LMECA2410 – Mechanics of Materials

Material Selection Project

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March 2, 2024

Project Overview

As recent graduates with an Engineering master's degree, We were hired by The BAT company. It aims to design various types of baseball bats to sell to their customers. Our job is to determine which material is best suited for each kind as a function of their field of application.

1 Design of a youth Bat

Our first task is to design a youth baseball bat. Our engineer team oversees finding the most suitable material for the bat. Its design can be simplified as a classical beam of length h and radius r. It will have the following dimensions: length = 700 mm and diameter = 40 mm. You also consider that a player cannot handle a reaction force with the ball larger than 500 N with the bat and that the bat must weigh less than 950 g. The bat must not deform plastically when hitting a ball to keep its initial shape. Additionally, The player must also be able to play outside in sunny and occasional mild rainy condition. Finally, the price of the bat must be kept as low as possible to be affordable by as many players as possible.

1.1 The Cheap Option

For Our Calculations we used the Classical Beam Theory with the critical force being applied at a distance 100 mm from the end, perpendicular to it.

For the choice of bat material, we already know precisely the dimensions and constraints that our material must satisfy.

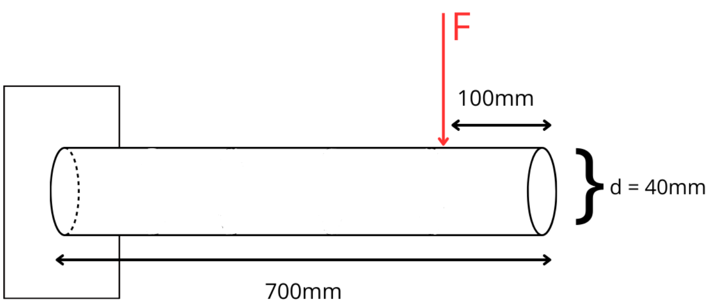

Figure 1: schematic representation of the problem

First constraint : No plastic deformation, we use the pure bending deformation theory,

$$\sigma_{max} = \frac{Mc}{I}$$

M : Moment of force

c : distance from the neutral axis to the extreme fiber

I : Moment of inertia of the cross section

$$\sum F = F_R + F = 0$$

$$F_R = -500[N]$$

$$M_A = M_F$$

$$M_F = 0.6 * 500 = 300[N/m]$$

$$\sigma = \frac{M\frac{d}{2}}{I} = \frac{300\frac{0.04}{2}}{\frac{\pi d^4}{64}} = 47746482.93[Pa]$$

So we need a material with σ_{yield} >= 47746482.93 [Pa]

The second constraint is the mass of the bat so,

$$mass = A * L * \rho = \frac{\pi d^2}{4} * h * \rho$$

Maximum mass allowed for the bat = 950g

$$\rho_{max} = \frac{0.950}{\pi\frac{0.04^2}{4} * 0.7} = 1259.98[kg/m^3]$$

So we need a material with this density: $\rho <= 1259.98[kg/m^3]$

Using the Granta level 3 Database, we can use these criteria as limits to generate and visualize all the materials that satisy this criteria.

In addition to the above criteria, we added a constraint to have materials that work well with limited water use and UV radiation

