Aalto University
School of Engineering

Selection of Engineering Materials

Task 1

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Problem Statement

Task 1.1

Read the case study 6.2 “Materials for Oars” from the textbook.

Now follow the same method to choose one material from the material group listed below for a wind turbine blade. In the simplest case, the blade is a beam in bending. It should be as light as possible and have a given bending stiffness.

- -First, define the **design requirements** in a table, including functions, constraints, objectives, and free variables, etc.
- Secondly, derive the formula for the material performance index from the performance objective. Note that the **derivation** (step-by-step) of the material performance index **must** be included in your report.
- Then draw the **maps** with level 2 and explain what the correct material **selection lines** are for this task.

Solution

For this assignment, I have taken the wind turbine blade to be a cantilever beam loaded at the tip (Harrison M, 2018). I have assumed a square cross-section for the beam for simplicity as it will impact several mathematical parameters in the derivation. The entire working onward is based on this assumption.

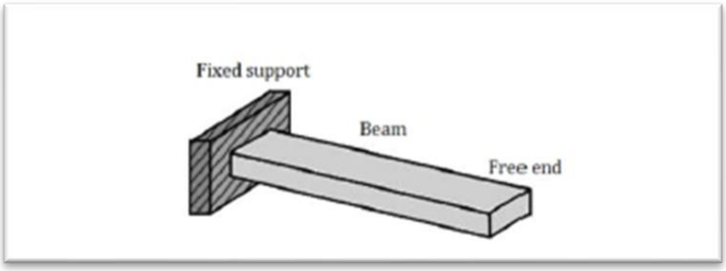


Figure 1: A cantilever beam

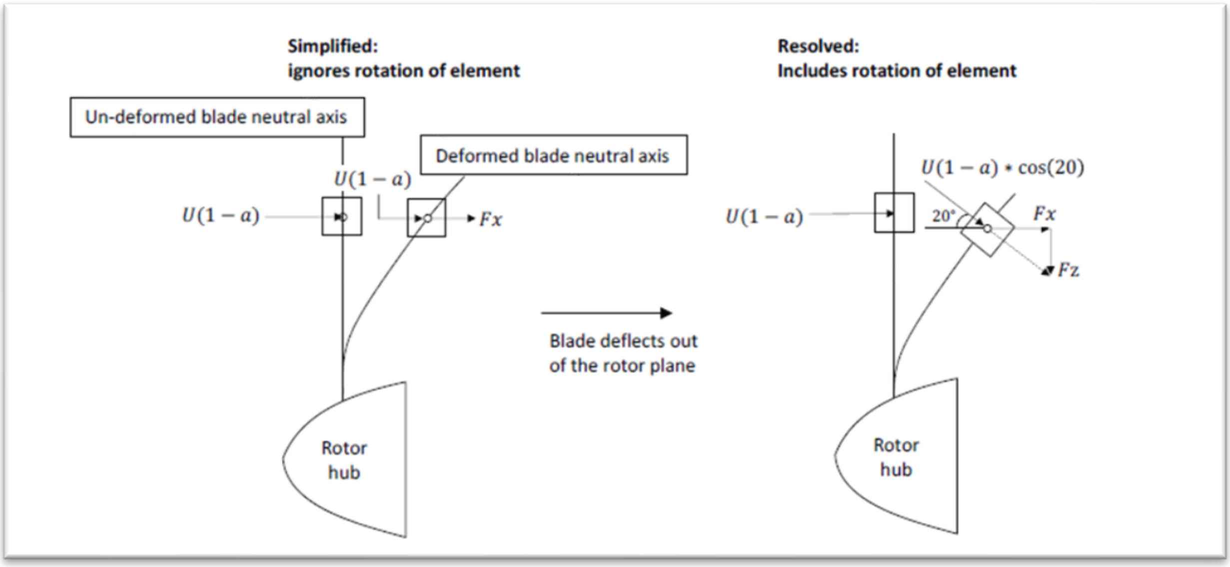


Figure 2: Wind turbine under loading. Added for showing similarity to a cantilever beam.

