Materials Selection

Excercises Unit 1

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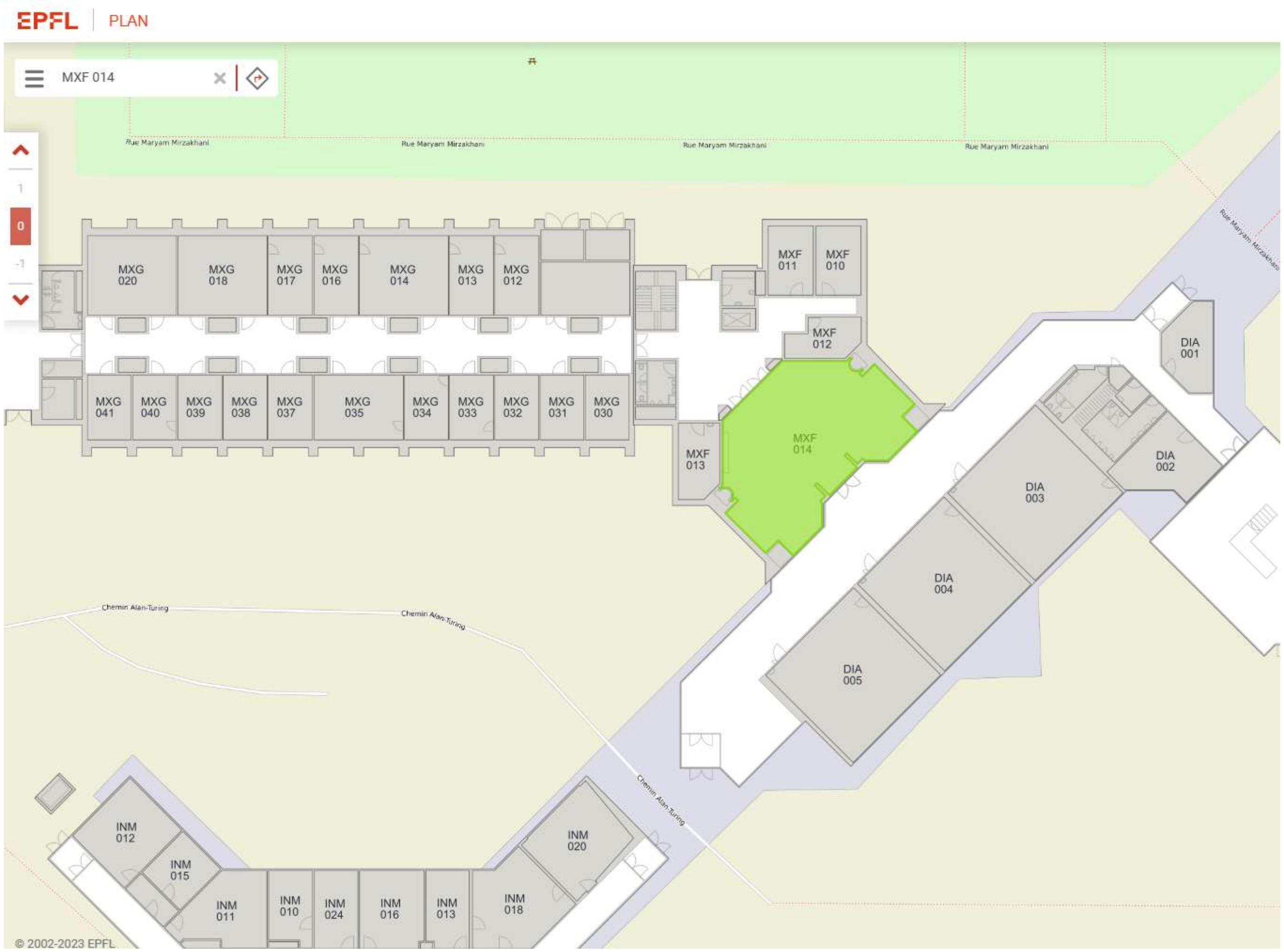
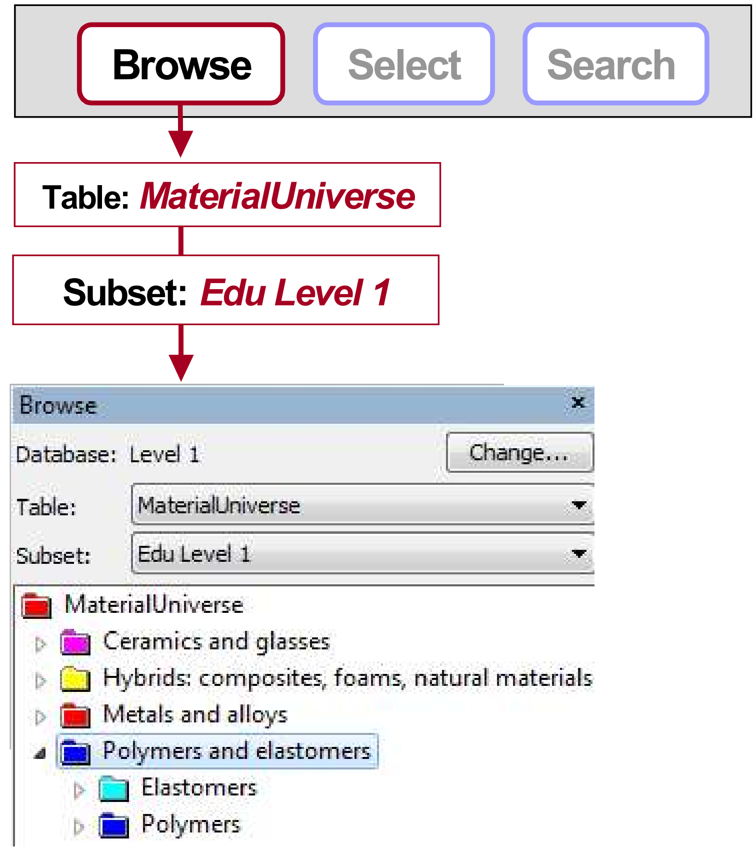
Exercises:

