MATERIALS SELECTION

LECTURE NOTES — MET 4501 — PROF. LEAH GINSBERG

HOW DO WE SELECT A MATERIAL FOR A MACHINE PART OR STRUCTURAL MEMBER? WE HAVE OPTIONS:

1. USE WHAT HAS BEEN USED BEFORE FOR A SIMILAR APPLICATION.
2. USE A SYSTEMATIC APPROACH
   (a) LIST ALL IMPORTANT MATERIAL PROPERTIES (STRENGTH, STIFFNESS, COST, WEIGHT, ETC.)
   (b) FOR EACH PROPERTY LIST ALL AVAILABLE MATERIALS.
   (c) RANK MATERIALS FROM BEST TO WORST. (E.G. 4340 STEEL WOULD TOP THE LIST FOR STRENGTH)
   (d) SELECT A FEW MATERIALS FROM THE TOP OF EACH LIST
   (e) MATERIALS THAT SHOW UP IN ALL REDUCED LISTS GET FURTHER REVIEW.
   (f) GRADE & WEIGHT MATERIAL PROPERTIES TO FORM A RANKED LIST.
3. USE MATERIALS SELECTION CHARTS. (I.E. ASHBY CHARTS)
   - SOFTWARE, LIKE CES EduPack CAN BE USED

FIGURE 2-23 (SEE SLIDES) PLOTS YOUNG'S MODULUS FOR VARIOUS MATERIALS. WHAT IF WE PUT SOMETHING ON THE x-AXIS? MAYBE ρ

- LINE RANGES IN FIG. 2-23 BECOME ELLIPSES (BUBBLES)
- GROUPS OF BUBBLES REPRESENT MATERIAL FAMILIES

THE RATIO OF STIFFNESS TO WEIGHT IS VERY IMPORTANT IN DESIGN, SO WE GIVE IT A SPECIAL NAME:

$$\text{SPECIFIC MODULUS/STIFFNESS} = \frac{E}{\rho}$$

THIS RATIO IS VERY USEFUL WHEN WE WANT TO MINIMIZE WEIGHT AND WE'RE LIMITED BY DEFLECTION. (OR NATURAL FREQUENCY)

AS $\frac{E}{\rho}$ INCREASES, PARTS EXHIBIT:

- LOWER DEFLECTION
- HIGHER STIFFNESS
- HIGHER NATURAL FREQUENCY

REMEMBER, FOR SHAFTS:

$$\omega_n = \sqrt{k/m}$$

AND FOR SPRINGS:

$$f = \frac{1}{2}\sqrt{\frac{kg}{W}} \quad \text{OR}$$

$$f = \frac{1}{4}\sqrt{\frac{kg}{W}}$$

LET'S CREATE A METRIC TO REPRESENT THE PERFORMANCE OF OUR DESIGNED MACHINE PART OR STRUCTURAL MEMBER:

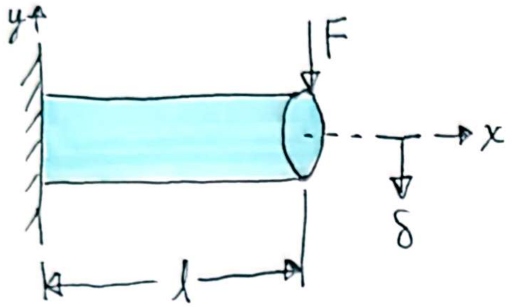
$$P = f(F, G, M)$$

- P — PERFORMANCE METRIC
- $=f$ — IS A FUNCTION OF
- F — FUNCTIONAL REQUIREMENTS
- G — GEOMETRIC PARAMETERS
- M — MATERIAL PROPERTIES

WE'LL ASSUME ITS SEPARABLE, MEANING THE VARIABLES AREN'T INTERDEPENDENT (& PROVE IT LATER FOR A CANTILEVER BEAM).

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

LET'S DESIGN A CANTILEVER BEAM, AS AN EXAMPLE, USING THE MASS AS OUR PERFORMANCE METRIC.



