GRANTA TEACHING RESOURCES

Introductory Level 2

Case Study: CHAINSAW

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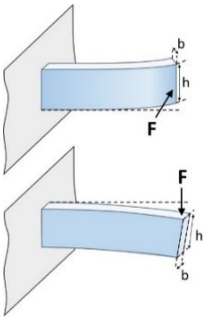
1. Material Selection in Design

For many products, mechanical performance is important and must be considered during their design. Some applications are dependent on high specific strength or specific stiffness, traditionally provided by metal alloys of some kind. Metals also have attractive fracture toughness and service temperature properties. For certain applications, it might be possible to find polymers that are more competitive, particularly in terms of cost, weight and corrosion resistance. In this Case Study, we look at materials for ***a lightweight blade of a chainsaw***, in which all of the above-mentioned properties are important and must be considered in the design process.

The systematic way to select materials by Ashby *et al*. involves identifying the *Function*, *Objectives* and *Constraints* for the design. It is vital to determine which mechanical properties are key to the performance. The blade has to endure forces both in the cutting direction and sideways, perpendicular to the cutting direction. This results in flexural (bending) loads on the blade. Strength will, of course, be one of the crucial parameters in the sense that the blade *must* be strong enough. However, it is not this property that limits the performance. Rather, like most equipment used for sports and racing (skis, rackets, bikes etc) it is the *Stiffness* that we want to promote. Our case study highlights stiffness and mass.

2. How to tackle the Problem



In CES EduPack, the situation can be mechanically likened to a fixed-end beam loaded in bending by horizontal or vertical forces, as shown to the left. A translation of the problem involves specification of the *function*, *constraints* and the *objective* of the selection.

Function: Beam of length L fixed at one end

Mechanical constraints on the bending stiffness can then be used to eliminate a free design parameter, which enables a selection based on material properties alone:

Constraints: Bending stiffness > S* (both directions)

This lower limit on S gives a minimum blade height:

Vertical: $S = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CE\,b^3h}{12\,L^3}$ $\boxed{h = \frac{12SL^3}{CEb^3}}$

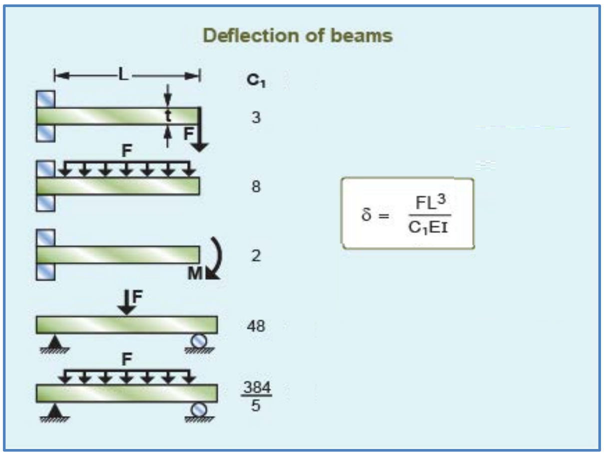
Horizontal: $S = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CE\,bh^3}{12\,L^3}$ $\boxed{h = \left(\frac{12SL^3}{CEb}\right)^{1/3}}$

Where:

m = mass
ρ = density
S = stiffness (F/δ)
δ = deflection

This beam: $\delta = FL^3/CEI$
C = constant (here, 3 to 8)
E = Young's modulus
I = second moment of area
($I = bh^3/12$ ↕ or $b^3h/12$ ↔)

It is worth mentioning that the constant, C, varies for point loads or distributed loads (and combinations thereof) on the beam. Constants will, however, not affect property charts and material property-based selection.



Other design constraints are:

- *Min/Max service temperature*: **-40°C / +110°C**
- *Resistance to water (fresh)*: **excellent**
- *Resistance to lubricating oil*: **excellent**
- *Resistance to petrol (gasoline)*: **excellent**
- *Mechanical properties*: ***considered separately***

To derive the *Performance Index*, we substitute *h* from each of the respective constraints, into the objective function to eliminate this free design parameter, the blade height (b is fixed by the chain-width).

