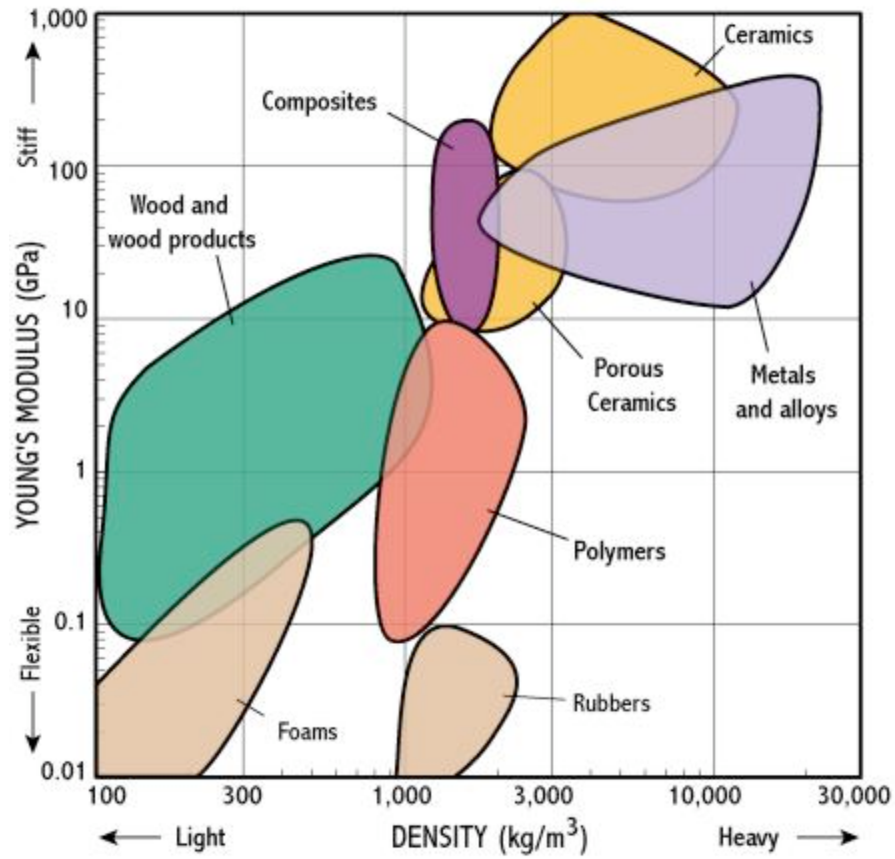
Material Selection Tutorial

- Selecting an appropriate material is a critical part of almost all engineering designs
- There are many factors to consider
  - Strength, stiffness, durability, corrosion, cost, formability, etc
- Methods
  - Experience: how do you get it? limiting
  - Ashby selection charts

  (http://www-materials.eng.cam.ac.uk/mpsite/DT.html)
  - Quantitative ranking of options (described here)

Ashby Material Selection Chart



http://www-materials.eng.cam.ac.uk/mpsite/tutorial/non_IE/selchart.html

Quantitative Ranking of Options for Material Selection*

- **Objective**: develop a rational method to select the best material for an application based upon known material parameters and the requirements of the application
- Use a 5-step method
  1. Select a quantity, Q, to minimize or maximize
  2. Classify the variables
  3. Determine the relationship between the geometry variable, the requirements, and material properties
  4. Determine Q as a function of requirements and material properties
  5. Rank candidate materials based upon function f_2

* Based on N.E. Dowling, *Mechanical Behavior of Materials*, section 3.8

Step 1: Select a quantity, Q, to minimize or maximize

- Mass (weight), m
- Cost, C

are the most common and the only ones that we will consider

Step 2: Classify the variables

- Requirements – variables that have prescribed values that will not change
- Geometry – variables that define the dimensions of the component and depend implicitly upon the material properties
- Material Properties – variables used to define the material in terms of physical behavior, mechanical behavior, and cost

Step 3: Determine the relationship between the geometry variable, the requirements, and material properties

- Strength
  - Bar, axial stress
  - Beam, flexural stress
- Stiffness
  - Bar, deformation
  - Beam, deflection

Step 4: Determine Q as a function of requirements and material properties

- $Q = f_1(\text{requirements}) * f_2(\text{material props})$

Step 5: Rank candidate materials based upon function f_2

- If both weight and cost are important then separate rankings can be generated and results combined
- Calculate geometry variable after ranking materials
  - Adjustments may be necessary if calculated dimensions are impractical (either too large or too small)
- There may be multiple requirements such as strength and serviceability
  - Often material can be selected based on strength and then the serviceability requirements checked

