Ansys Granta EduPack™ Case Study

Chainsaw

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Ansys Software Used

This resource uses Ansys Granta EduPack™, a teaching software for materials education.

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 (Figure 1), in which all of the above-mentioned properties are important and must be considered in the design process.

Figure 1: Close up of a chainsaw blade in action. The blade houses the chain, which does the cutting.

The systematic way to select materials by Ashby *et al.*[1] 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

Using the Granta EduPack software, 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.

1 To learn more about this Ashby Selection Methodology, check out this White Paper

2.1 Function

We can consider the function of a chainsaw blade as *a beam of length L, which is fixed at one end* (like in Figure 2).

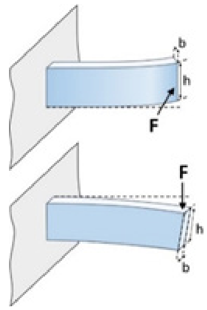

Figure 2: the different loading directions available for a beam in bending with one end fixed

2.2 Constraints

By applying the mechanical constraint of *Bending Stiffness > S** (where S* is some critical value), we can eliminate a free design parameter, which enables a selection based on material properties alone. The relevant equations for both vertical and horizontal loading conditions can be found below.

$$S_{Vertical} = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CEbh^3}{12L^3} \qquad S_{Horizontal} = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CEb^3h}{12L^3}$$

where m is mass, ρ is density, S is stiffness, δ is deflection (FL^3/CEI), C is constant, E is Young's modulus, and I is the second moment of area ($I_{vertical}=bh^3/12$ and $I_{horizational}=b^3h/12$).
This lower limit on S gives a minimum blade height, h, as shown in the equations below.

$$h_V = \left(\frac{12SL^3}{CEb}\right)^{1/3} \qquad h_H = \frac{12SL^3}{CEb^3}$$

It is worth mentioning that the constant, C, varies for point loads or distributed loads (and combinations thereof) on the beam (Figure 3). Constants will, however, not affect property charts and material property-based selection.

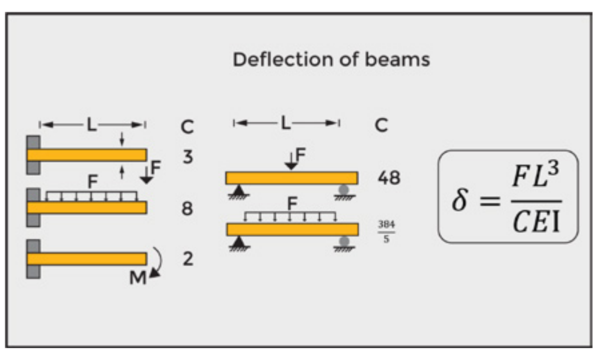

Figure 3: Graphic that shows the various values for constant C, which depend on the beam loading conditions

Other design constraints we consider are:

- Min/Max service temperature: -40°C / +110°C
- Resistance to water (fresh): excellent
- Resistance to lubricating oil: excellent
- Resistance to petrol (gasoline): excellent
- No ceramics, foams, or natural materials in subset

2.3 Objectives

For the objectives, we are looking to *minimize mass,* or *m=ALρ=bhLρ*. To do this, we want to derive a set of performance indices[2]. Since there are two loading conditions of interest, we need two performance indices. To derive them, we substitute h for vertical and horizontal loading into the mass equation above to eliminate the free design parameter, the blade height (b is fixed by the chain-width). This gives us the two equations below.

$$m_V = L^2 \left(\frac{12Sb^2}{C}\right)^{1/3} \left(\frac{\rho}{E^{1/3}}\right) \qquad m_H = \left(\frac{12SL^4}{Cb^2}\right)\left(\frac{\rho}{E}\right)$$

For this case study, we only care about the material property component of these indices. The convention, using the basic Ashby selection methodology, is to define the Material index (Performance index for the material) as the reciprocal of the ratios above. We obtain:

$$M_V = \frac{E^{1/3}}{\rho} \qquad M_H = \frac{E}{\rho}$$

These correspond to index lines with slopes 3 (M_V) and 1 (M_H), respectively, which we will use below.

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 Young's Modulus: 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 Granta EduPack Level 2 database. Adding data can be done by right-clicking over the chart and completing the empty record. Figure 4 shows a plot of Young's modulus and density with the two performance index lines and our reference record.

