MATERIALS SELECTION

MET 4501

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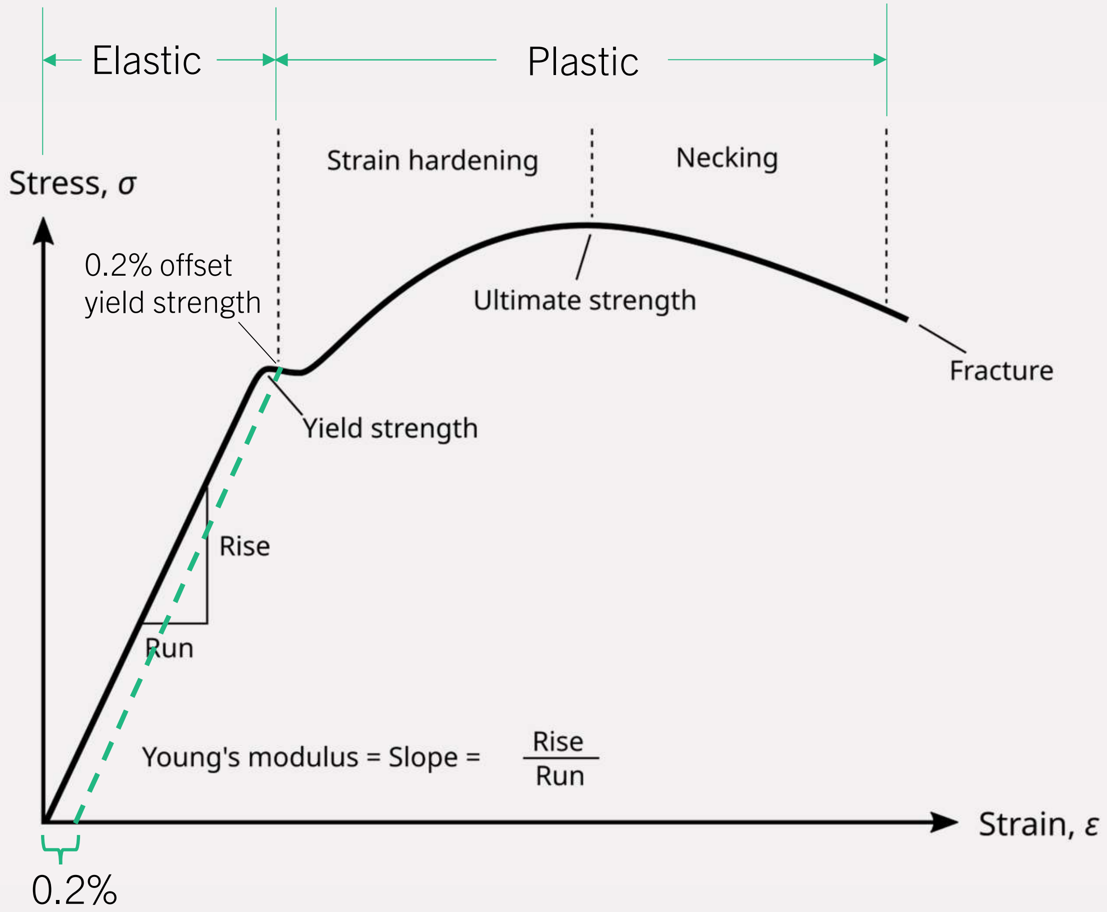
TYPICAL STRESS-STRAIN CURVE FOR MILD STEEL

- Young's modulus is a mechanical property of materials that measures the effective stiffness when force is applied lengthwise.

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

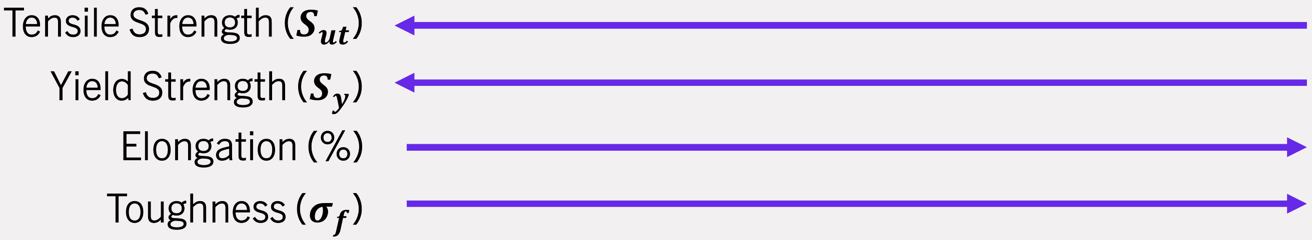
- It is often difficult to detect at which point the material changes from elastic to plastic. In such cases, the 0.2% offset yield strength is calculated to distinguish the two regions.



THERMAL AND MECHANICAL PROCESSING

- *Cold working (*plastically deforming) a metal increases strength and lowers ductility.
- Raising the temperature (*annealing*, *normalizing*, and/or *tempering*) causes:
  - Recovery (stress relief)
  - Recrystallization
  - Grain growth
- *Hot working* allows these processes to occur simultaneously with deformation.
  - If hot worked parts are not cooled carefully, quenching effects can be present in the final part.
- *Quenching* is rapid cooling from elevated temperature, preventing the formation of equilibrium phases.
  - In steels, quenching austenite (FCC [γ] iron) can result in martensite instead of equilibrium phases – ferrite (BCC [α] iron) and cementite (iron carbide).
  - Most applications require that quenched parts be tempered.