in room MXF 014



Browsing

1.1 Find the *Level 1* record for ***Polyester*** in Polymers and elastomers: Thermosets



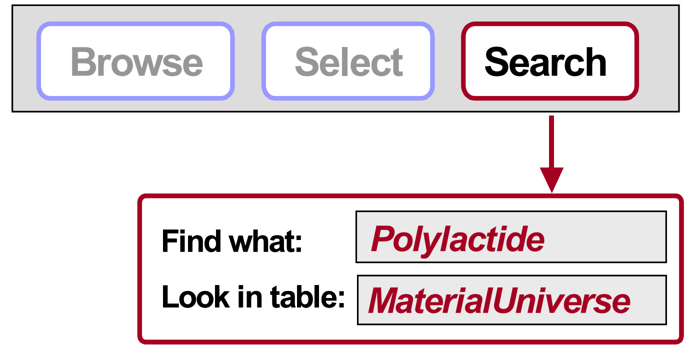
Searching

1.2 Find, by searching, the record for ***Polylactide***: What is it (Level3)?

Answer: Polylactide, PLA, is a biodegradable polyester derived from renewable maize / corn.

1.3 Find records for materials that are used for ***Lenses***: What are they made of (Level1)?

Answer: Silica glass, Cellulose polymers (CA), Silicon, Soda-lime glass, Polystyrene (PS), Polyamides (Nylons, PA), and Polycarbonate (PC).



Exploring the science

1.4 How is ***Fracture Toughness*** measured?

Answer: ***Definition and measurement.***
The fracture toughness, K1c, (units: MPa $m^{1/2}$ or $MN/m^{1/2}$) measures the resistance of a material to the propagation of a crack. It is measured by loading a sample containing a deliberately-introduced contained crack of length   or a surface crack of length (Figure 1), recording the tensile stress   or the bending load at which the crack suddenly propagates.

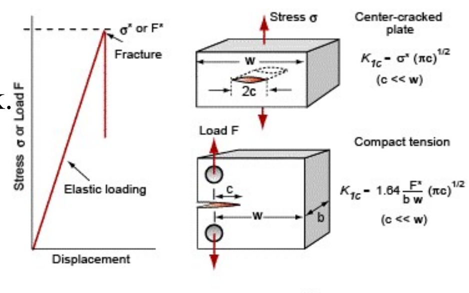


Figure 1. Measuring fracture toughness, K_{1c}.

Mechanical properties
- Young's modulus
- Fracture toughness
- ……..

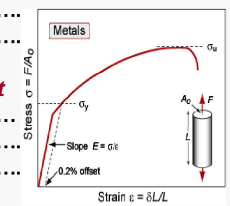
Thermal properties
- Thermal conductivity
- Maximum use temperature
- ……..

