Task 1: Selection basics, Henri Wahlman 790608

Task 1.1

In this task I need to select a good material for a wind turbine blade. I will be using the same method as described in textbook's case study 6.2. The chapter 5 of the textbook offered the instructions for selecting a material for a specific purpose. The procedure concludes *translation and deriving the index, screening, ranking* and *documentation research.* Translation is about identifying the problem and deriving variables we can use later. Screening is made based on translation. We eliminate different materials based on the information gathered during translation phase. Ranking helps to find the suitable materials after screening. We rank materials based on certain criteria. Then we choose few best materials based on ranking. Then material by material a specific research is made from material documentations and the most suitable material is chosen.

As mentioned in the task introduction, I can assume that the wind turbine blade is a simple beam that is allowed to bend but of course not to break. The beam should be as light as possible and have at least a given bending stiffness S from the fact that it has to support varying force while bending. The shape of a beam can vary. For now we can assume that the beam is simple circular beam as in figure 1 but not a hollow. Also, the beam has a specific length L. Functioning as a wind turbine blade it cannot brake if little rocks or birds collide with it. So it needs to be also tough enough, not a brittle. Let's collect these fact to the table 1.

Figure 1. Wind turbine blade. The blade base is circular in shape. [1]

Table 1 Design requirements for a wind turbine blade

Function	Wind turbine blade – simple beam in bending
Constraints	Beam length L (known) Bending stiffness S (known) Not brittle / tough enough: fracture toughness > 1
Objective	Minimize the mass m
Free variables	Radius r of a circular blade (cross section area A) Choice of material

So we need to minimize the mass m. The blade mass is:

m = A * L * ρ = πr^2 * L * ρ

Minimizing the mass requires reducing the cross-section A because L is constant. The blade must still manage the bending load F so required bending stiffness S_required must be at least:

$$S < \frac{CEI}{L^3} = S_{required}$$

where C is constant (depends on the distribution of the loads, not needed). The second moment of area for circular section is:

$$I = \frac{\pi r^4}{4} = \frac{\pi r^2 * \pi r^2}{\pi * 4} = \frac{A^2}{\pi * 4}$$

Next we need to get rid of the free variable r or A. Eliminating r and becoming function of mass (more detailed step-by-step at the end of the report):

$$m = \boxed{\sqrt{\frac{S_r * L^3 * 4 * \pi}{C}} * L} * \frac{\rho}{E^{\frac{1}{2}}}$$

Variables in the box are all specific constants. We are left with material variables. In material science it is more convenient to find maximum value of something. That is why I invert the material property we are searching for:

$$M = \frac{E^{\frac{1}{2}}}{\rho}$$

This is the property we want to maximize. This helps when we are going to search a suitable material from EduPack. For EduPack we are going to make a index line with the slope of 2. That is because the scale is logarithmic and we get the following line equation out of M:

$$E^{\frac{1}{2}} = \rho * M \;\leftrightarrow\; logE^{\frac{1}{2}} = log\rho * logM \;\leftrightarrow\; logE = 2 * log\rho * logM$$

Now we have the following information for choosing the material. It has to have at least 1MPa.m^0.5 fracture toughness and we need to maximize the material property M with the slope 2. We will see these limitations in figure 2.

$\frac{E^{1/2}}{\rho}$

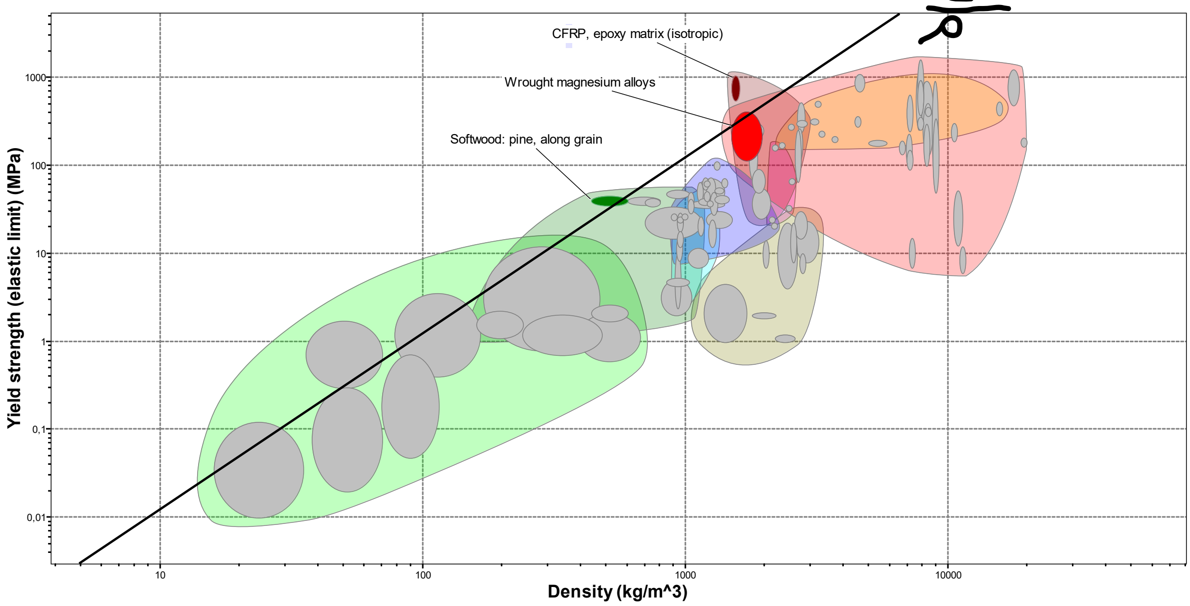

Figure 2. Materials passed the limitation process.