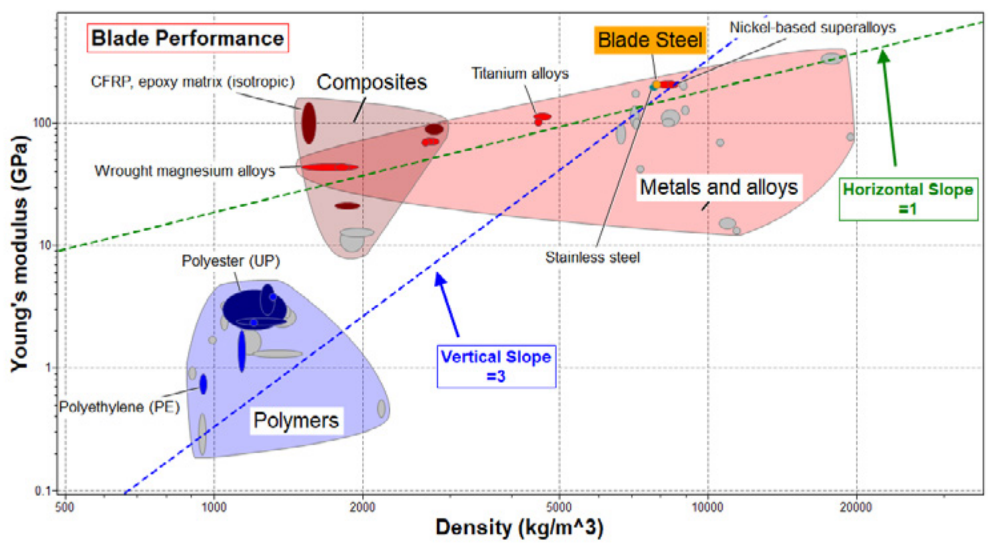

Figure 4: Chart of Young's Modulus vs. Density with M_V=3 and M_H=1 and the reference material highlighted

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

2 To learn more about performance indices, check out this Reference Booklet

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: $M = E / (c_m \cdot \rho)$

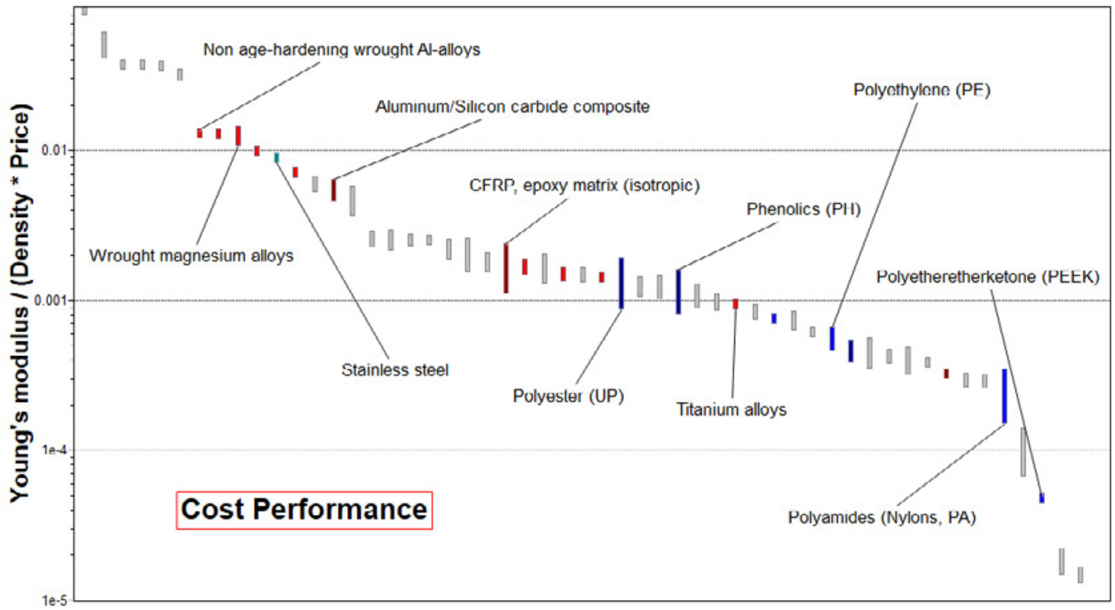

*Figure 5: Chart of Young's Modulus/Cost*Density*

From Figure 5, we can see that material cost considerations favor 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 case study, we have explored the systematic way to understand materials for a chainsaw blade using the Granta EduPack software. 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.

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