TEMPERING



Tensile Strength (S_{ut}) ←

Yield Strength (S_y) ←

Elongation (%) →

Toughness (σ_f) →

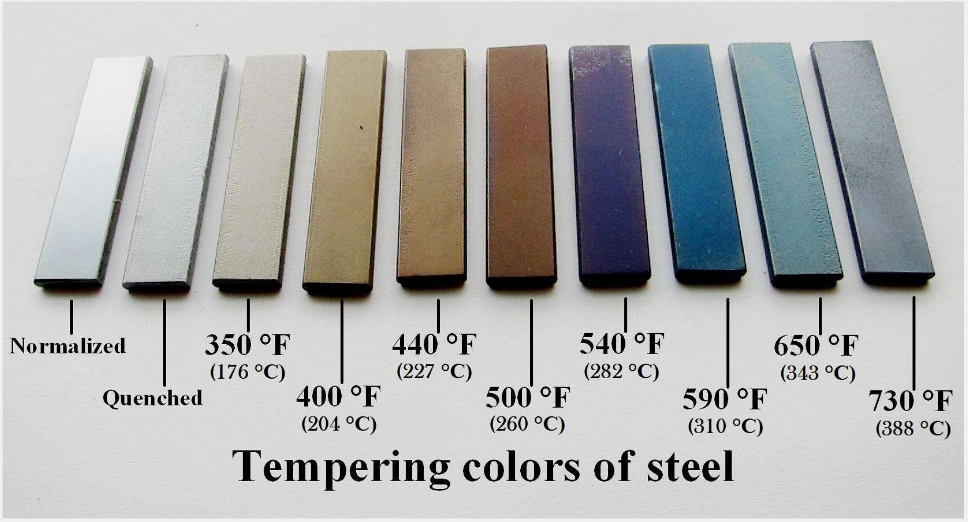


Image source: https://practicalmaintenance.net/?p=1329

ASHBY CHARTS

MET 4501

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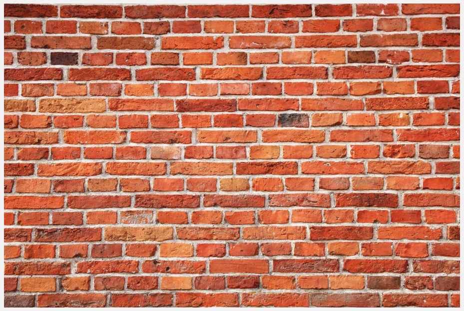
MATERIAL FAMILIES