Everything above our selection line could be considered for the blade material. With the selection line we have maximized the material property M. Now we are left with three materials; softwood, wrought magnesium alloys and CFRP. Next through material documentations we select the material for our use. I'll just use quick internet search about those materials.

Softwood

Softwood is used in furniture, boats, flooring, doors… [2]

Magnesium alloys

These alloys are used in welded structures, computer cases, aircraft fuselages, helicopter gears… [3]

CFRP (carbon-fiber-reinforced-polymers)

These polymers are used in wind turbine blades, aerospace, automotive… [4, 5]

Just by quick research we know that CFRP has been used in these kinds of applications. The material I select for the wind turbine blade is therefore CFRP!

Task 1.2

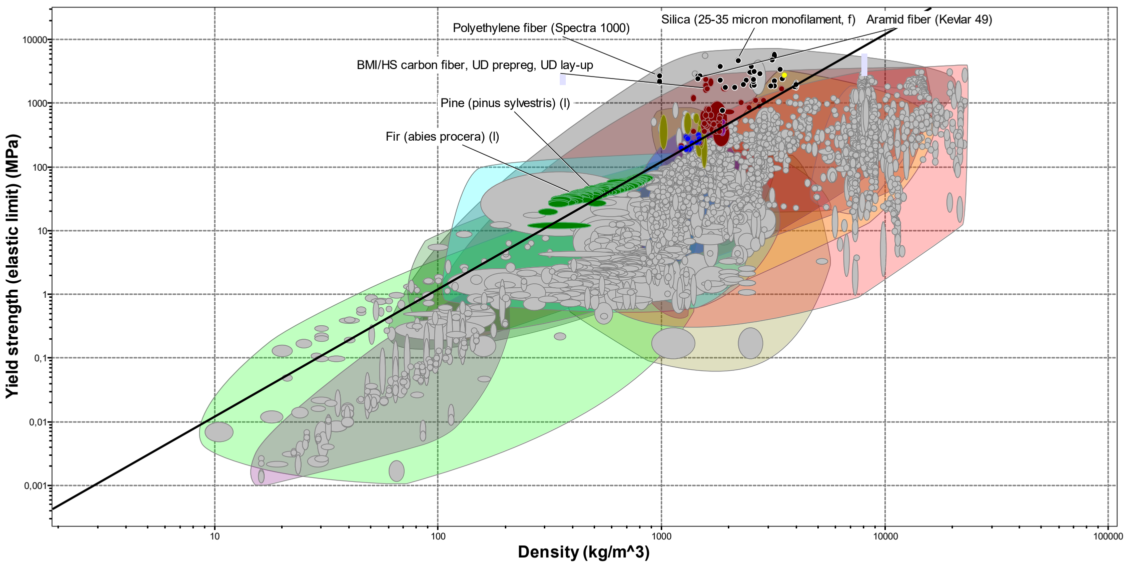

Figure 3. Level 3 selection of materials based on same limitations as in task 1.1.

The biggest difference is clearly the amount of materials. These materials are something you can buy straight from a material seller. In figure 2 there are kind of “material categories”. Just like CFRP. There are many real specific materials that belong into category CFRP which is why there are much more materials presented. Another relevant observation is that in figure 2 the softwood bubble is pretty small but in figure 3 dark green softwood materials are in a much wider range. The same thing is shown with another groups as well.

References

1. Michael Hardy. 2021. New way for making wind turbine blades stronger and sustainable. [Referenced 9/23]. Available at: https://thumbwind.com/2021/12/10/making-wind-turbine-blades/
2. Wikipedia. 2019. Softwood. [Referenced 9/23]. Available at: https://en.wikipedia.org/wiki/Softwood
3. Dr. Dmitri Kopeliovich. 2012. Wrought magnesium alloys. [Referenced 9/23]. Available at: https://www.substech.com/dokuwiki/doku.php?id=wrought_magnesium_alloys
4. Iberdrola. 2023. Wind turbines. [Referenced 9/23]. Available at: https://www.iberdrola.com/sustainability/wind-turbines-blades
5. Wikipedia. 2021. Carbon-fiber-reinforced polymers. [Referenced 9/23]. Available at: https://en.wikipedia.org/wiki/Carbon-fiber-reinforced_polymers

$$\frac{CEI}{L^3} = S_{required} \qquad m = A * L * \rho \qquad I = \frac{\pi r^4}{4} = \frac{\pi r^2 * \pi r^2}{\pi * 4} = \frac{A^2}{\pi * 4}$$

$$S_r = \frac{CE \frac{A^2}{\pi 4}}{L^3} \Leftrightarrow A = \sqrt{\frac{S_r L^3 \pi 4}{C}} \cdot \frac{1}{E^{1/2}}$$

$$m = \sqrt{\frac{S_r L^3 \pi 4}{C}} \cdot \frac{1}{E^{1/2}} \cdot L \cdot \rho$$

$$= \sqrt{\frac{S_r L^3 \pi 4}{C}} \cdot L \cdot \frac{\rho}{E^{1/2}}$$