Design Requirements

Function	Wind turbine blade – light weight and stiff
Constraints	• Length is specified. • Bending stiffness is specified.
Objectives	Minimize the mass 'm'
Free Variables	• Area • Material

Material Performance index

Since mass 'm' is the quantity that needs to minimized, hence the relation we will use for it is:

$$Density = mass/volume$$

$$m = \rho/V$$

$$m = \rho * A * L$$

$$m = \rho * b^2 * L$$

As we are dealing with a cantilever beam, therefore its relation for stiffness is;

$$\mathrm{S} = \frac{\mathrm{c_2} * \mathrm{EI}}{\mathrm{L}^3}$$

where C_2 is a constant and cis different for each loading situation.

The second moment of area I for square cross-section is;

$$I = \frac{bh^3}{12}$$

Since all sides are equal in a square, b=h

$$I = \frac{b^4}{12}$$

Plugging in the value of second moment of area in stiffness equation

$$S = \frac{C_2 * Eb^4}{12L^3}$$

$$b^4 = \frac{S * 12L^3}{C_2 * E}$$

$$b^2 = \sqrt[2]{\frac{S * 12L^3}{C_2 * E}}$$

Plugging this value in equation of mass ‘m’

$$m = \rho * \sqrt[2]{\frac{S * 12L^3}{C_2 * E}} * L$$

$$m = \sqrt[2]{\frac{S * 12L^3}{C_2 * E}} * L * \frac{\rho}{E^{\frac{1}{2}}}$$

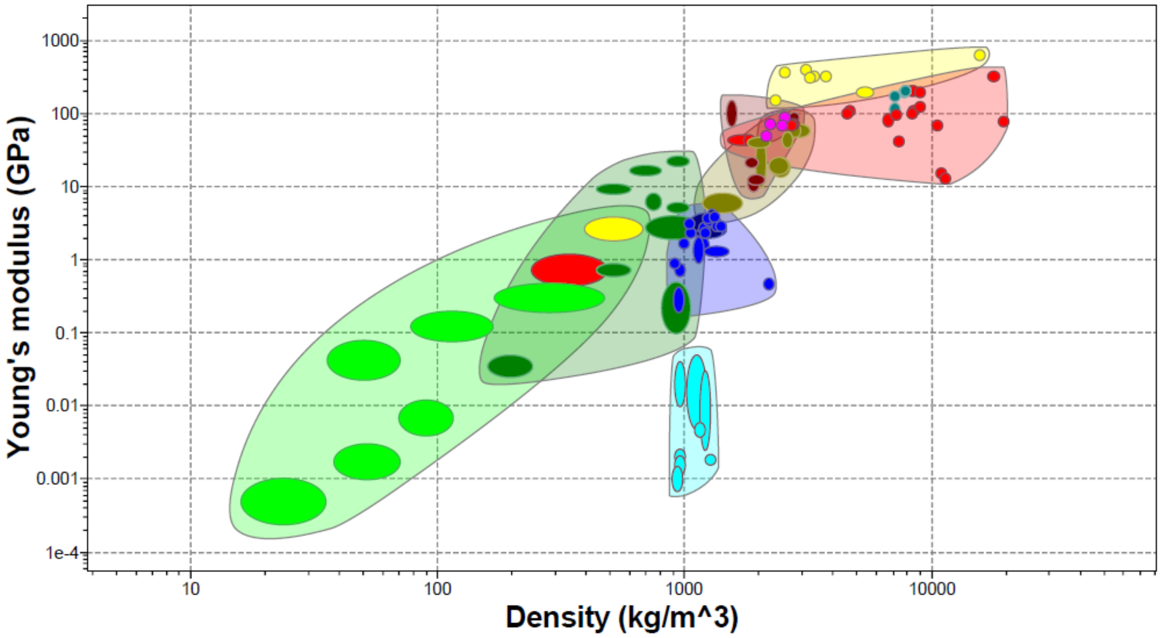
The quantities S, L, and C_2 are all specified or constant; the best materials for a light, stiff beams are those with the largest values of index M (Material Performance Index), where

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

Young’s modulus and density will be plotted on logarithmic scales. Hence the relationship becomes.

