

Chapter 23: Materials Selection & Design

Issues to address...

- Price and availability of materials
- How do we select optimal materials based on optimal performance?
- Applications:
 - mirror support for a large telescope
 - design of minimum mass, maximum strength
 - shafts under torsion
 - bars under tension
 - plates under bending

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Price and Availability

- Current prices: e.g., Procurement Weekly (journal)
 - Large short-term fluctuations due to supply/demand: prices can fluctuate 10-15% in a single month
 - Long-term trend: prices are increasing
 - rich deposits are depleted
 - less rich sources require increased energy to refine

Energy content (GJ/tonne)*

Al	280	cement	7
plastics	85-180	brick	4
copper	140, rising to 300	timber	2.5-7
zinc	68	gravel	0.2
steel	55	oil	44
glass	20	coal	29

*from Ashby + Jones, Engineering Materials I; in 1994, \$4.5/GJ

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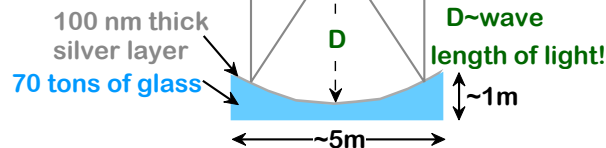


Case Study: Telescope Mirror Support*

- British infrared telescope, Mauna Kea, Hawaii (Fig. 7.1, Ashby and Jones)



- Mt. Palomar, CA: \$176M cost \sim (mass mirror)²



*Case study taken from Ashby and Jones, Engineering Materials I, 1996.

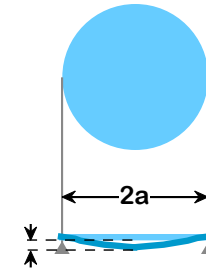
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Mirror Deflection Analysis

- Deflection of simply supported disk due to its own weight (Poisson's ratio = 1/3 assumed)

$$\frac{\text{mass} \times \text{accel due to gravity}}{\text{elastic modulus} \times \text{thickness of mirror}^3} = \frac{2}{3} \frac{Mga^2}{Et^3}$$



- Mass, M, of the disk $M = a^2t$
- Radius a is specified. Eliminate t from above eqns.

$$M = \frac{2}{3g} a^{0.5} \frac{3}{E} a^{0.5}$$

Specified by the design Material parameters!

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Candidate Materials-Mirror Support

- Analysis for a 200 inch telescope

Material	E(GPa)	(Mg m ⁻³)	M~(3/E) ^{0.5}
steel	200	7.8	1.54
concrete	47	2.5	0.58
aluminum	69	2.7	0.53
glass	69	2.5	0.48 currently used
GFRP	40	2.0	0.45
wood	12	0.6	0.13
foamed polyurethane	0.06	0.1	0.13
CFRP	270	1.5	0.11 minimum mass

- Analysis warrants further study!

*Case study taken from Ashby and Jones, Engineering Materials I, 1996.

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Cost-Mirror Support Cost $\tilde{c}M$

- Analysis for a 200 in telescope

Material	\tilde{c}	M	$\tilde{c}M$
steel	1	1	1.5
concrete	0.1	0.58	0.06 minimum mirror cost
aluminum	10	0.53	5.3
glass	3	0.48	1.4 currently used
GFRP	4.5	0.45	2.0
wood	2.5	0.13	0.33
foamed polyurethane	2.6	0.13	0.34
CFRP(Vf = 0.65)	45	0.11	5.0 minimum mirror mass

- Material cost analysis changes the ordering

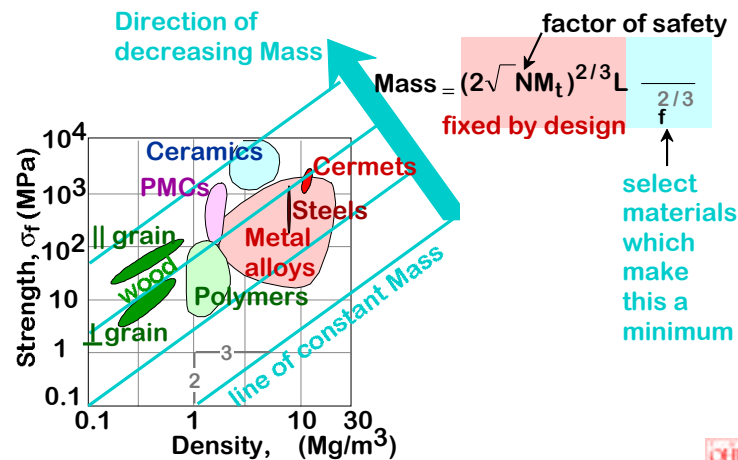
*Case study taken from Ashby and Jones, Engineering Materials I, 1996.

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Design of a Lightweight and Strong Circular Shaft

-length L, must not fail under torque M_t

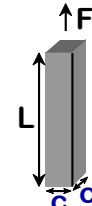


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Design of Lightweight and Strong/Stiff Tension Bars

Problem 23.D2: Derive conditions for strength and stiffness performance for a bar of length L in tension.



- Mass of the bar:

$$M = Lc^2$$

- L is fixed; c is unknown.
- Use either condition below to eliminate c.

- Strength relation

$$\frac{f}{N} = \frac{F}{c^2}$$

strength performance

$$M / f$$

- Stiffness relation

$$\frac{F}{c^2} = \frac{E}{L} \quad (= E)$$

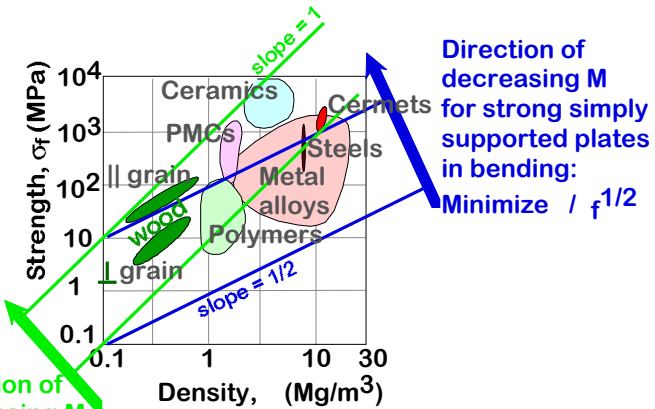
stiffness performance

$$M / E$$

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Design of Lightweight and Strong Bars & Plates



Direction of decreasing M for strong tension members (based on analysis, prev. slide): Minimize ρ / σ_f

Direction of decreasing M for strong simply supported plates in bending: Minimize $\rho / \sigma_f^{1/2}$