Objective: Minimize mass, $m = A\ L\ \rho = b\ h\ L\ \rho$

This yields two performance indices, one for each case:

Vertical: $$m = L^2\left(\frac{b^2 12S^*}{C}\right)^{1/3}\left(\frac{\rho}{E^{1/3}}\right)$$

Horizontal: $$m = \left(\frac{12S^*L^4}{Cb^2}\right)\left(\frac{\rho}{E}\right)$$

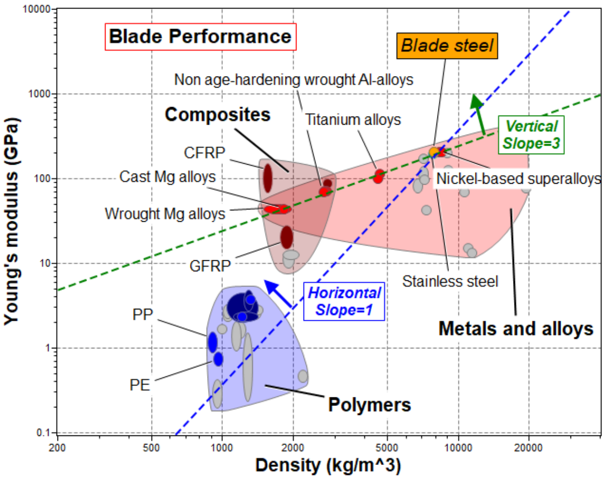
These two expressions have been arranged as to the material properties at the end. The convention, using the basic Ashby selection methodology, is to define the *Material index* (Performance index for the material) as the reciprocal of these ratios. We obtain:

$$M_V = \left(\frac{E^{1/3}}{\rho}\right) \qquad M_H = \left(\frac{E}{\rho}\right)$$

These correspond to index lines with slopes 3 (M_V) and 1 (M_H), respectively, in a property chart of E *vs* ρ, as seen below where both these lines have been introduced.

3. Benchmarking the Performance

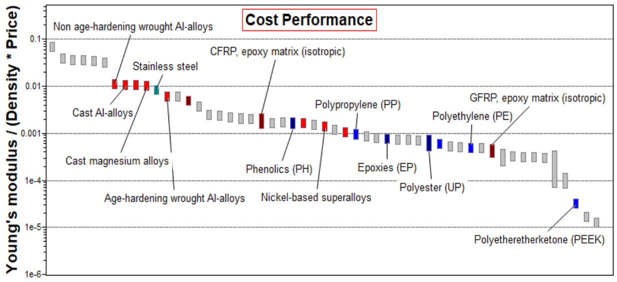
In order to compare the relevant properties of an existing blade material with other material candidates, "benchmarking", we add a reference record to this property chart, called "*Blade steel*". We will use *Yield strength: 208 – 216 GPa* and *Density: 7800 – 7900 kg/m*^{3}, from a *Low alloy steel, AISI 4140, oil quenched & tempered at 315°C*. This is similar to a real alloy used in chainsaw blades and to *Stainless Steel* in the Level 2 database of CES EduPack. Adding data can be done by right-clicking over the chart and completing the empty record.



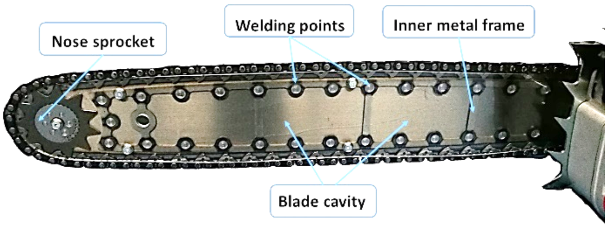
If index lines for maximization, with slopes 1 and 3, are added to the chart, just below the reference, materials that fall below this reference are screened out. If the vertical performance index is considered (slope=3), we can see that Ni based alloys and superalloys, Ti, Al, and Mg alloys perform as good as the reference and CFRP performs even better. The horizontal performance index (slope=1) shows that the materials perform better in the order of Ti, Al, Mg and CFRP. The vertical index is considered more important, since the blade is thinner and more susceptible to deformation in this direction.

4. Reality Check

So far, we have considered lightweighting, limited by stiffness and taking durability into account. There are several other aspects that need to be considered in selecting materials, though. Cost, being one of the most important. A second selection stage can be added in combination with the first. The cost performance index to maximize for stiffness-limited design is: $M = E / (\rho \cdot c_m)$:



From this Bar chart, we can see that material cost considerations favour Al alloys, Mg alloys and stainless steel over composites and polymers. It is likely, that this consideration greatly influenced currently used materials. In real chainsaw blades, the strength relies on structural design. There are several kinds of blades in real use which differ by internal structure, such as cavity filler, material combinations and the manufacturing processes.



5. Conclusions

In this simplified industrial case study, we have explored the systematic way to understand materials for a chainsaw blade using CES EduPack. Considering materials like Ti, Al, Mg or CFRP may improve the performance of the chainsaw blade in terms of a stiffness-limited design. Engineering Design, however, is always a balance of various material properties, costs, manufacturing processes and degree of innovation.