Sample Problem

- We must bridge a gap of L = 8'
- The bridge must have a width of b = 4"
- A load P = 300 lb can be applied at any point
- There must be a safety factor X = 1.5 for strength
- The deflection, v, must not exceed 1"
- Weight (mass) and cost have equal importance

OBJECTIVE: select the best candidate material from…

AISI 1020 steel
7075-T6 aluminum
Polycarbonate
AISI 4340 steel
Ti-6Al-4V (titanium alloy)
Loblolly pine
GFRP (glass fiber reinforced polymer)
CFRP (carbon fiber reinforced polymer)

Step 1: Select a quantity, Q, to minimize

Here, mass and cost have equal importance

- Mass, m
- Cost, C

Select Q to be the sum of the normalized mass and cost

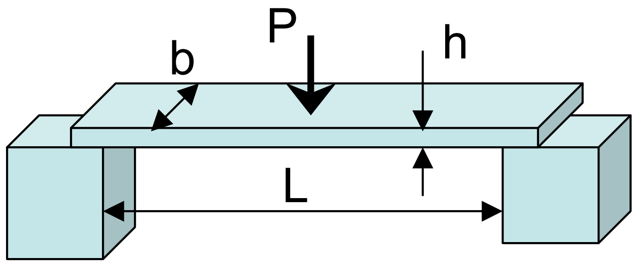
- $Q = m/\min(m) + C/\min(C)$

Step 2: Classify the variables

- Requirements: L = 8’, b = 4”, P = 300 lb, X = 1.5, v = 1”
- Geometry: restrict analysis to a rectangular cross-section, h = height
- Material Properties (need step 3 & 4 results here): ρ = mass density, E = Young’s modulus, S = strength, C_m = cost index

Step 3: Determine the relationship between the geometry variable, the requirements, and material properties

- We have a simply supported beam with a rectangular cross-section
- The worst case occurs when the concentrated load, P, is applied at the center



Strength – elastic flexural formula shows the maximum stress occurs at the extreme fibers of the beam at midspan

$$\sigma = \frac{Mc}{I}, M = PL/4, c = h/2, I = bh^3/12$$

$$\sigma = \frac{PL}{4}\frac{h}{2}\frac{12}{bh^3} = \frac{3PL}{2bh^2}$$

$$S = X\sigma = \frac{3PLX}{2bh^2} \quad \Rightarrow \quad h = \left[\frac{3PLX}{2bS}\right]^{1/2}$$

Deflection – from integration, is found to be maximum at midspan

$$v = \frac{PL^3}{48EI} = \frac{12PL^3}{48Ebh^3} = \frac{PL^3}{4Ebh^3} \quad \Rightarrow \quad h = \left[\frac{PL^3}{4Ebv}\right]^{1/3}$$

Step 4: Determine Q as a function of requirements and material properties – strength basis

Try using strength as the basis for material selection and then check deflection

$$m = \rho bhL = \rho bL\left[\frac{3PLX}{2bS}\right]^{\frac{1}{2}} = \left[\frac{3}{2}PL^3Xb\right]^{\frac{1}{2}}\left[\frac{\rho}{S^{\frac{1}{2}}}\right]$$

$$C = C_m m = \left[\frac{3}{2}PL^3Xb\right]^{\frac{1}{2}}\left[\frac{\rho C_m}{S^{\frac{1}{2}}}\right]$$

f_2

Step 5: Rank materials based upon function f_2 – strength basis

Requirements

L (in) =	96
P (lb) =	300
b (in) =	4
X =	1.5
v (in) =	1

Use spreadsheet to determine rankings

Selection Table - strength basis (check deflection)

Material	Density (slug/in3)	Strength (psi)	Cost Index	f2 for mass	Norm Mass	Mass Rank	f2 for cost	Norm Cost	Cost Rank
AISI 1020 steel	8.87E-03	37708	1	4.57E-05	9.34	8	4.57E-05	6.01	2
AISI 4340 steel	8.87E-03	159971	3	2.22E-05	4.53	7	6.65E-05	8.75	3
7075-T6 aluminum	3.03E-03	68020	6	1.16E-05	2.38	4	6.98E-05	9.17	4
Ti-6Al-4V	5.05E-03	171864	45	1.22E-05	2.49	5	5.49E-04	72.13	7
Polycarbonate	1.35E-03	8992	5	1.42E-05	2.90	6	7.11E-05	9.34	5
Loblolly pine	5.73E-04	12763	1.5	5.07E-06	1.04	2	7.60E-06	1.00	1
GFRP	2.25E-03	55112	10	9.57E-06	1.96	3	9.57E-05	12.58	6
CFRP	1.80E-03	134880	200	4.89E-06	1.00	1	9.78E-04	128.67	8