Electrical properties
- Electrical conductivity
- Dielectric strength
- ……..

Eco properties
- Embodied energy
- CO_2 footprint
- ……..

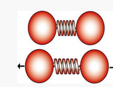
Young's modulus

Definition……………………………….
……………………………………………
…………………
…………………



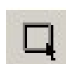
Measurement
…………………
…………………
…………………

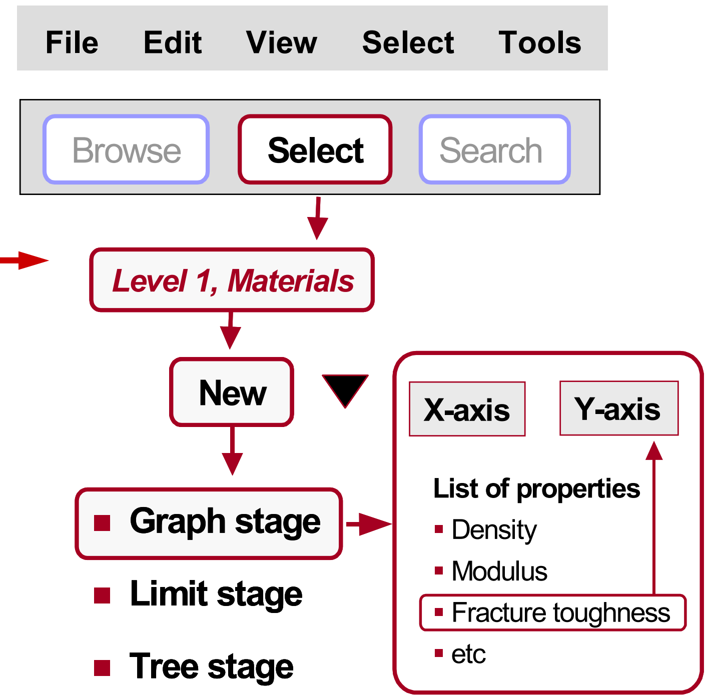
Origins
…………………
…………………
…………………



Making bar charts

1.5 Make a bar chart with ***Fracture toughness*** on the Y-axis using Level 1, Materials

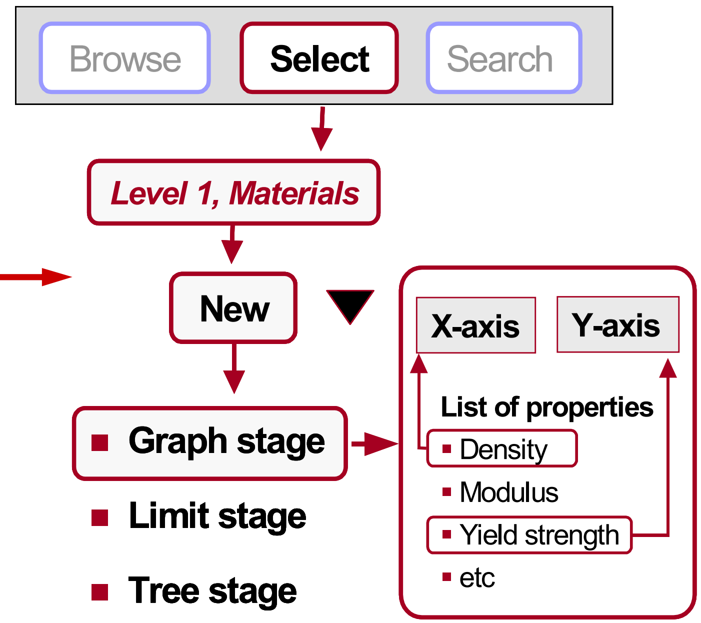
- Click on **Select** and proceed as shown opposite
- Label two (or more) materials by clicking on the bars.
- Find the bar for **Magnesium alloys** (right click on name in Browse and select "Highlight").
- Change the name to **Mg-alloys** and make the font larger (right click on name on the bar chart and select "Rename" to change the name and "Format" to change font size, colour etc.).
- Use the BOX selection tool  to find the four materials with the highest values of fracture toughness. (Answer: Low alloy steels, Nickel alloys, Stainless steels, Titanium alloys).
- Change the UNITS from Metric to Imperial or *vice versa* (Settings – Units – US Imperial / Metric)



Making bubble charts

1.6 Make a bubble chart with ***Density*** on the X-axis and ***Yield strength*** on the Y-axis using Level 1, Materials settings