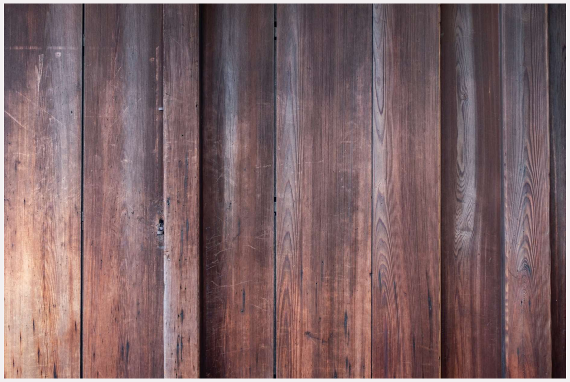

Metals


Ceramics


Glass


Polymers


Elastomers


Composites

YOUNG’S MODULUS FOR VARIOUS MATERIALS

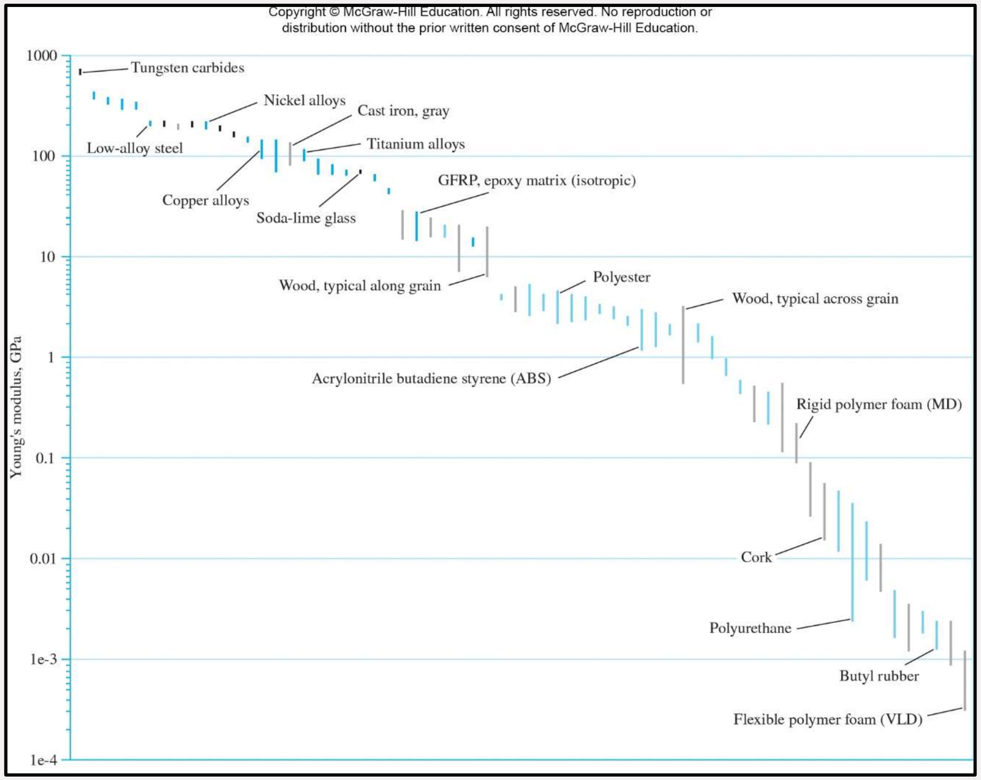


Fig. 2–23

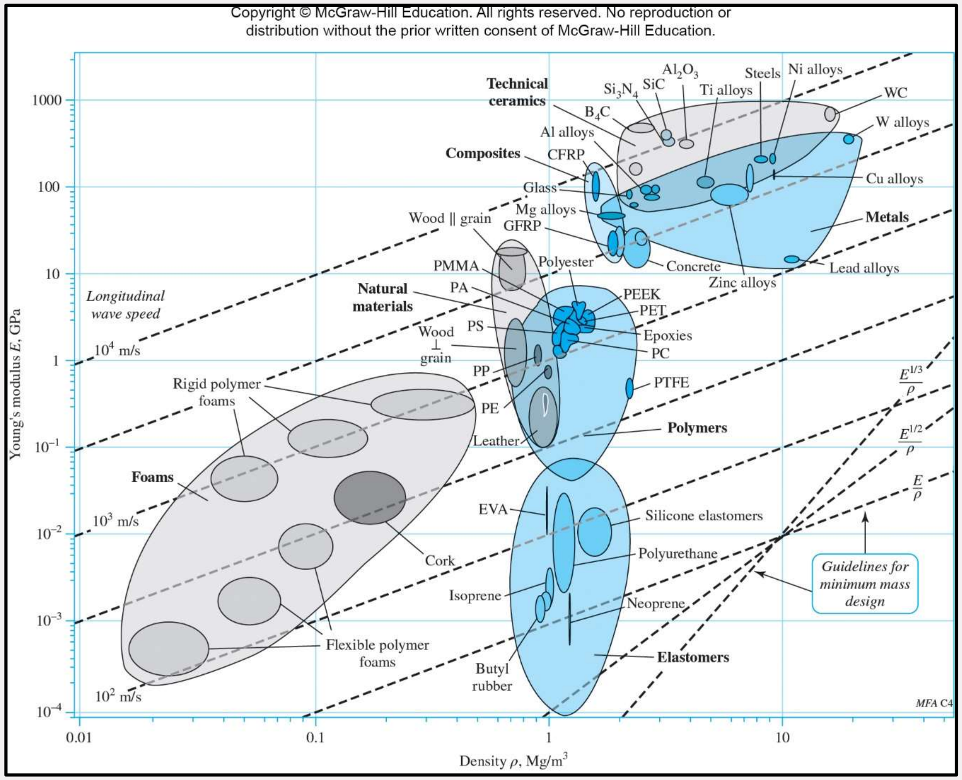


Fig. 2–24

THE PERFORMANCE METRIC

The *performance metric* depends on (1) the functional requirements, (2) the geometry, and (3) the material properties.

$$P = \left[\begin{pmatrix} \text{fuctional} \\ \text{requirements } F \end{pmatrix}, \begin{pmatrix} \text{geometric} \\ \text{parameters } G \end{pmatrix}, \begin{pmatrix} \text{material} \\ \text{properties } M \end{pmatrix} \right]$$

$$P = f(F,\ G,\ M) \qquad \textbf{(2 - 38)}$$

- The function is often separable,

$$P = f_1(F) \cdot f_2(G) \ \cdot f_3(M) \qquad \textbf{(2 - 39)}$$

- $f_3(M)$ is called the *material efficiency coefficient.*
- Maximizing or minimizing $f_3(M)$ allows the material choice to be used to optimize P.

PERFORMANCE METRIC EXAMPLE

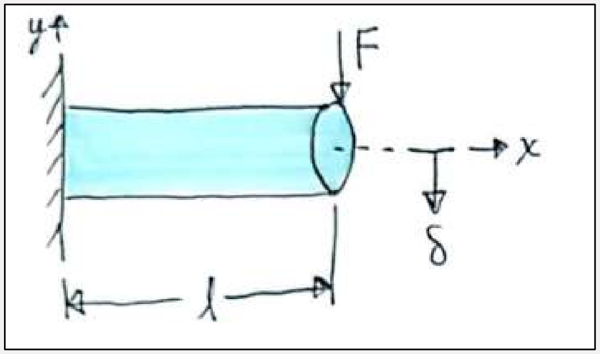
Requirements: light, stiff, end-loaded cantilever beam with circular cross section.

Mass *m* of the beam is chosen as the performance metric to minimize.

Stiffness is functional requirement.