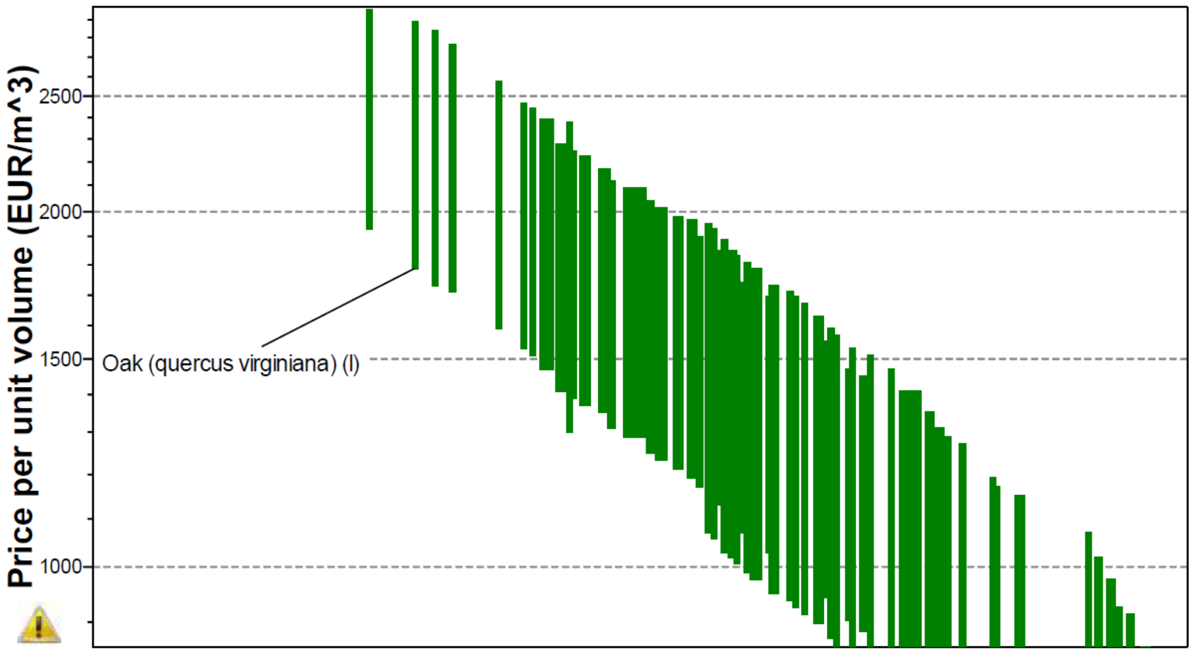

Figure 2: Wood Materials

From the many materials available we selected chose wood materials because they have better aestethics and durability. We chose Oak for our bat because it is very accessible to get and easy to work with in the carpentry. This material has been used before to manufacture bats.

1.2 Other Considerations

When we added some environmental considerations like the use of recycled materials that are also biodegradable, the choice of material this time was plastics. We chose PLA for our project as it is very accessible to get and works well with many manufacturing processes including 3D printing which makes our production more flexible for also prototyping. PLA will be slightly more expensive but it will be lighter and for indoor use it is very reliable.