$$(M * \rho)^2 = E$$
$$log\, E = 2\, log\, \rho * 2\, log\, M$$

Charts



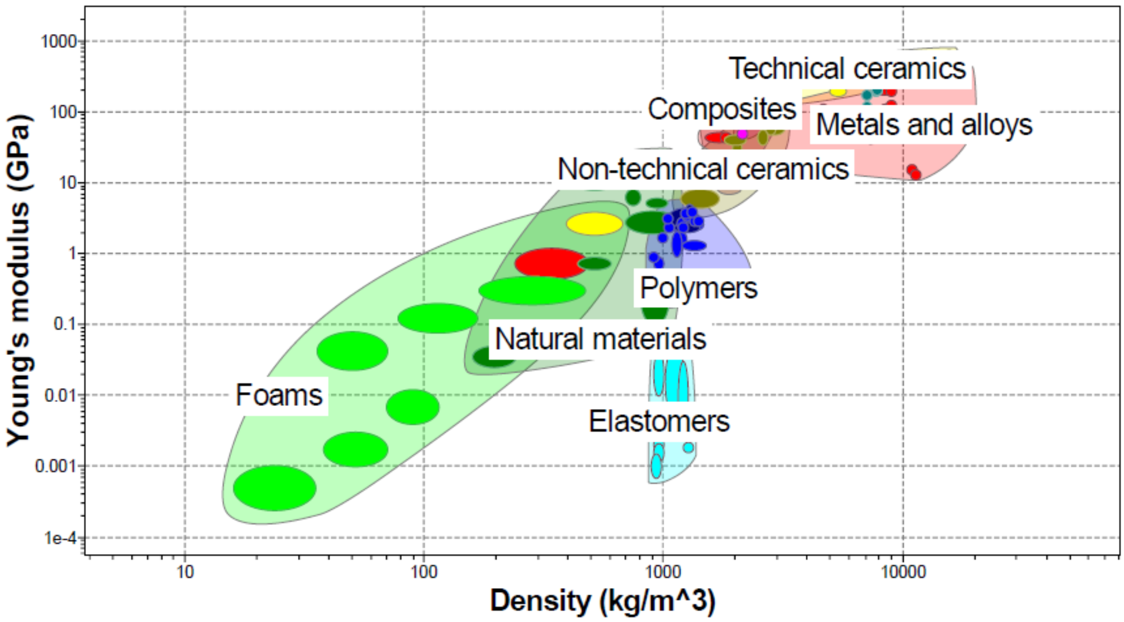


Figure 3: Young's Modulus vs Density graph without the application of performance perimeters.

This graph has been plotted at level 2. As we are interested in a specific range of materials. This range will be specified by our performance index (M).
After observing the trend in different research papers, I have come to conclusion that I need another performance parameter for systematically shortlisting material. For this I have chosen Young's modulus to be a minimum of 70 GPa (Gutub, 2013).

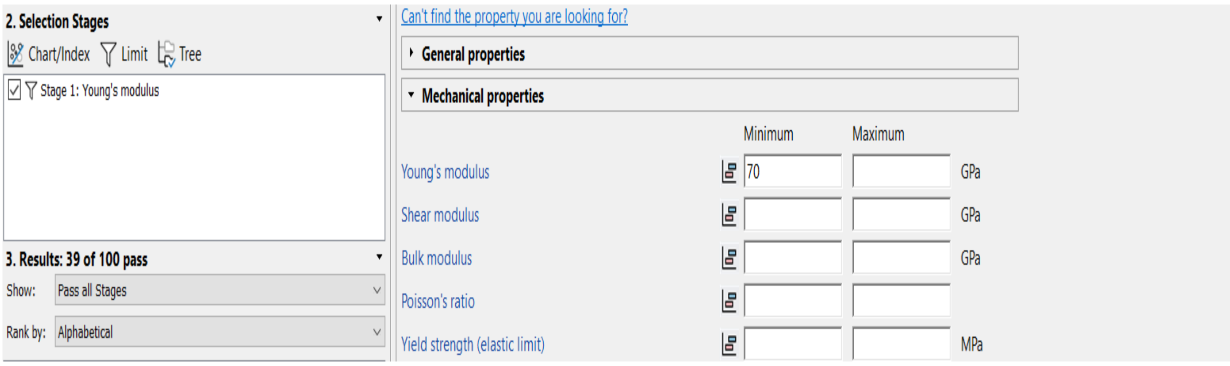


Figure 4: Application of minimum value of young's modulus to the chart

As shown in the snippet, after applying the limit of 70 GPa on the existing chart, materials get shortlisted from 100 to 39.