Stiffness is related to material and geometry.

$$k = \frac{F}{\delta}$$



The mass of this cantilever beam is:

$$m = 2\sqrt{\frac{\pi}{3}}(k^{1/2})(l^{5/2})\left(\frac{\rho}{E^{1/2}}\right)$$

(See posted notes for derivation)

PERFORMANCE METRIC EXAMPLE

$$P = f_1(F) \cdot f_2(G) \cdot f_3(M) \qquad \textbf{(2-39)}$$

$$m = \underbrace{2\sqrt{\frac{\pi}{3}}(k^{1/2})}_{f_1(F)}\underbrace{(l^{5/2})}_{f_2(G)}\underbrace{\left(\frac{\rho}{E^{1/2}}\right)}_{f_3(M)} \qquad \textbf{(2-44)}$$

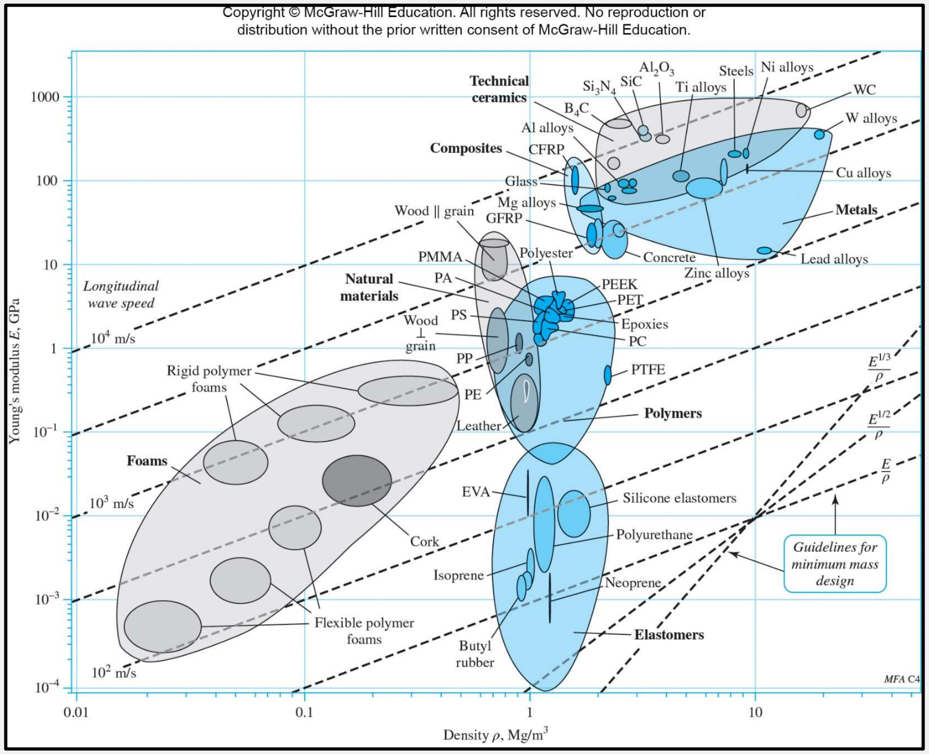
- To minimize *m*, need to minimize $f_3(M)$, or maximize

$$M = \frac{E^{1/2}}{\rho} \qquad \textbf{(2-46)}$$

M is called *material index.*

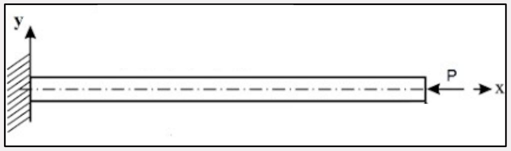
SPECIFIC MODULUS

- *Specific Modulus* – ratio of Young's modulus to density, *E* / *ρ.*
- Also called *specific stiffness.*
- Useful to minimize weight with primary design limitation of deflection, stiffness, or natural frequency.
- Parallel lines representing different values of *E* / *ρ* allow comparison of specific modulus between materials.

