LMAPR2020: Materials Selection

Second homework on the basics

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Question 1 : Choose an object of your own and give its specifications

The object should deal with electrical problematic:

Power cable sheath for outdoor lighting

- Function: Protect cables from bad weather and insulate electrically
- Constraints:
  - Must be waterproof, moisture and rain resistant
  - Must be electrically insulated (not conductive)
  - Must be UV resistant
  - Must withstand temperatures from -30°C to 50°C
  - must be capable of withstanding normal mechanical stresses of use, including torsional and compressive forces
- Objective : Minimize the cost
- Free variable :
  - Material
  - Thickness of the cable sheath

Question 2

Material Index for a Panel and Comparison with a Tie and a Beam

Material Index Derivation for a Panel

A panel is a thin structure that resists bending. Failure occurs when the applied stress exceeds the material's strength. To minimize mass while ensuring structural integrity, we derive the material index.

Using the bending stress equation:

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

The mass of the panel is:

$$m = At\rho$$

t is the panel thickness.

To minimize mass while ensuring safety ($\sigma \leq \sigma_y$), the material index is:

$$M_{\text{panel}} = \frac{\sigma_y^{1/2}}{\rho}$$

Comparison with a Tie and a Beam

Structure	Load Type	Material Index
Tie	Pure Tension	$\frac{\sigma_y}{\rho}$
Beam	Bending	$\frac{\sigma_y^{1/2}}{\rho}$
Panel	Surface Bending	$\frac{\sigma_y^{1/2}}{\rho}$

Table 1: Comparison of Material Indices

Conclusion

The material index for a panel is:

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

which is the same as a beam, showing that both structures fail under bending in a similar way.

$$M = \frac{\sigma_y}{\rho}$$

The panel behaves like a beam in bending but differs from a tie.

Question 3

- Function: Torsion spring of a pen which take its initial position after each cycle.
- Constraint : Does not deform plastically
- Objective : Minimize the mass
- Free variable : diameter

$$F = \frac{\pi d^3 \sigma_y}{32R} \text{ ; } F = ku \text{ with } u = x \text{ and R fixed}$$

$$m = n(2\pi R)d\rho$$

We doesn't want any plastic deformation so:

$$kx \leq \frac{\pi d^3 \sigma_y}{32R}$$

we isolate the diameter :

$$d = (\frac{kx32R}{\pi \sigma_y})^{1/3} \text{ and } d = \frac{m}{n2\pi R\rho}$$

This lead to:

$$m = n2\pi R\rho(\frac{kx32R}{\pi\sigma_y})^{1/3} = (n2\pi R)(\frac{kx32R}{\pi})^{1/3}(\frac{\rho}{\sigma_y^{1/3}})$$

So finally we get:

$$M = \frac{\sigma_y^{1/3}}{\rho} \text{ to maximize}$$

By using Granta edupack software we plot the graph of the yield strength as a function of the density and draw a line with a slope of 3.

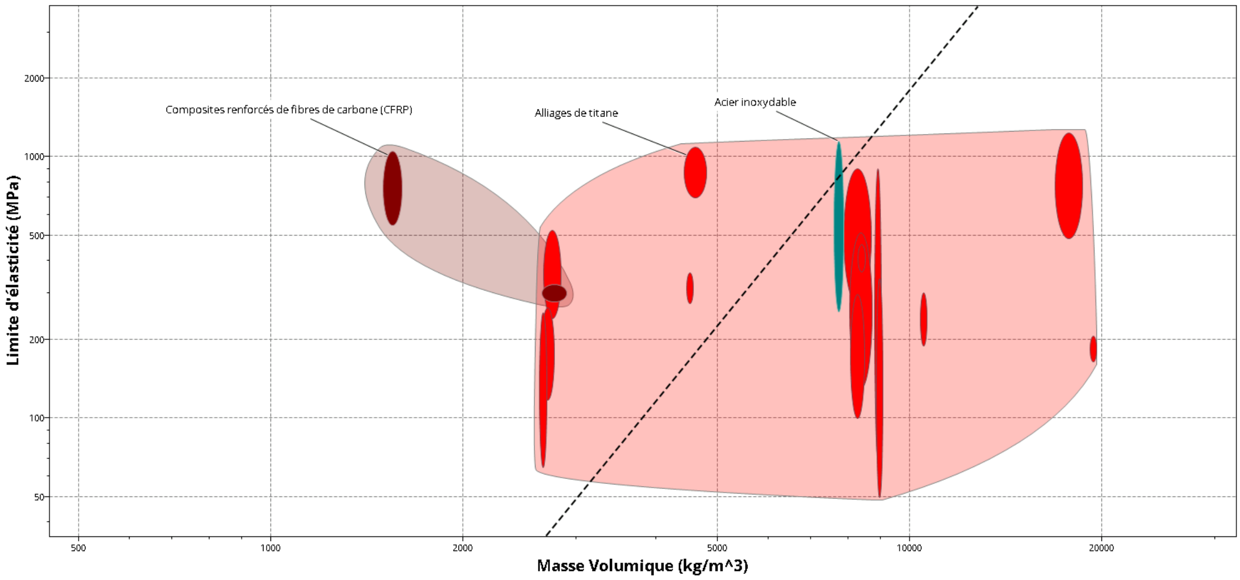

Figure 1: Graph of the Yield strength as a function density

We can see from the graph that we have different choices but after some research, carbon fiber is overpriced for a simple pen and titanium is very difficult to machine therefore and in connection with existing pens the best choice turns out to be **stainless steel**.