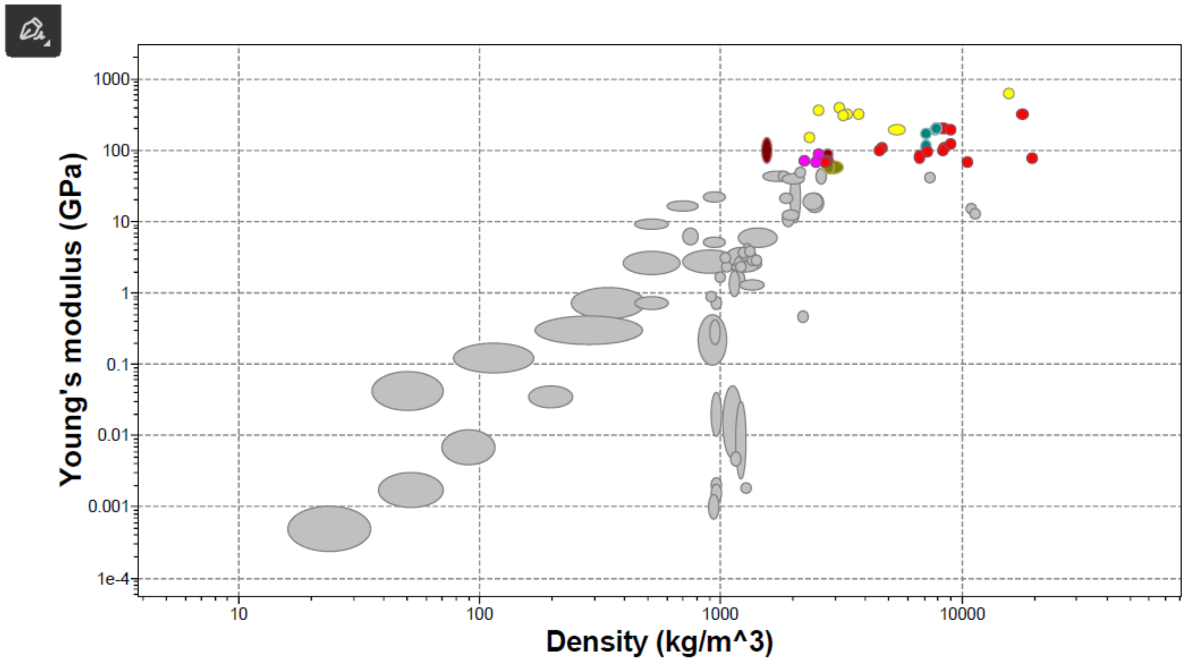
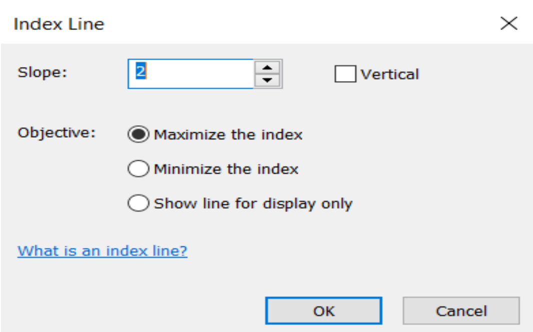
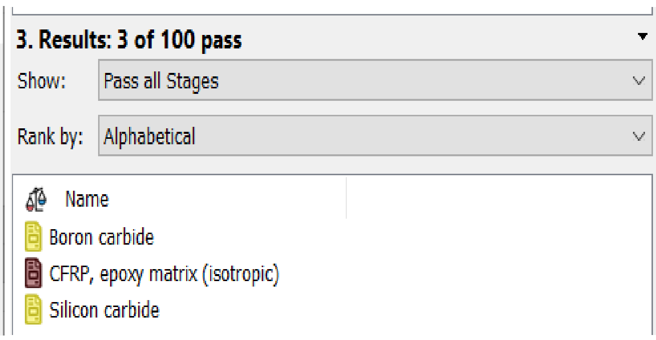


Figure 5: Application of Young's Modulus as a limiting parameter.

Now I will apply the performance index 'M' to the chart to further shortlist materials with slope of 2 as derived from logarithmic equation.