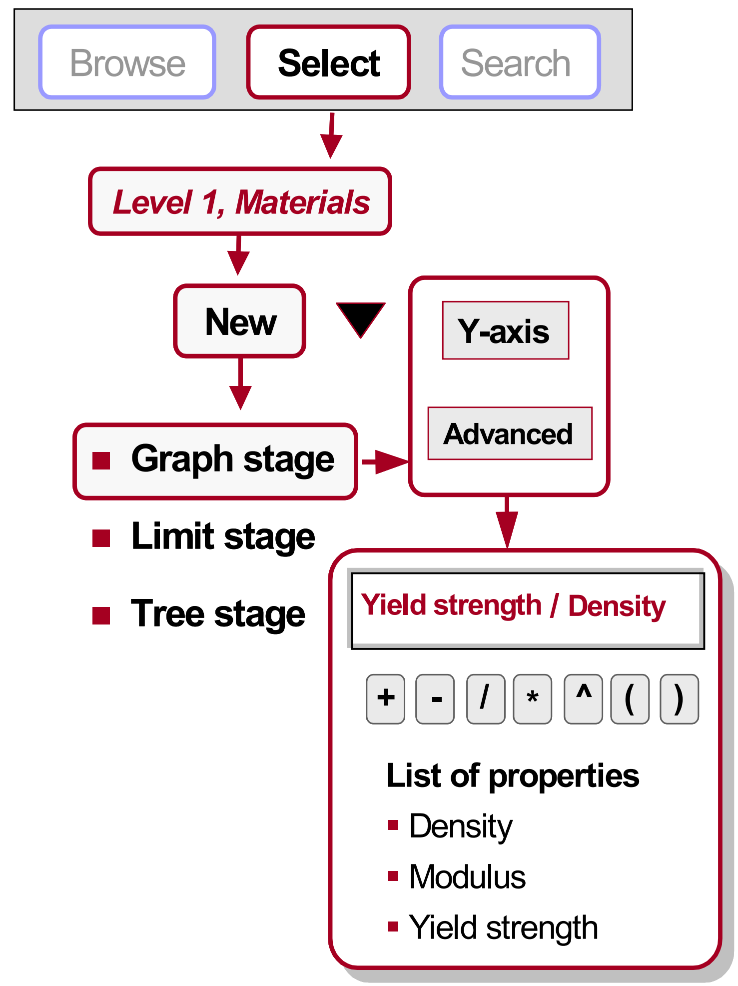
- Click on **Select** and proceed as shown opposite
- Label two (or more) material by clicking on the bars.
- Switch on the envelopes
- 2.2a) Do any metals have yield strength less than 10 MPa (2 kpsi)?
- 2.2b) Use the BOX selection tool to find materials with a yield strength larger than 600 MPa (90 kpsi) and a density less than 2000 kg/m^3 (120 lbs/cubic ft).
- 2.2c) Discriminate data with “line slope”: Find metallic materials with highest fracture toughness per density.



Making functions of properties

1.7 Make a bar chart with ***Yield strength / Density*** on the Y-axis using Level 1, Materials

- Label the axis “Yield strength/Density”
- Which two materials have the highest values?



Selecting light, strong materials (1)

