ME 321L - Mechanical Analysis for Design - Spring 2025

Individual Assignment 4: Material Selection

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1 Application A: Strong, Lightweight Platform in Bending

1.1 Identify Constraints

- Fixed length L and width W
- Free variable: thickness t (can vary)
- Must withstand an applied force F without failing in bending
- Must resist moisture and radiation
- Must be machinable
- Cost constraint: Must be ≤ 3 \$/lb

1.2 Performance Index

The objective is to minimize mass while ensuring bending strength.

Mass equation:

$$m = \rho V = \rho LWt$$

Bending failure constraint:

$$\sigma_b = \frac{My}{I}$$

where:

$$M = \frac{FL}{4} \quad \text{(bending moment)}$$
$$y = \frac{t}{2} \quad \text{(distance from neutral axis)}$$
$$I = \frac{Wt^3}{12} \quad \text{(second moment of area)}$$

Substituting these values:

$$\sigma_b = \frac{\frac{FL}{4} \cdot \frac{t}{2}}{\frac{Wt^3}{12}} = \frac{3FL}{2Wt^2}$$

Solving for t:

$$t = \left(\frac{3FL}{2W\sigma_b}\right)^{1/2}$$

Substituting t into the mass equation:

$$m = \rho LW \left(\frac{3FL}{2W\sigma_b}\right)^{1/2}$$
$$m = L^{3/2} W^{1/2} F^{1/2} \rho \sigma_b^{-1/2}$$

From this, the functional, geometric, and material parameters can be determined:

$$m = f_1(F) \cdot f_2(G) \cdot f_3(M)$$

where:

- $f_1(F) = F^{1/2}$ (functional parameter)
- $f_2(G) = L^{3/2} W^{1/2}$ (geometric parameter)
- $f_3(M) = \rho \sigma_b^{-1/2}$ (material parameter)

Thus, the material index can be determined:

$$M = \frac{\sigma_b^{1/2}}{\rho}$$

M must be maximized, or (alternatively) $\frac{1}{M}$ has to be minimized.

1.3 Selected Materials

1. Aluminum, 7068, T6511
2. Magnesium, ZK60A-T5
3. Aluminum, 7255, T7751

1.4 Step 8: Ashby Plot

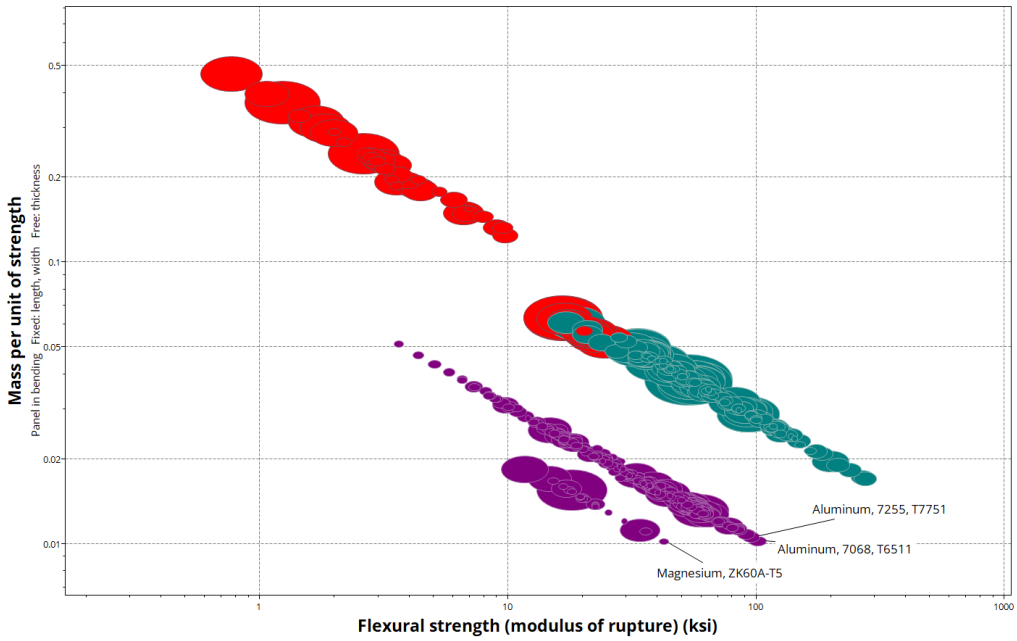


Figure 1: Ashby Plot for Application A

2 Application B: Stiff, Low-Cost Tie Rod in Tension

2.1 Step 1: Identify Constraints

- Fixed length L
- Free variable: radius r (can vary)
- Axial displacement must be $\leq \delta$
- Must be manufacturable via extrusion (Polymer Extrusion or Metal Hot Forming)
- Must withstand 1500°F without melting