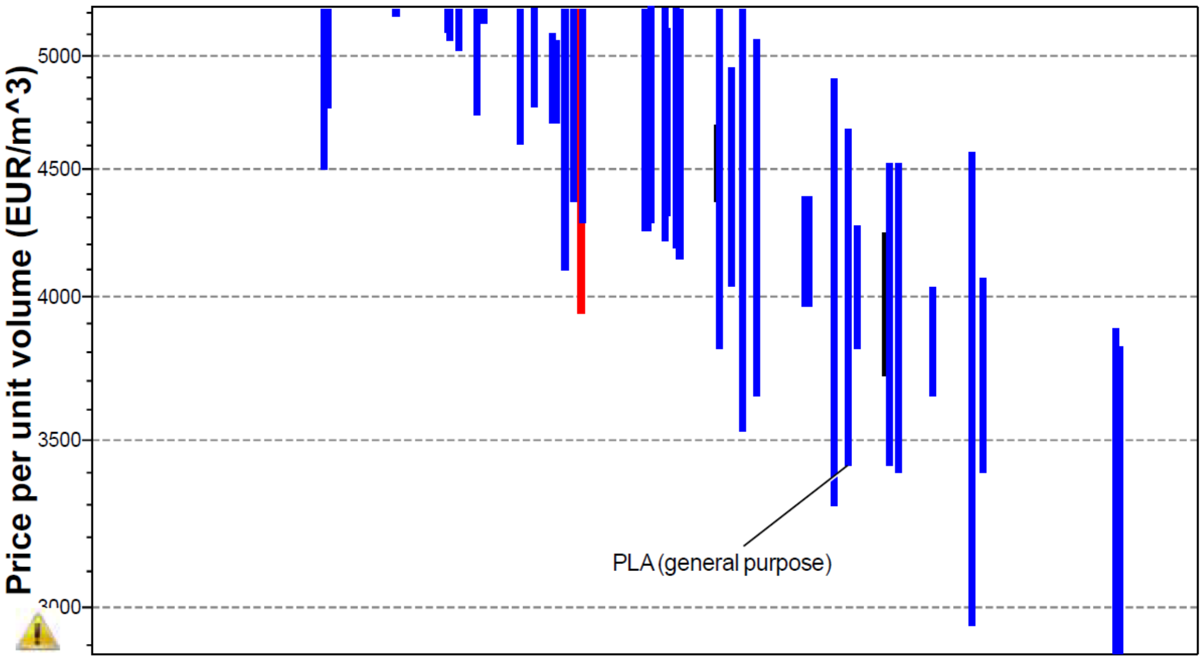

Figure 3: Plastic Materials

2 Design of an Athlete Bat

Our new task is to redesign the bat used by athletes for the next league with a focus on minimizing mass.

2.1 Initial Design

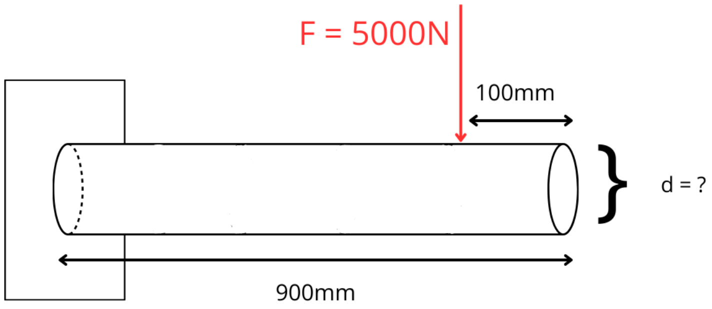

Figure 4: schematic representation of the problem

It is stated in the baseball rules that the length of the bat must be 900 mm. No specification is mentioned about its diameter. Once again, the bat cannot deform plastically under the

force of 5 kN applied by the athlete. The objective here is to minimize the weight of the bat to allow the athletes to execute a hit as fast as possible.
This bat must be durable, athletes do not want it to be replaced after each match. To ensure that, you define a minimum fatigue strength at $10^7 cycles$ of $30MPa$ and a minimum toughness of $3kJ/m2$.

For our calculations we used bending deformation using classical beam theory as in our first design,

$$M_F = F * d = 0.8 * 5000 = 4000[N/m]$$

$$\sigma = \frac{M\frac{d}{2}}{I} = \frac{4000\frac{d}{2}}{\frac{\pi d^4}{64}}$$

$$\sigma_{max} = \frac{128000}{\pi d^3}$$

$$d = (\frac{128000}{\sigma_y \pi})^{\frac{1}{3}}$$

For the mass we have:

$$m = A * L * \rho = \frac{\pi d^2}{4} * h * \rho$$

$$m = 0.225 * \pi * (\frac{128000}{\pi})^{\frac{2}{3}} * \frac{\rho}{\sigma^{\frac{2}{3}}}$$

Minimize the mass of the bat is equivalent to minimize the $\frac{\rho}{\sigma^{\frac{2}{3}}}$ term or maximize it's invert.

Using the Granta level 3 Data we put in the constraints of required toughness and Fatigue strength to generate the materials that can satisy our applications. The Materials we got were grouped in Plastics, Metals and Alloys, Composites and Steels.