4.1 The material index for selecting light strong materials is

$$M = \sigma_y / \rho$$

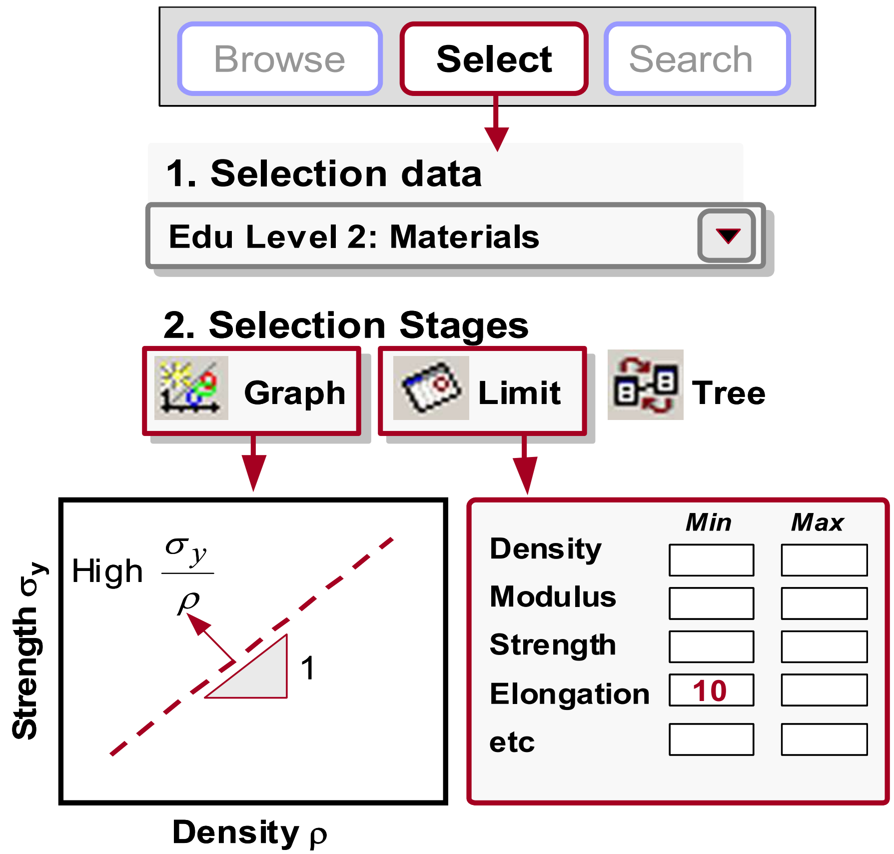
where σ_y is the yield strength and ρ the density.

- Make a Graph stage with these two properties as axes
- Impose a selection line (slope 1) to find materials with the highest values of M.
- Add a Limit stage to impose the additional constraint:

  Elongation > 10%

Results: Difficult to obtain

- ✓ Age-hardening wrought Al-alloys
- ✓ Nickel-based superalloys
- ✓ Titanium alloys
- ✓ Wrought magnesium alloys



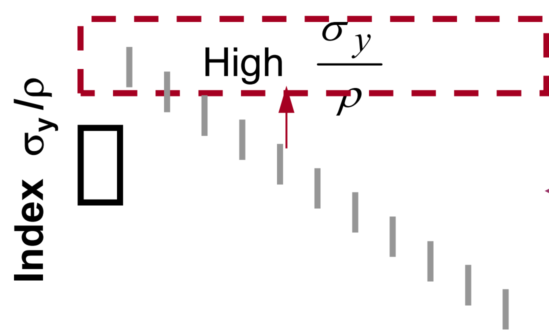
Selecting light, strong materials (2)

4.2 Repeat the selection of 4.1, but use the Advanced facility to make a bar-chart with the index

$$M = \sigma_y / \rho$$

on the Y-axis.

- Impose a Box selection to find materials with the highest values of M.
- Add a Limit stage to impose the additional constraint: Elongation > 10%