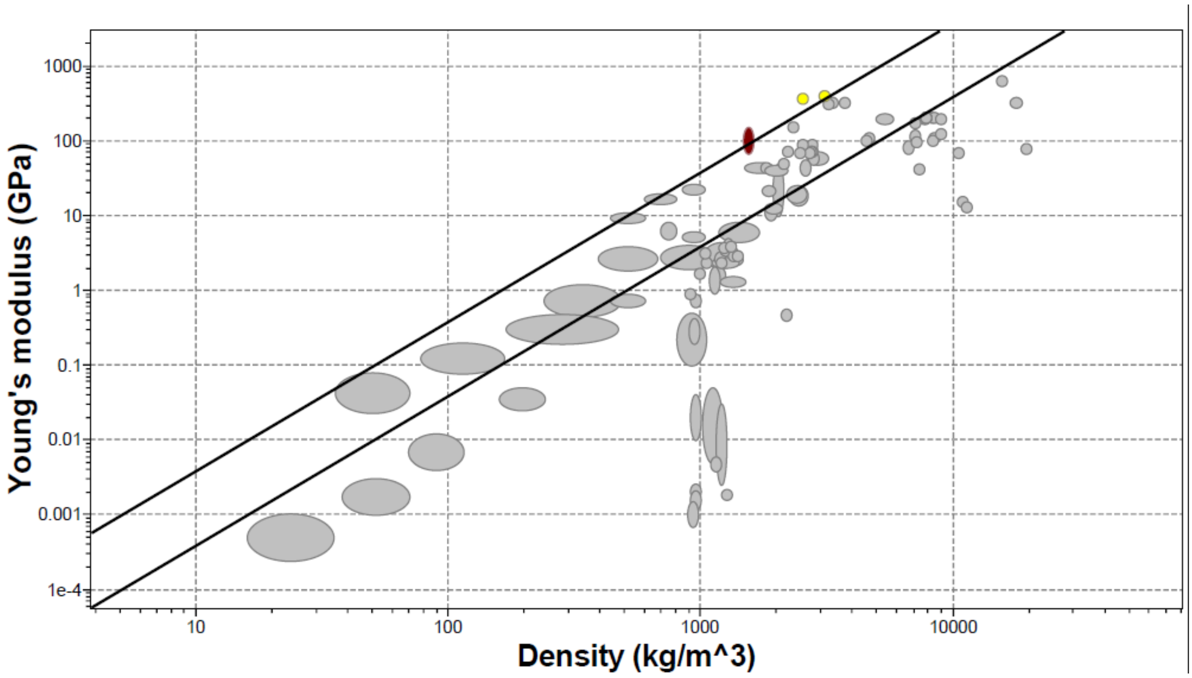


Figure 6: Material selection charts after the application of material performance index.

After the application of material performance index, only three sub families have been shortlisted. These are boron carbide, CFRP and silicon carbide.

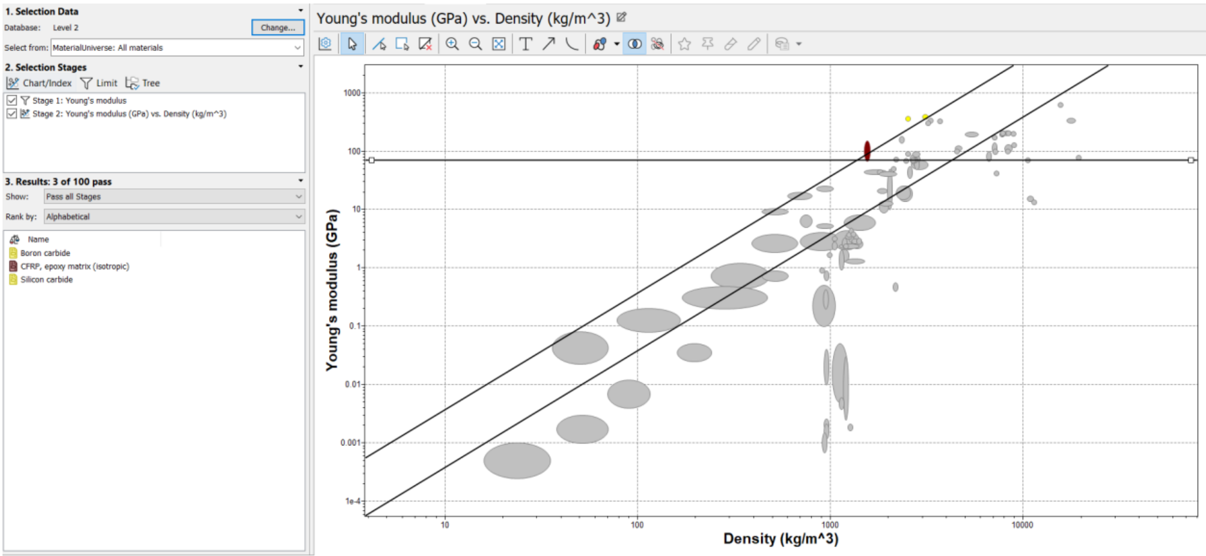


Figure 7: Complete graph after the application horizontal line that corresponds to 70GPa Young's Modulus.