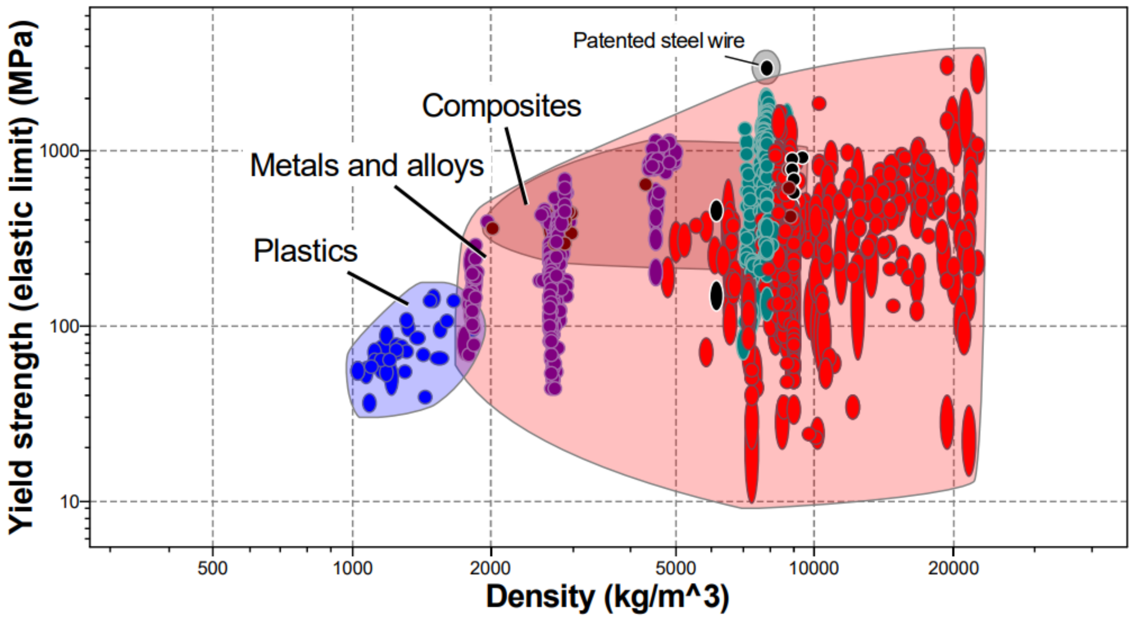

Figure 5: Yield strength (elastic limit) (MPa) vs. Density (kg/m^3)

As our goal was to minimize the weight, we chose the material with the least desnity from all the material groups but we also made considerations of the yield strength as durability was very important too.

Below are the materials we chose fror every group.

- In Plastics we chose COC and it has the least mass in all our choices and is relatively durable.
- In Metals Magnesium, Elektron ZW3 was the best choice as it had low density but also relatively higher yield strength which makes it very durable comoared to the plastics.
- In the composites we chose the Mg-12 SiC(p) material it had a low density and an an even larger yield strength which makes it very durable and in the end this was our preffered choice for the material
- We didn't consider steels as they were so heavy and therefore defeated the purpose of our design