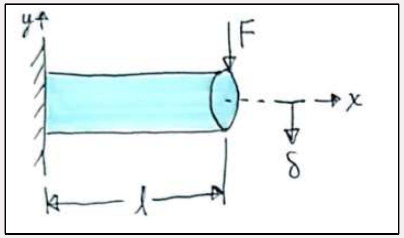


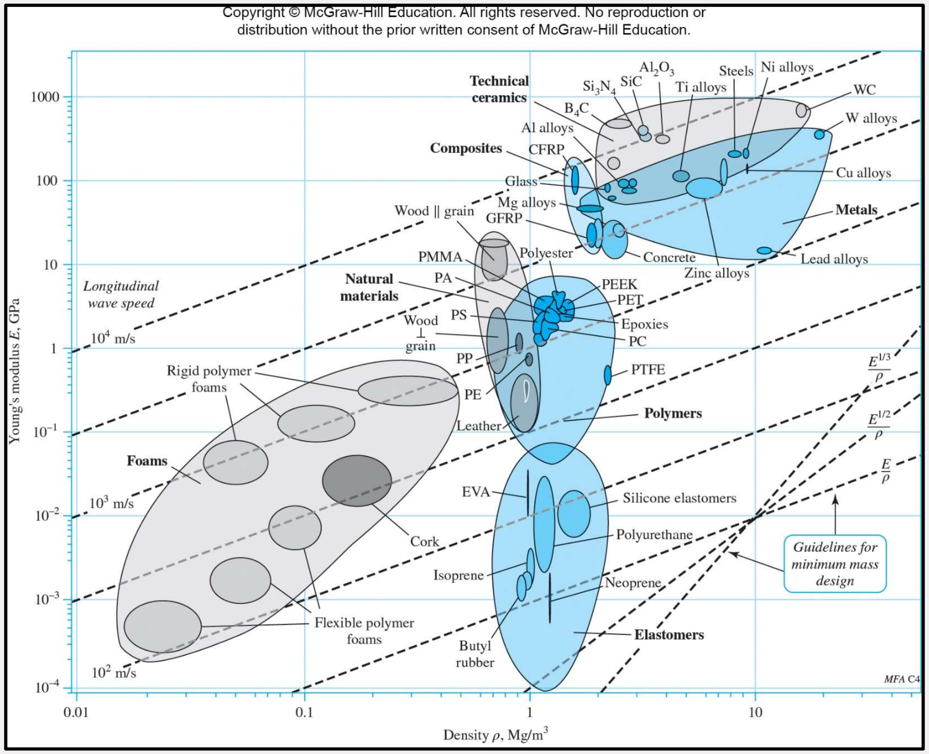
MINIMUM MASS GUIDELINES FOR YOUNG'S MODULUS-DENSITY PLOT

- Guidelines plot constant values of E^{β}/ρ.
- β depends on type of loading.
- $\beta = 1$ for axial.



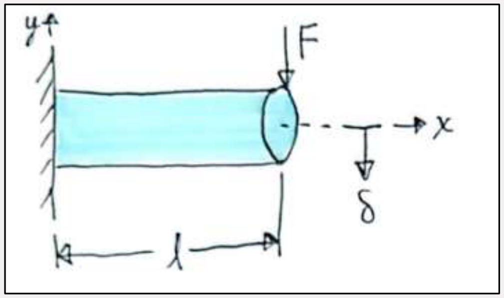
- $\beta = 1/2$ for bending.