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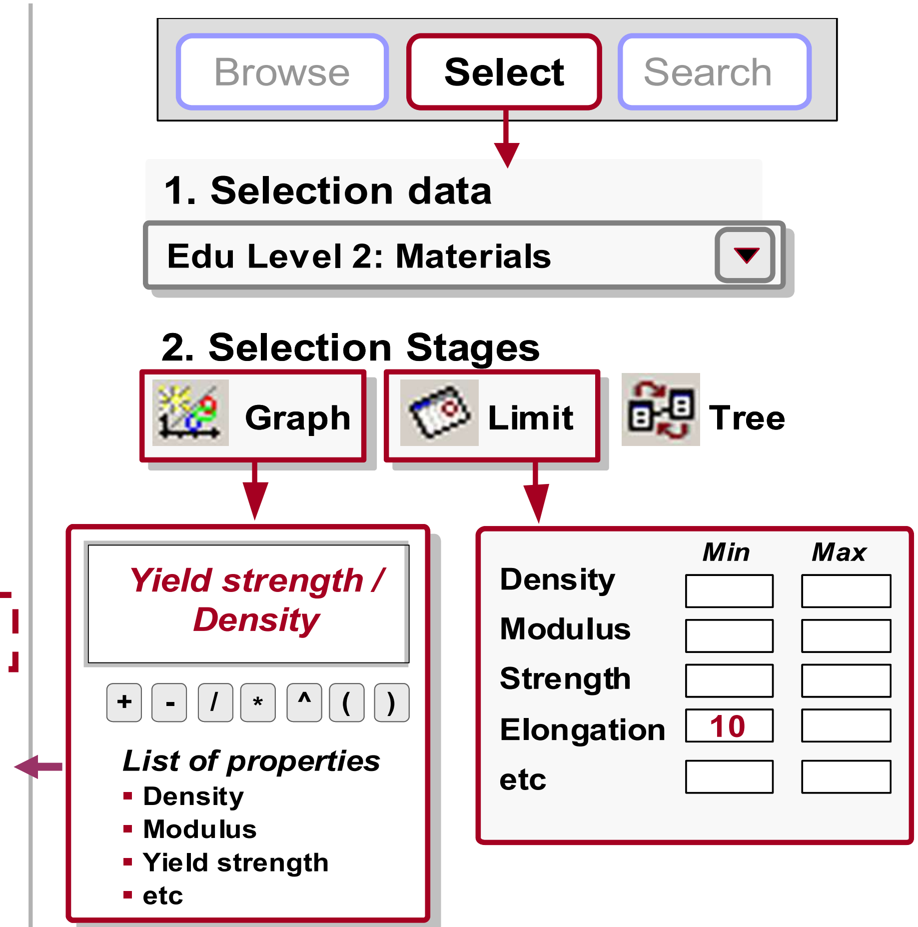
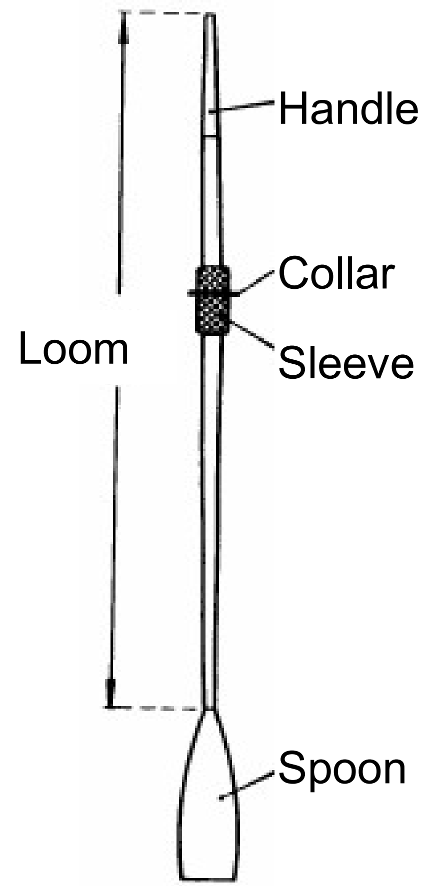


Materials for oars

Specification

Function	Light, stiff beam
Objectives	Minimum weight
Constraints	• Length specified • Stiffness *S* specified • Cost within reason • Toughness adequate
Free variables	• Cross-section area • Material

Oars are stiffness-limited, minimum weight, designs



Materials for oars

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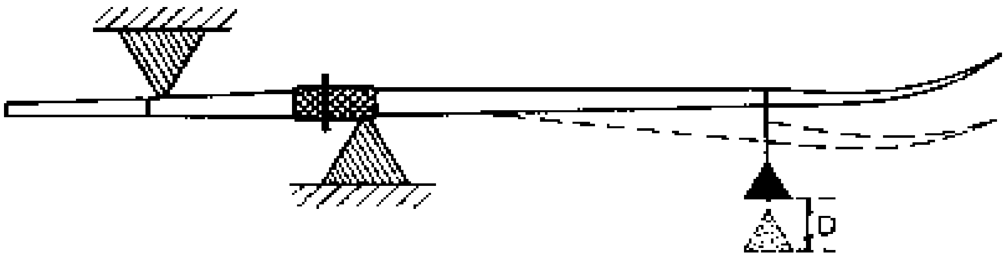


Mass m of the oar – assuming a solid cylinder - is

$$m = AL\rho = \pi R^2 L\rho$$

Knowing that :

$$\left.\begin{aligned} S &= \frac{CEI}{L^3} \\ \text{where} \quad I &= \frac{\pi R^4}{4} \end{aligned}\right\} \Rightarrow m = 2\left(\frac{\pi S L^5}{C}\right)^{1/2}\left(\frac{\rho}{E^{1/2}}\right)$$

Materials for oars

Material index, set by objective

Minimise $M_1 = \frac{\rho}{E^{1/2}}$

Density (→ ρ)

Modulus (→ E)

Material limits, set by constraints

Shock-resistance requires not only the fracture toughness *(K_{Ic})* must be adequate but also the toughness (G_c)