Material	Q	Combined Rank	Depth, h (in)	Modulus (psi)	Deflection (in)	Stress (psi)	Safety Factor	Check Deflection
AISI 1020 steel	15.35	6	0.655	29441624	2.00	25139	1.50	NG
AISI 4340 steel	13.28	4	0.318	30021755	17.15	106647	1.50	NG
7075-T6 aluminum	11.55	2	0.488	10297317	13.86	45347	1.50	NG
Ti-6Al-4V	74.63	7	0.307	16968818	33.78	114576	1.50	NG
Polycarbonate	12.25	3	1.342	348078	19.71	5995	1.50	NG
Loblolly pine	2.04	1	1.127	1783901	6.50	8509	1.50	NG
GFRP	14.54	5	0.542	3045685	34.18	36742	1.50	NG
CFRP	129.67	8	0.347	11022480	36.16	89920	1.50	NG

Step 4: Determine Q as a function of requirements and material properties – deflection basis

Try using deflection as the basis for material selection and then check strength

$$m = \rho bhL = \rho bL\left[\frac{PL^3}{4Ebv}\right]^{1/3} = \left[\frac{PL^6b^2}{4v}\right]^{1/3}\left[\frac{\rho}{E^{1/3}}\right]$$

$$C = C_m m = \left[\frac{PL^6b^2}{4v}\right]^{1/3}\left[\frac{\rho C_m}{E^{1/3}}\right]$$

f_2

Step 5B: Rank materials based upon function f_2 – deflection basis

Requirements

L (in) =	96
P (lb) =	300
b (in) =	4
X =	1.5
v (in) =	1

Use spreadsheet to determine rankings

Selection Table - deflection basis (check strength)

Material	Density (slug/in3)	Strength (psi)	Cost Index	f2 for mass	Norm Mass	Mass Rank	f2 for cost	Norm Cost	Cost Rank
AISI 1020 steel	8.87E-03	37708	1	2.87E-05	6.08	8	2.87E-05	4.06	2
AISI 4340 steel	8.87E-03	159971	3	2.85E-05	6.04	7	8.56E-05	12.09	4
7075-T6 aluminum	3.03E-03	68020	6	1.39E-05	2.95	4	8.36E-05	11.81	3
Ti-6Al-4V	5.05E-03	171864	45	1.97E-05	4.16	6	8.85E-04	124.93	7
Polycarbonate	1.35E-03	8992	5	1.92E-05	4.06	5	9.58E-05	13.52	5
Loblolly pine	5.73E-04	12763	1.5	4.72E-06	1.00	1	7.08E-06	1.00	1
GFRP	2.25E-03	55112	10	1.55E-05	3.28	3	1.55E-04	21.87	6
CFRP	1.80E-03	134880	200	8.07E-06	1.71	2	1.61E-03	227.96	8

Material	Q	Combined Rank	Depth, h (in)	Modulus (psi)	Deflection (in)	Stress (psi)	Safety Factor	Check Strength
AISI 1020 steel	10.14	2	0.826	29441624	1.00	15831	2.38	OK
AISI 4340 steel	18.13	5	0.821	30021755	1.00	16039	9.97	OK
7075-T6 aluminum	14.76	3	1.172	10297317	1.00	7859	8.66	OK
Ti-6Al-4V	129.10	7	0.992	16968818	1.00	10964	15.67	OK
Polycarbonate	17.58	4	3.626	348078	1.00	822	10.94	OK
Loblolly pine	2.00	1	2.103	1783901	1.00	2442	5.23	OK
GFRP	25.16	6	1.759	3045685	1.00	3489	15.80	OK
CFRP	229.67	8	1.146	11022480	1.00	8224	16.40	OK

Sample Problem Results

- Material selection based only on strength results in the deflection criterion being violated
- Material selection based only on deflection results in the strength criterion being satisfied
- We can say that deflection governs this design
- Pine is best, 1020 steel is second best, CFRP is worst