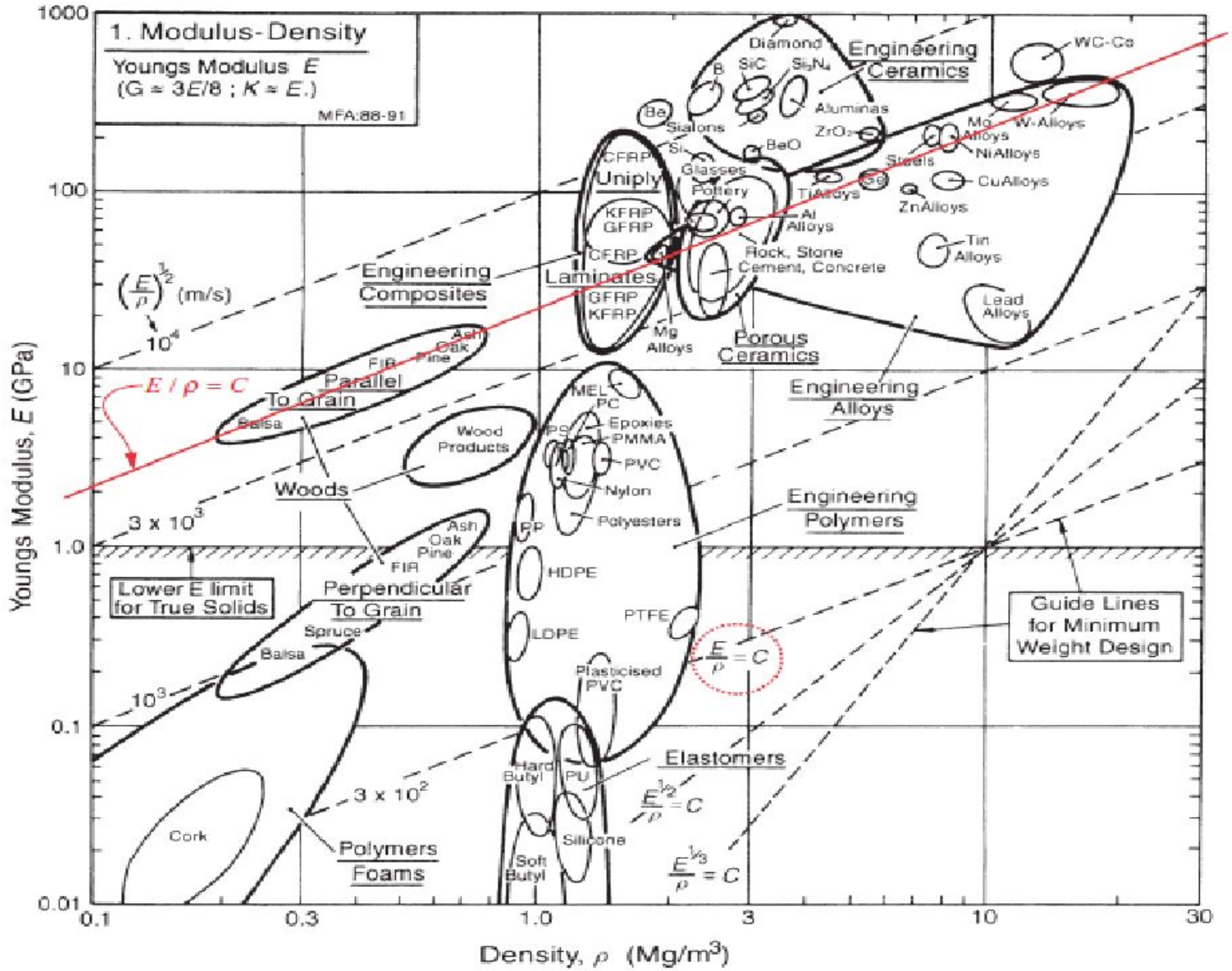


FIGURE 2-23

Young's Modulus Plotted Against Density for Engineering Materials (From Fig. 4-3, p. 37 in M. F. Ashby, *Materials Selection in Mechanical Design*, 2ed, Butterworth-Heinemann 1999, with permission)