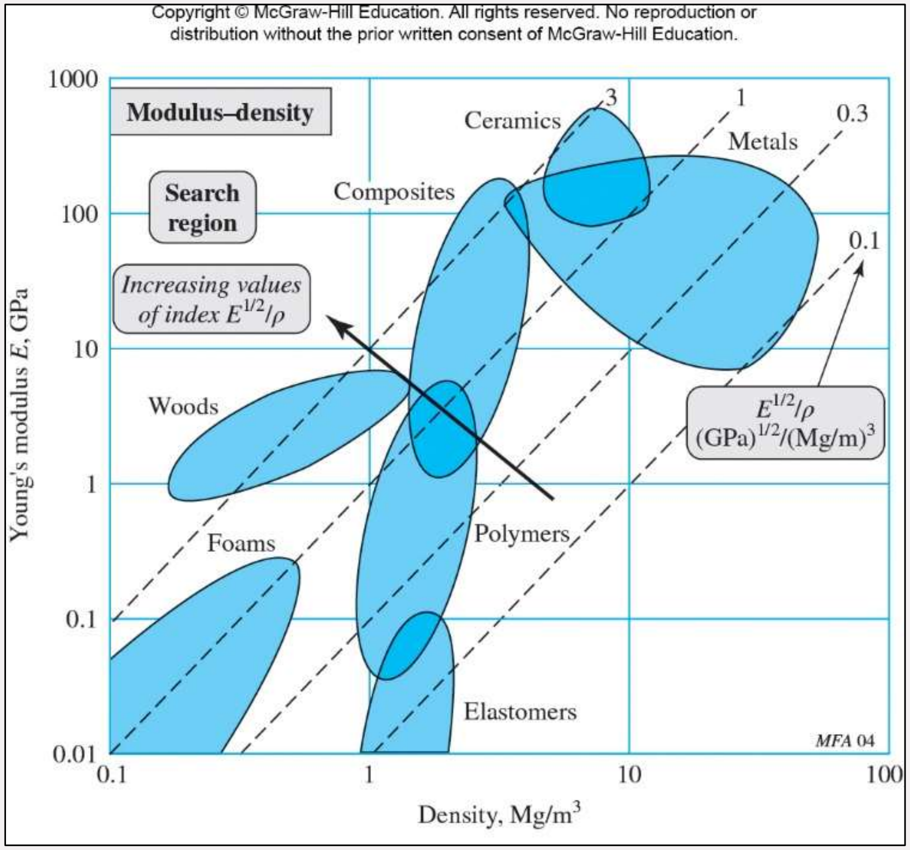




PERFORMANCE METRIC EXAMPLE

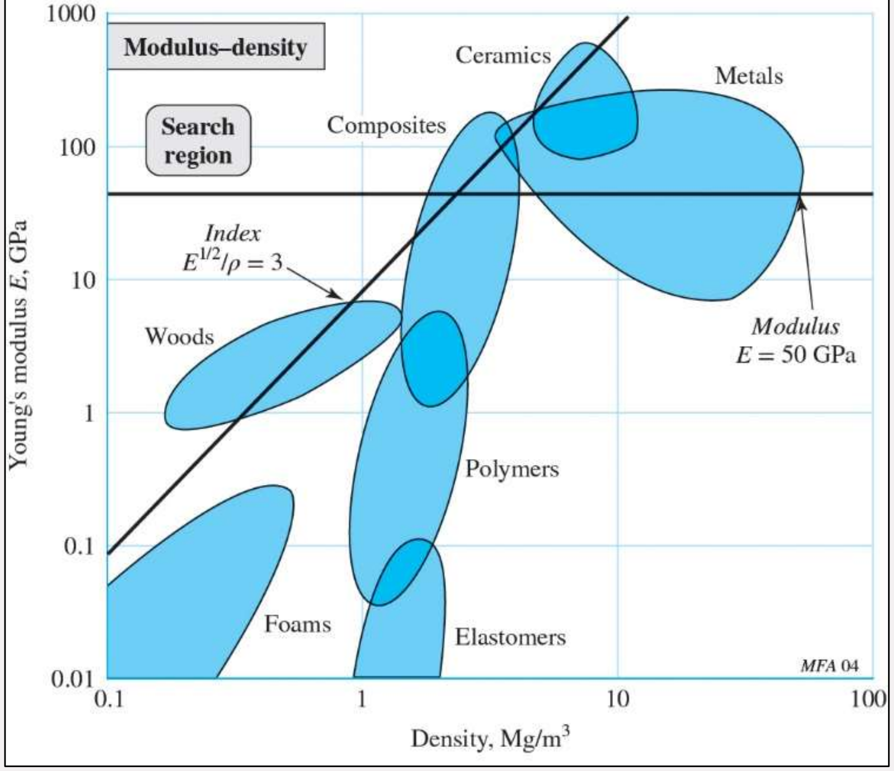
- Returning to the example, $\beta = ½$.
- Use guidelines parallel to $E^{1/2}/\rho$.
- Increasing M, move up and to the left.
- Good candidates for this example are certain woods, composites, and ceramics.





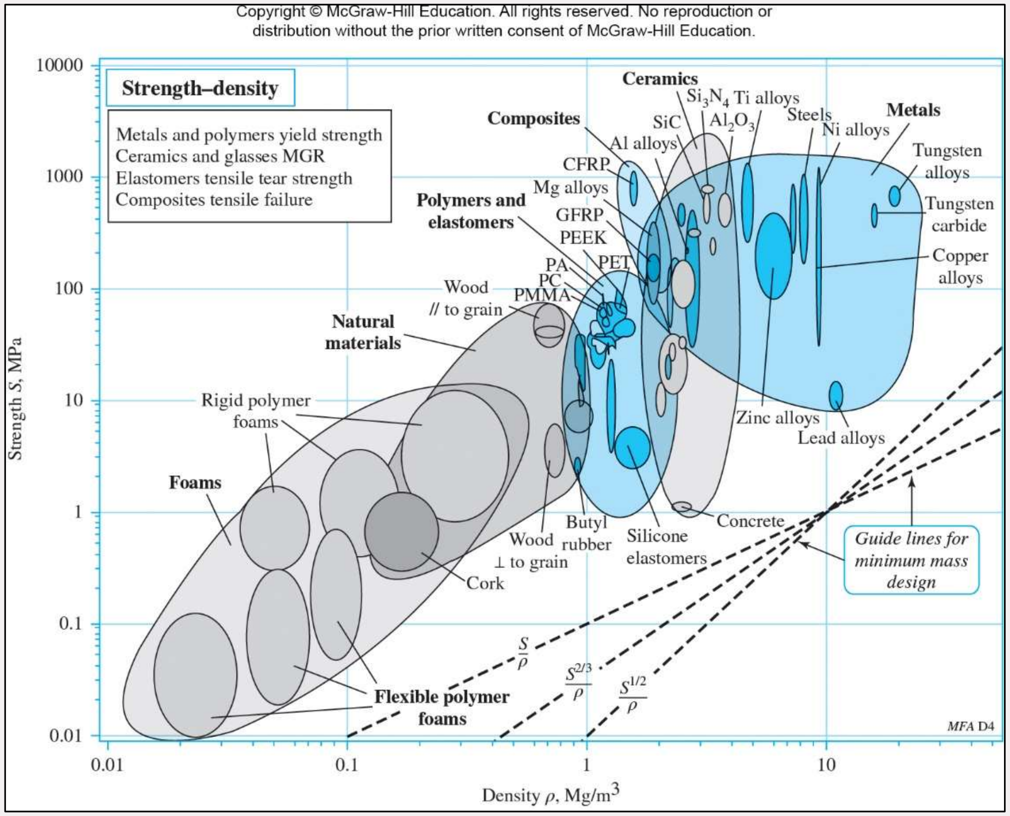
PERFORMANCE METRIC EXAMPLE

- Additional constraints can be added as needed.
- For example, if it is desired that *E* > 50 GPa, add horizontal line to limit the solution space.
- Wood is eliminated as a viable option.



STRENGTH VS DENSITY

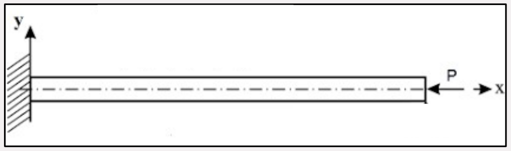
- *Specific Strength* – ratio of strength to density, *S* / *ρ.*
- Useful to minimize weight with primary design limitation of strength.
- Parallel lines representing different values of *S* / *ρ* allow comparison of specific strength between materials.