Question 4

The cost is often proportional to either the mass or the volume of the material. It can therefore be expressed as:

$$C = C_m \cdot m = C_m \cdot \rho \cdot V$$

where C_m is the cost per unit mass of the material.

Therefore, for a material index where the objective is to minimize mass, $M = \frac{\text{Mechanical Properties}}{\rho}$ becomes:

$$M = \frac{\text{Mechanical Properties}}{\rho \cdot C_m}$$

Question 5

Shaft used in Strepy Thieu boat lift :

- Function: Transmit rotational torque to synchronize connected shafts, ensuring coordinated movement
- Constraint:
  - Must not undergo plastic deformation under maximum operating torque
  - Must not fail under normal operational loads
  - Must be corrosion resistant
  - Must maintain mechanical properties and structural integrity within a temperature range of -30°C to 60°C
  - Must withstand cyclic loading due to repetitive rotations without fatigue failure
- Objectives: Minimize rotational deflection
- Free variable:
  - Wall thickness
  - Material

So we know from the Appendix B that:

$$\sigma_{max} = \tau_{max} = \frac{Td_0}{2K} = \frac{G\theta d_0}{2L}$$

By using the tresca criterion to avoid plasticity deformation we get:

$$\tau_{max} \leq \frac{\sigma_y}{2}$$

This lead to :

$$\frac{G\theta d_0}{2L} \leq \frac{\sigma_y}{2} \text{ so } \theta \leq \frac{\sigma_y L}{G d_0}$$

At the end we the Material index to maximize:

$$M = \frac{G}{\sigma_y}$$

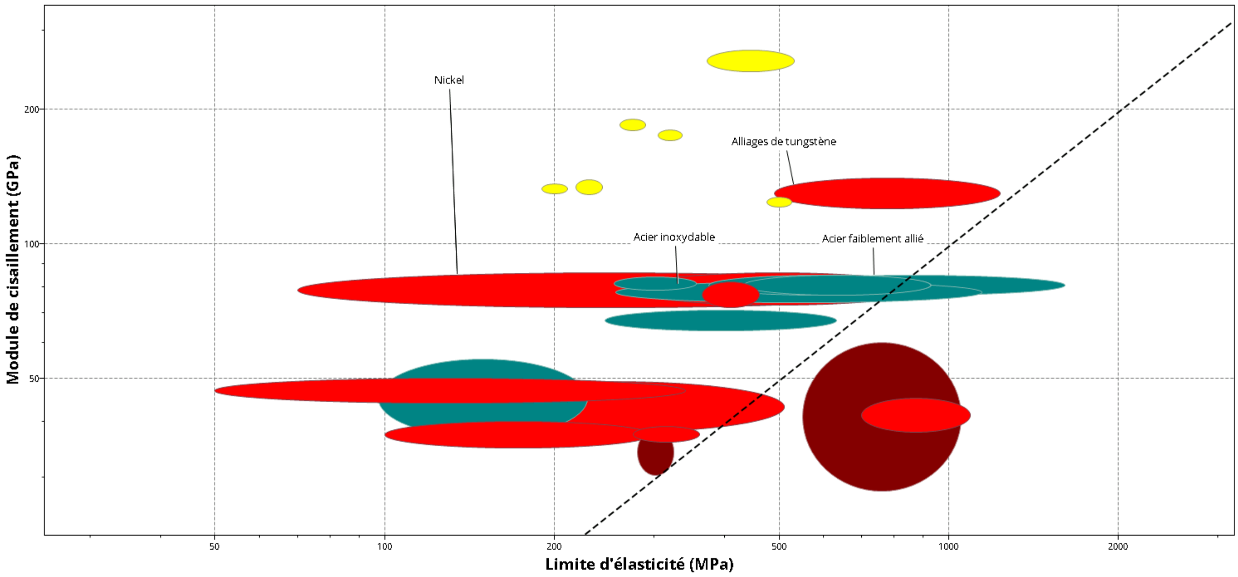

Figure 2: Graph of the Shear Modulus as a function of σ_y

Finally, after applying certain limits and maximizing the material index we arrive at several possible choices. Firstly, Nickel and tungsten are not good candidates because of their high cost, and tungsten is difficult to machine. We will therefore choose **low alloy steel** because it is more rigid than stainless steel.