Materials Selection Charts

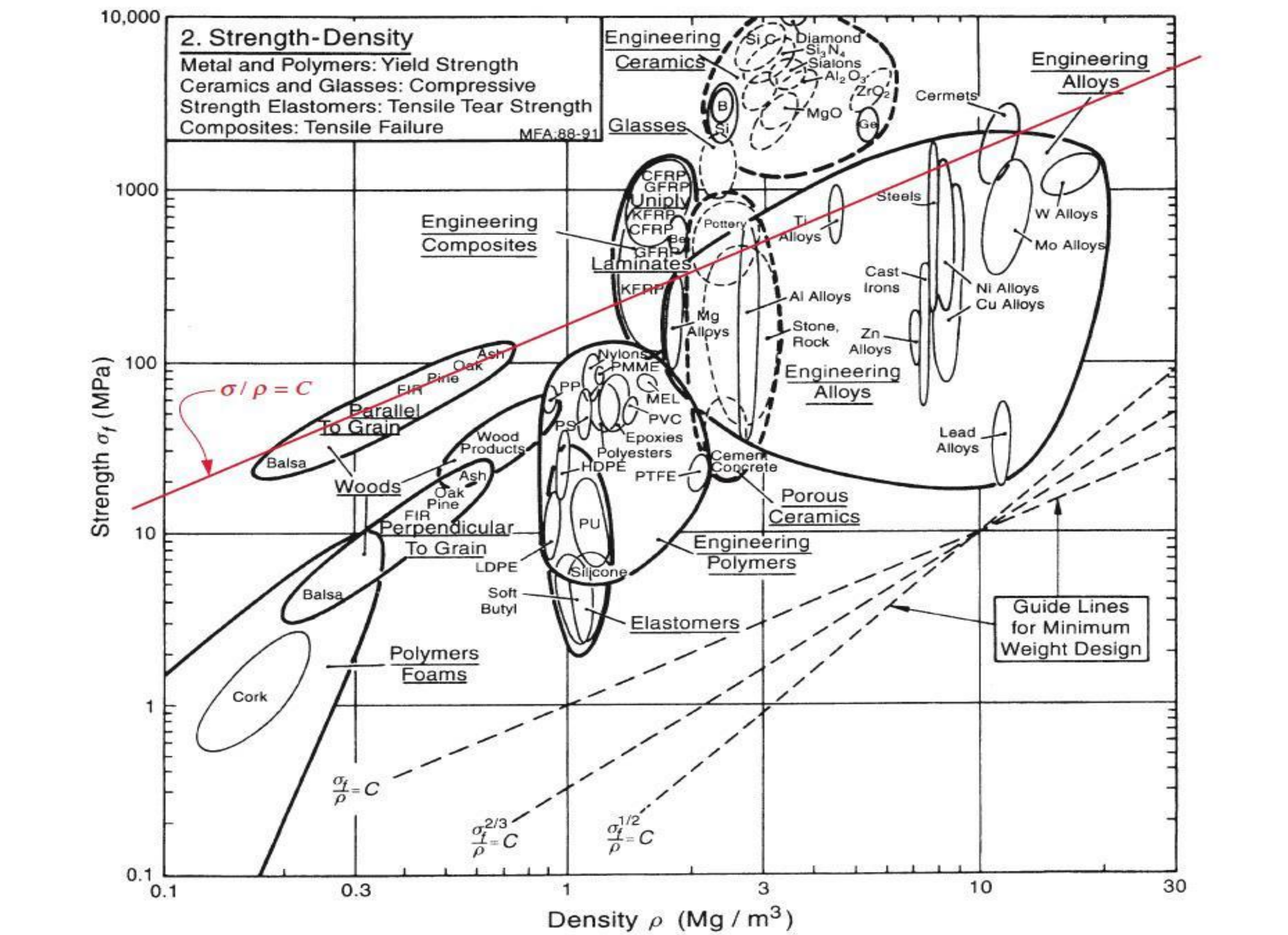


FIGURE 2-24

Strength Plotted Against Density for Engineering Materials (From Fig. 4-4, p. 39 in M. F. Ashby, *Materials Selection in Mechanical Design*, 2ed, Butterworth-Heinemann 1999, with permission)

Modulus - Density Chart

- Modulus spans 5 orders of magnitude.
  - 0.01 GPa for foams to 1000 GPa for diamond.
- The charts therefore use *logarithmic* scales, where twice the distance means *ten* times.
- This makes it possible to show the full range on one chart.

Materials Selection Charts

- Allow easy visualisation of properties.
- Show lots of different materials.
- Can be ‘drilled down’ to specifics.
- Show balances of properties.
- Ideal for a first ‘rough cut’ selection.

Bigger Picture

Is the product *performance* driven or *cost* driven?

This makes a huge difference when choosing materials.

Manufacturing Process

Although we usually choose materials first sometimes it is the shape and process which is the limiting factor.

Case Study (2) Drink Container

- What are the requirements?

Case Study (2) Drink Container

- Provide leak free environment for storing liquid.
- Comply with food standards & protect liquid from health hazards.
- For fizzy drinks, withstand pressure.
- Brand image & identity
- Easy to open
- Easy to store & transport
- Cheap for high volumes

Possible Materials

- Steel
- Aluminium
- Glass
- Plastic
- Paper