2.2 Performance Index

The objective is to minimize cost while ensuring stiffness.

Cost equation:

$$C = C_m m = C_m \rho V = C_m \rho L A$$

where $A = \pi r^2$.

Stiffness constraint (Hooke's Law for axial deformation):

$$\delta = \frac{FL}{EA}$$

Rearranging for A:

$$A = \frac{FL}{E\delta}$$

Substituting A into the cost equation:

$$C = C_m \rho L \cdot \frac{FL}{E\delta}$$
$$C = C_m \rho L^2 F E^{-1} \delta^{-1}$$

From this, the functional, geometric, and material parameters can be determined:

$$C = f_1(F) \cdot f_2(G) \cdot f_3(M)$$

where:

- $f_1(F) = F\delta^{-1}$ (functional parameter)
- $f_2(G) = L^2$ (geometric parameter)
- $f_3(M) = C_m \rho E^{-1}$ (material parameter)

Thus, the material index can be determined:

$$M = \frac{E}{C_m \rho}$$

M must be maximized, or (alternatively) $\frac{1}{M}$ has to be minimized.

2.3 Step 7: Selected Materials

1. Carbon Steel, AISI 1050, oil quenched & tempered at 650°C
2. Carbon Steel, AISI 1030, as rolled
3. Carbon Steel, AISI 1030, normalized

2.4 Step 8: Ashby Plot

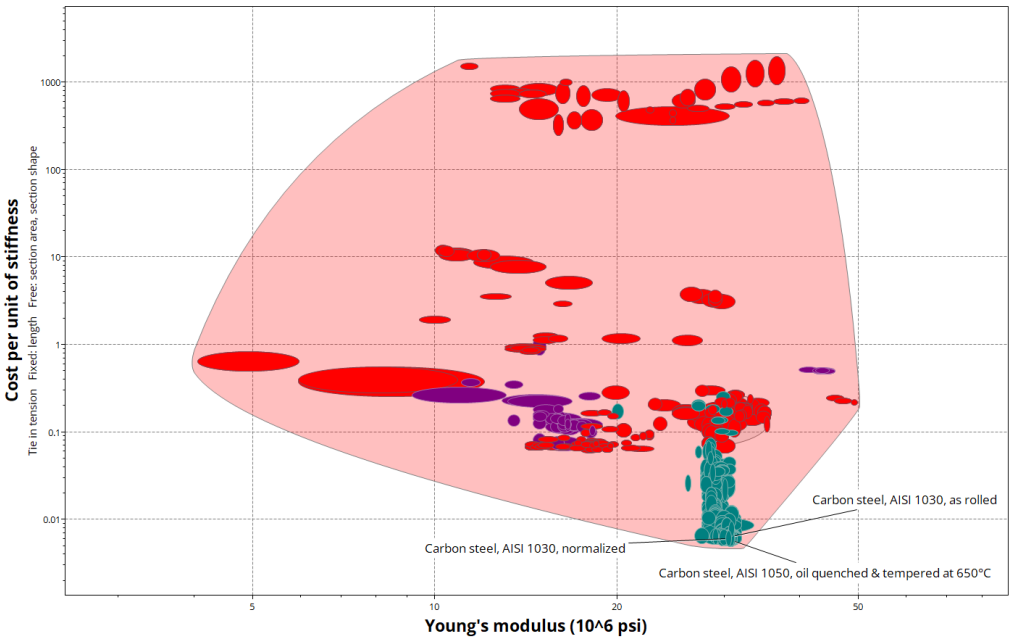


Figure 2: Ashby Plot for Application B