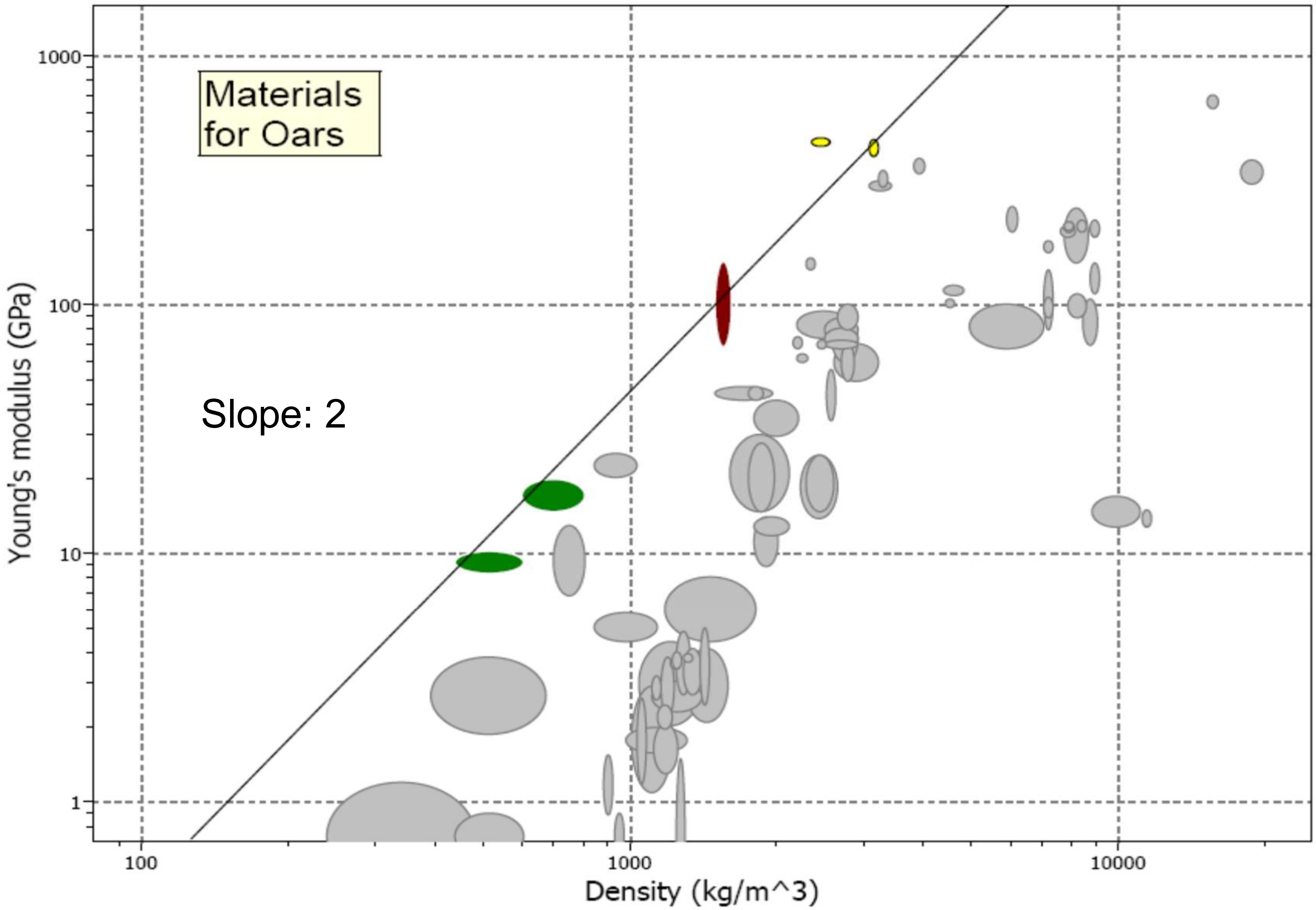
$$G_c = \frac{K_{Ic}^2}{E} \geq 1\ kJ/m^2$$