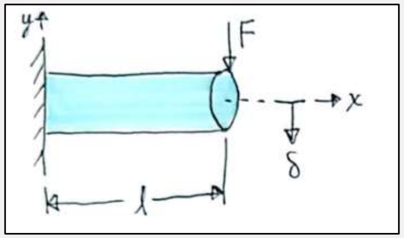
STRENGTH VS DENSITY

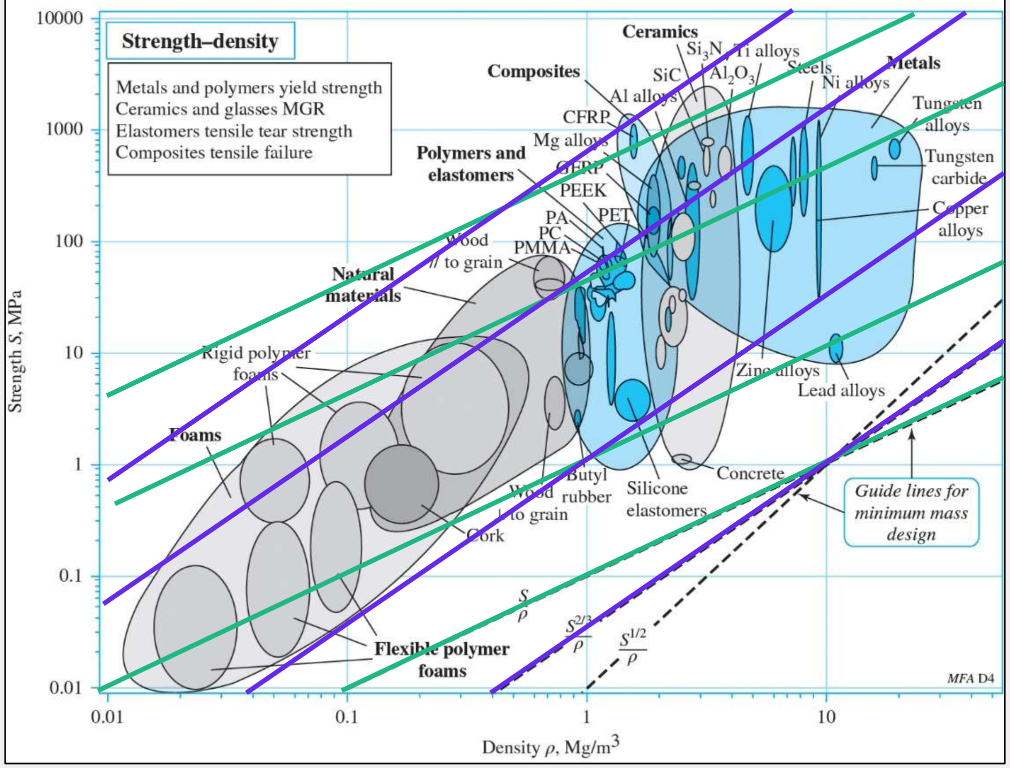
Guidelines plot constant values of S^{β}/ρ.

- β depends on type of loading.
- $\beta = 1$ for axial.