THE STIFFNESS IS : $k = \frac{F}{\delta}$ (HOOKE'S LAW)

THE DEFLECTION IS GIVEN IN TABLE A-9 IN SHIGLEY (OR YOU CAN DO SOME INTEGRATION TO DERIVE IT YOURSELF):

$$\delta_{max} = \frac{Fl^3}{3EI}$$

PLUGGING THIS DEFLECTION INTO OUR EQUATION FOR STIFFNESS,

$$k = \frac{3EI}{l^3}$$

THE SECOND MOMENT OF AREA FOR A CIRCULAR CROSS-SECTION IS:

$$I = \frac{\pi D^4}{64} = \frac{\left(\frac{\pi}{4}D^2\right)^2}{4\pi} = \frac{A^2}{4\pi}$$

THEN, PLUGGING THIS INTO OUR EQUATION FOR STIFFNESS:

$$k = \frac{3E}{l^3} \cdot \frac{A^2}{4\pi}$$

SOLVING FOR A,

$$A = \sqrt{\frac{4\pi k l^3}{3E}}$$

THE MASS OF A CYLINDRICAL BEAM IS: $m = \rho V = \rho A \cdot l$

THEREFORE,

$$m = \rho l \sqrt{\frac{4\pi k l^3}{3E}}$$

SEPARATING OUT EACH COMPONENT,

$$m = \underbrace{2\sqrt{\frac{\pi}{3}}\left(k^{1/2}\right)}_{f.(F)} \underbrace{\left(l^{5/2}\right)}_{f.(G)} \underbrace{\left(\frac{\rho}{E^{1/2}}\right)}_{f.(M)}$$

TO MINIMIZE MASS (m) WITH MATERIAL CHOICE, WE NEED TO MINIMIZE $f_3(M) = \frac{\rho}{E^{1/2}}$, OR MAXIMIZE

$$M = \frac{E^{1/2}}{\rho}$$, CALLED THE MATERIAL INDEX (IN BENDING)

LOOKING AT THE GUIDELINES IN FIGURE 2-25 (SEE SLIDES), THE MATERIAL FAMILIES WITH THE HIGHEST MATERIAL INDEX (IN BENDING) ARE WOODS, COMPOSITES, CERAMICS.

OTHER LIMITS MAY WARRANT FURTHER INVESTIGATION:

- IF WE NEED $E \geq 50$ GPa, WE CAN ADD A HORIZONTAL LINE, AS SHOWN IN FIGURE 2-26 (SEE SLIDES), AND ELIMINATE WOOD AS AN OPTION.
- IF COST IS A LIMITING FACTOR, COMPOSITES MAY NEED TO BE ELIMINATED.

THE GENERAL FORM OF THE MATERIAL INDEX IS:

$$M = \frac{E^{\beta}}{\rho}$$, WHERE THE EXPONENT β IS $\beta = 1$ FOR AXIAL, $\beta = 1/2$ FOR BENDING

WE MAY BE MORE CONCERNED WITH STRENGTH THAN DEFLECTION. IN THAT CASE, SPECIFIC STRENGTH MAY BE OF MORE INTEREST:

$$\text{SPECIFIC STRENGTH} = \frac{S}{\rho}$$

AND WE CAN DRAW GUIDELINES ON AN ASHBY CHART IN THE FORM OF $\frac{S^{\beta}}{\rho}$, WHERE $\beta = 1$ FOR AXIAL, $\beta = 2/3$ FOR BENDING

THERE ARE MANY OTHER FACTORS WE COULD CONSIDER IN MATERIAL SELECTION (ENVIRONMENT, COST, AVAILABILITY, MACHINABILITY)

WE CAN ALSO ADJUST MATERIAL PROCESSING. WITH ALL THESE VARIABLES, SOFTWARE CAN BE VERY HELPFUL FOR BOOKKEEPING.

JUST MAKE SURE YOU KNOW HOW TO USE IT!