The Selections are visualized in the graph below

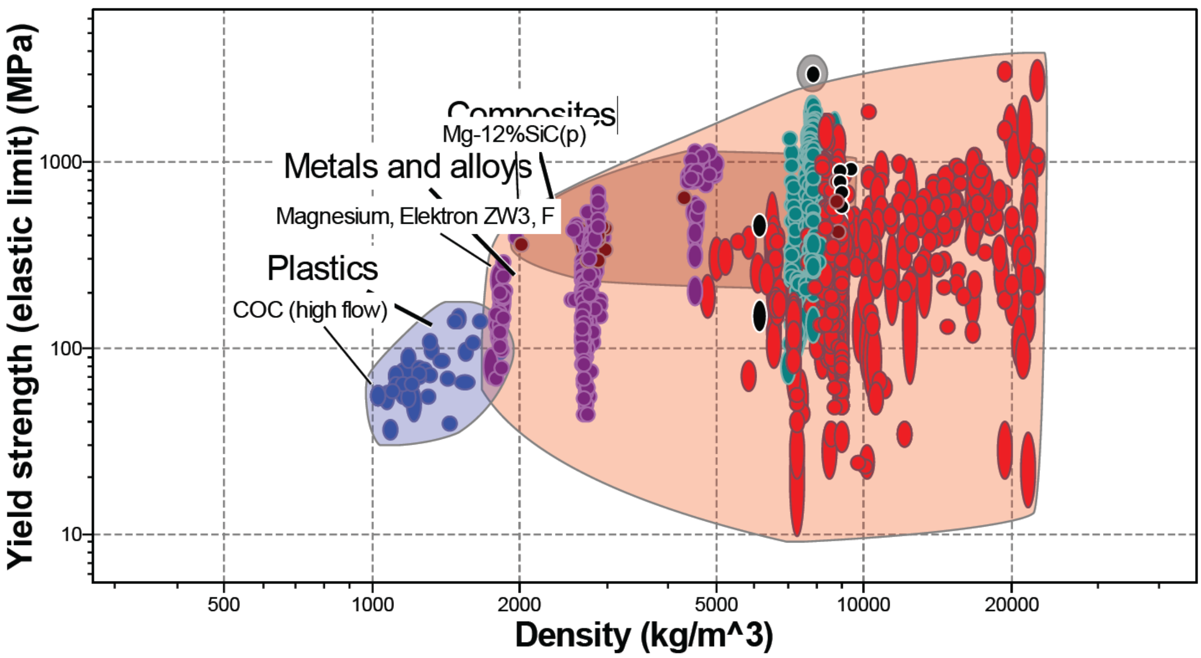

Figure 6: Material Selection

2.2 Axial Loading Consideration

To go further with our design, we assume that the bat can also be subject to axial loading when falling on the ground. As a result, the bat must have at least 5 kN of axial stiffness. To find the most suitable material for this bat we used two indices and a coupling constant for our calculations.

Axial Stiffness is defined as :

$$k = \frac{F}{\delta} = \frac{EA}{L}$$

So,

$$A = \frac{K * L}{E}$$

where:

F is the axial force applied to the member,

δ is the axial deformation (change in length) of the member,

E is the elastic modulus of the material,

A is the cross-sectional area of the member, L is the original length of the member.

$$m = \rho * A * L = \rho * \frac{KL}{E} * L$$
$$m = L^2 * K * (\frac{\rho}{E})$$

So to minimize the total mass we need to minimize $\frac{\rho}{E}$ or maximize it's invert.

Now we need to calculate the coupling constant,

$$m_1 = 836.96 * \frac{\rho}{\sigma^{\frac{2}{3}}}$$

$$M1 = \frac{\rho}{\sigma^{\frac{2}{3}}}$$
$$m_2 = L^2 * K * (\frac{\rho}{E})$$
$$M2 = \frac{\rho}{E}$$

And so,to make the link between M1 and M2 we find :

$$836.96 * \frac{\rho}{\sigma^{\frac{2}{3}}} = L^2 * K * \frac{\rho}{E}$$

$$\log{(M1)} = \log{(M2)} + \log{(\frac{L^2 * K}{836.96})}$$

With the Coupling constant:

$$C = \log{(\frac{L^2 * K}{836.96})} = 0.685$$

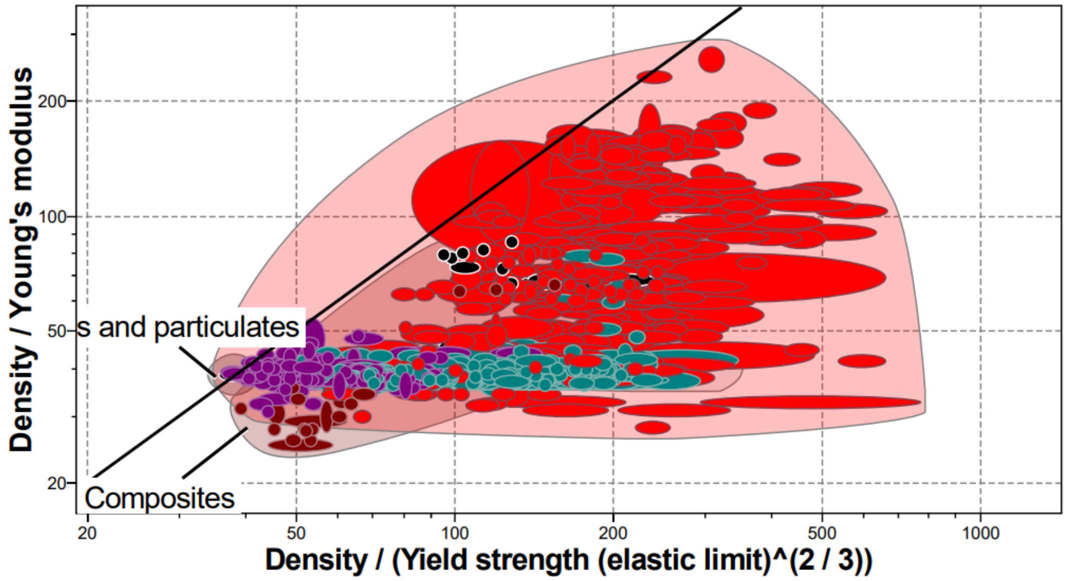

Figure 7: Material Selection for the Professional Bat

Several families of materials are suitable for our bat. We need to minimize M1 and M2 therefore we focus on the elements at the bottom left of the graph.

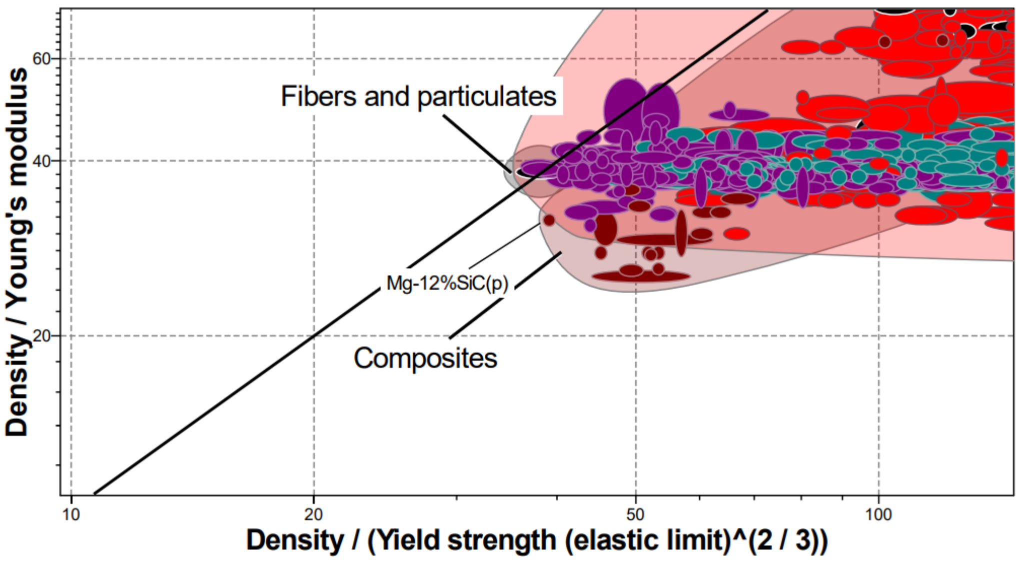

Figure 8: Focus on material selection for the Professional Bat

As we can see, composite materials are best suited to our different specifications and limitations. Our choice ultimately falls on the MG12-SiC(p) due to its very light weight and its relatively good mechanical strength $\sigma_{yield} = 370$ MPA. An aluminum alloy could also have been suitable because his yield strength is 500 MPA but it is significantly heavier than our alloy which justifies our choice. Finally, the diameter of or bat with the MG12-SiC(p) material, must be at least 4,8cm to avoid elastic deformation compare to the allumium alloy with a minimum diameter of 4,43cm, it's negligeable compare to the difference of mass between the two materials. We have a bat of 3,25kg for the MG-SiC(p) and 3,72kg for alluminium alloy !