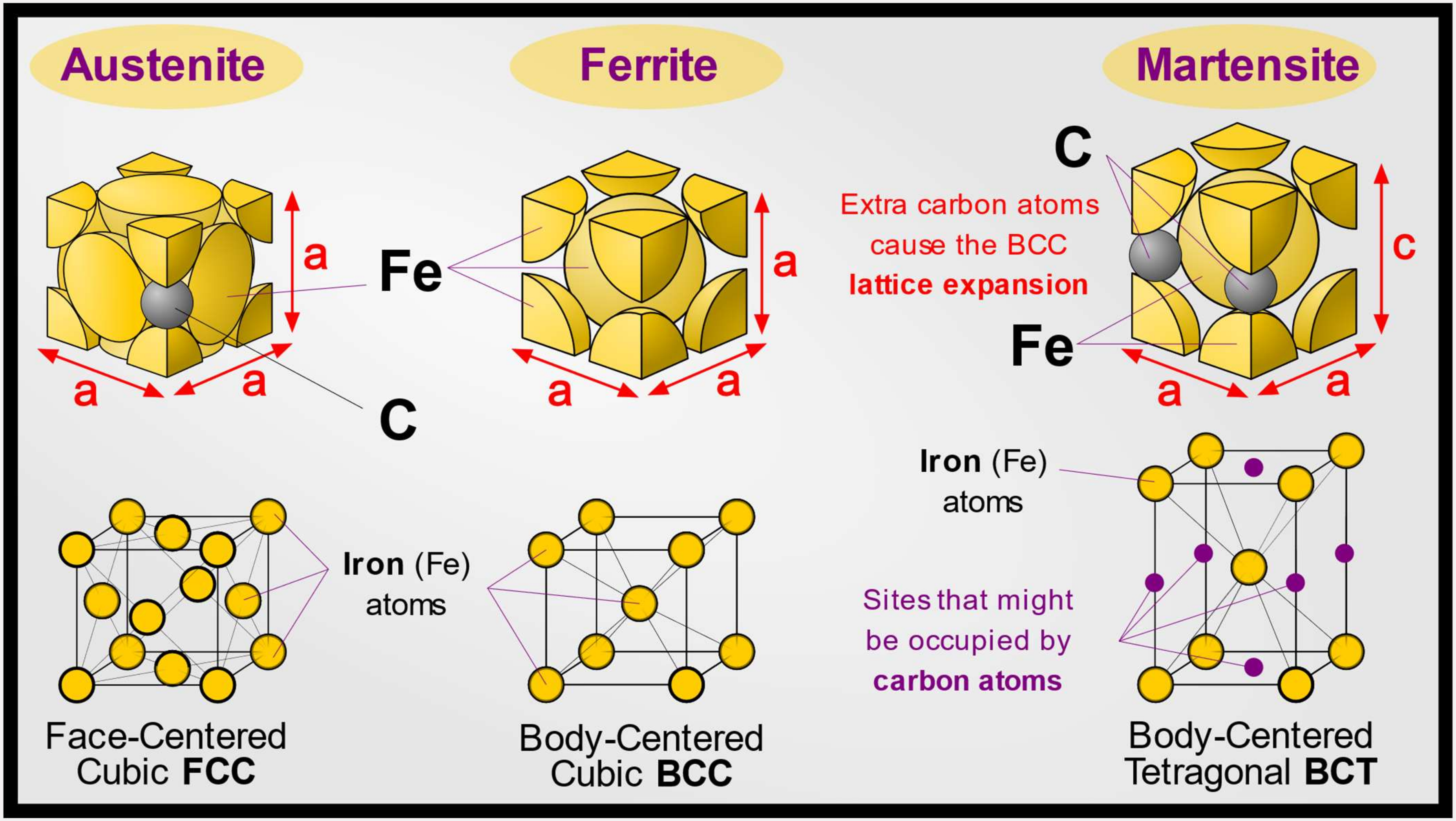


- $\beta = 2/3$ for bending.





QUESTIONS?



Extra carbon atoms cause the BCC **lattice expansion**

Sites that might be occupied by **carbon atoms**

Face-Centered Cubic **FCC**

Body-Centered Cubic **BCC**

Body-Centered Tetragonal **BCT**

Source: https://msestudent.com/wp-content/uploads/2020/05/FCC-BCC-BCT-OPT.svg

Material Families and Classes (Table 2–5) 1

Family	Classes	Short Name
Metals (the metals and alloys of engineering)	Aluminum alloys	Al alloys
	Copper alloys	Cu alloys
	Lead alloys	Lead alloys
	Magnesium alloys	Mg alloys
	Nickel alloys	Ni alloys
	Carbon steels	Steels
	Stainless steels	Stainless steels
	Tin alloys	Tin alloys
	Titanium alloys	Ti alloys
	Tungsten alloys	W alloys
	Lead alloys	Pb alloys
	Zinc alloys	Zn alloys

- *(Continued)*

Material Families and Classes (Table 2–5) 2

Family	Classes	Short Name
Ceramics		
Technical ceramics (fine ceramics capable of load-bearing application)	Alumina	Al_2O_3
	Aluminum nitride	AlN
	Boron carbide	B_4C
	Silicon carbide	SiC
	Silicon nitride	Si_3N_4
	Tungsten carbide	WC
Nontechnical ceramics (porous ceramics of construction)	Brick	Brick
	Concrete	Concrete
	Stone	Stone
Glasses	Soda-lime glass	Soda-lime glass
	Borosilicate glass	Borosilicate glass
	Silica glass	Silica glass
	Glass ceramic	Glass ceramic

- *(Continued)*

Material Families and Classes (Table 2–5) 3

Family	Classes	Short Name
Polymers (the thermoplastics and thermosets of engineering)	Acrylonitrile butadiene styrene	ABS
	Cellulose polymers	CA
	Ionomers	Ionomers
	Epoxies	Epoxy
	Phenolics	Phenolics
	Polyamides (nylons)	PA
	Polycarbonate	PC
	Polyesters	Polyester
	Polyetheretherkeytone	PEEK
	Polyethylene	PE
	Polyethylene terephalate	PET or PETE
	Polymethylmethacrylate	PMMA
	Polyoxymethylene(Acetal)	POM
	Polypropylene	PP
	Polystyrene	PS
	Polytetrafluorethylene	PTFE
	Polyvinylchloride	PVC

- *(Continued)*

Material Families and Classes (Table 2–5)[4]

Family	Classes	Short Name
Elastomers		
(engineering rubbers, natural and synthetic)	Butyl rubber	Butyl rubber
	EVA	EVA
	Isoprene	Isoprene
	Natural rubber	Natural rubber
	Polychloroprene (Neoprene)	Neoprene
	Polyurethane	PU
	Silicon elastomers	Silicones
Hybrids		
Composites	Carbon-fiber reinforced polymers	CFRP
	Glass-fiber reinforced polymers	GFRP
	SiC reinforced aluminum	Al-SiC
Foams	Flexible polymer foams	Flexible foams
	Rigid polymer foams	Rigid foams
Natural materials	Cork	Cork
	Bamboo	Bamboo
	Wood	Wood

- Source: From Ashby, M. F., Materials Selection in Mechanical Design, 3rd ed., Elsevier Butterworth- Heinemann, Oxford, 2005. Table 4–1, 49–50.