It can be seen, that the material performance indices have helped in shortlisting from 100 materials to 3 materials which can be studied in detail by the user.

Task 1.2:

Level 3 Database

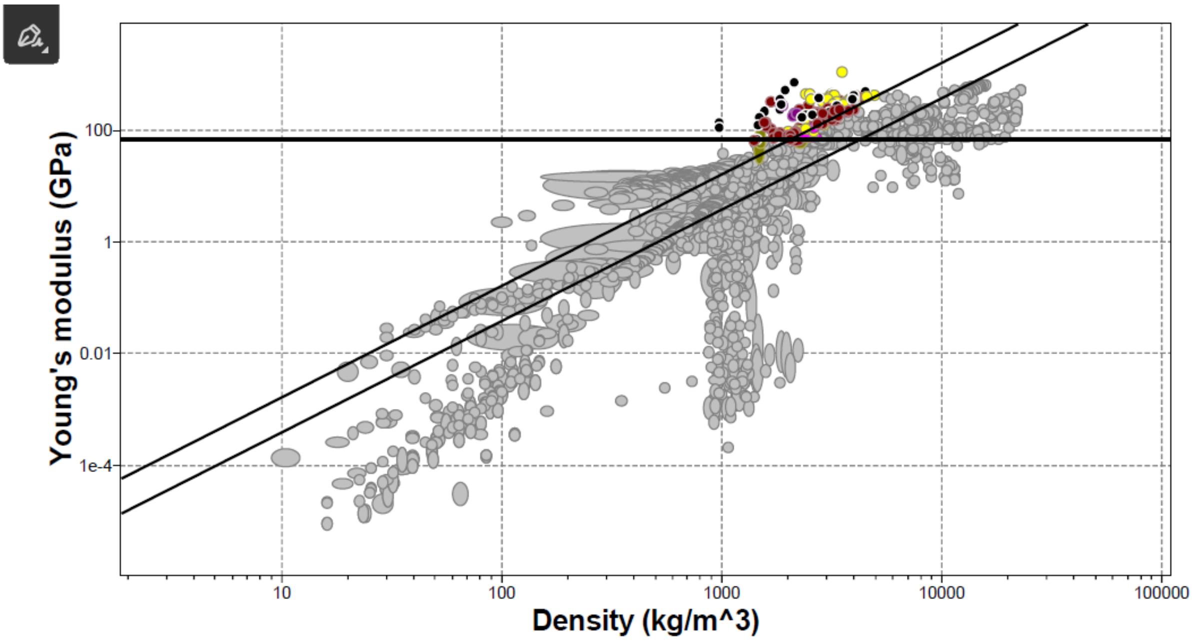


Figure 8: Level 3 database of previously selected performance index and property limits.

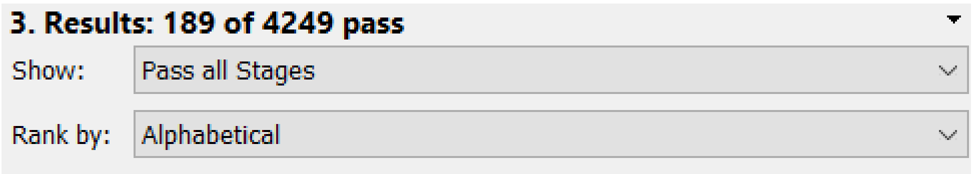
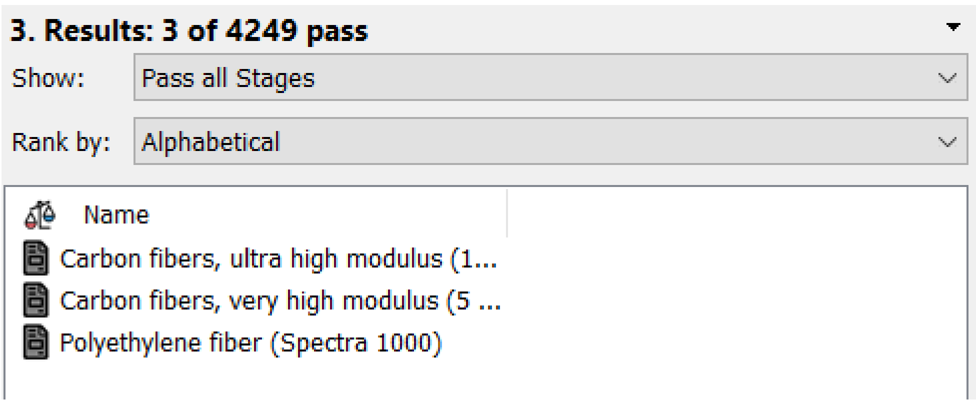