Cost of the material must be reasonable

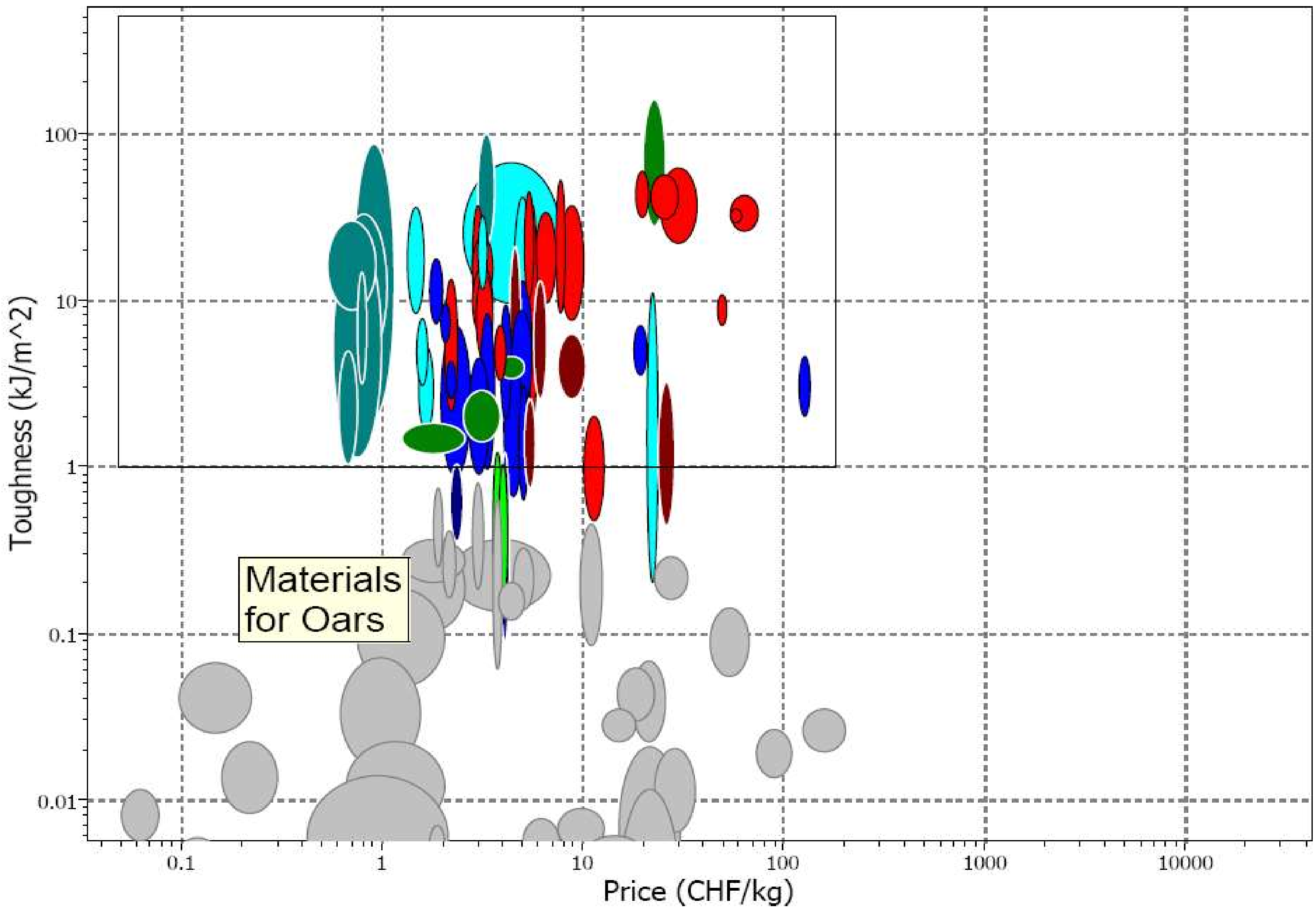
C_m < 100 CHF/kg

Use the graphical box tool to apply both constraints. Implement the toughness on the Y-axis using the advanced function to calculate the toughness

Solutions - Materials for oars -- CES chart



Solutions - Materials for oars -- CES chart



Oars: Conclusions

Now we know what oars *should* be made of. What, in reality, is used? Racing oars and sculls are made of wood or of a high performance composite: carbon-fiber reinforced epoxy, CFRP.

Wooden oars are made today, as they were 100 years ago, by craftsmen working largely by hand. The wood is cut into strips, four of which are laminated together to average the stiffness. The final spruce oar weighs between 4 and 4.3 kg, and costs (in 1994) about CHF 325.
Composite blades are a little lighter than wood, for the same stiffness. The advantage of composites lies partly in the saving of weight (typical weight: 3.9 kg) and partly in the greater control of performance: the shaft is molded to give the stiffness specified by the purchaser. At a price, of course: a CFRP oar costs about CHF 750.