Figure 9: Level 3 databse amount of shortlisted material.

Observations:

After switching to level 3 database, I have observed that about 189 more materials were shortlisted as compared to the previous level 2 database. Hence, it can be surmised that level 3 data base has more material catalogues.



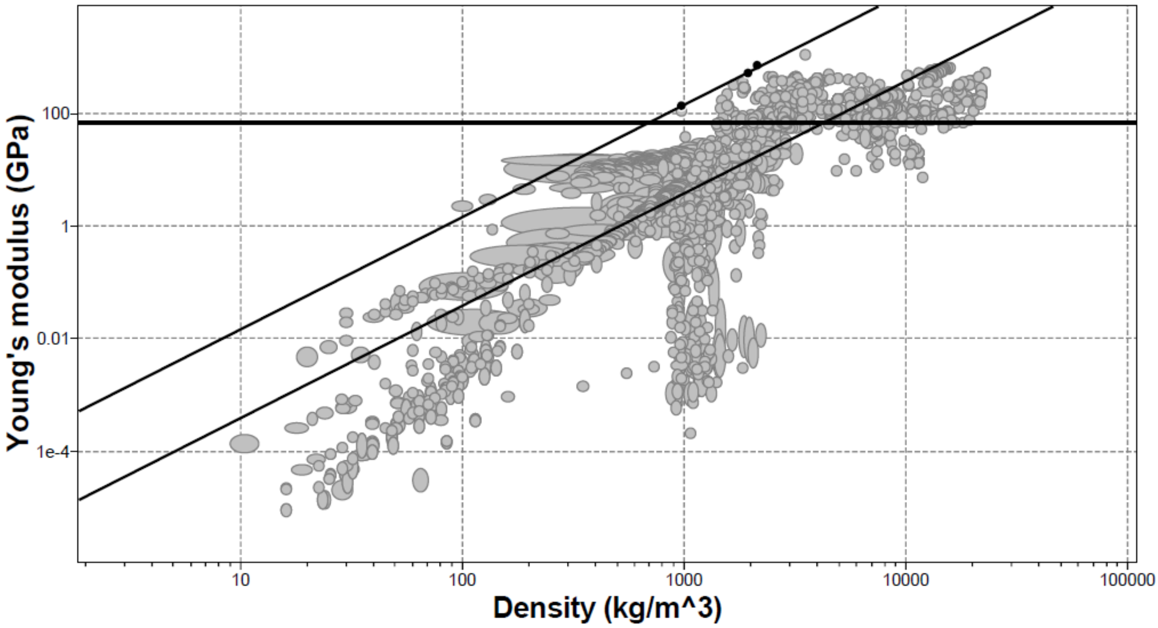


Figure 10: Shortlisting to top 3 materials after modifying the material index.

As these snippets demonstrate, the top 3 materials have been shortlisted again and unlike previous level 2, more detailed information has been provided about the materials that is required for shortlisting.

References

Gutub, B. M. (2013). *Material Selection Strategy and surface treatment of plymer composites for wind turbine blades fabrication.* Retrieved from Google Scholar: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=chrome-extension%3A%2F%2Fefaidnbmnnnibpcajpcglclefindmkaj%2Fhttps%3A%2F%2Fjournals.sagepub.com%2Fdoi%2Fpdf%2F10.1177%2F096739111302100708&btnG=

Harrison M, K. (2018, June). *Aerodynamic modelling of wind turbine balde loads during extreme deflection events.* Retrieved from Google Scholar: Harrison, M., Kloosterman, M., & Urbano, R. B. (2018, June). Aerodynamic modelling of wind turbine blade loads during extreme deflection events. In Journal of Physics: Conference Series (Vol. 1037, No. 6, p. 062022). IOP Publishing.