Material selection:

Translation, screening, ranking, documentation

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Learning objectives for this lecture unit

Ansys software mentioned	• Ansys Granta EduPack™, a teaching software for materials education

Intended Learning Outcomes	
Knowledge and Understanding	Knowledge and understanding of the design process using Material Indices
Skills and Abilities	Ability to use the Ansys Granta EduPack software to apply screening and ranking to material properties
Values and Attitudes	Appreciation of design-led decision-making using Ansys Granta EduPack software tools

Resources

- **Text:** "Materials: engineering, science, processing and design" 4th edition by M.F. Ashby, H.R. Shercliff and D. Cebon, Butterworth Heinemann, Oxford, 2019, Chapter 3, 5 and 7.
- **Text:** "Materials Selection in Mechanical Design", 5th edition by M.F. Ashby, Butterworth Heinemann, Oxford, 2016, Chapters 4-5

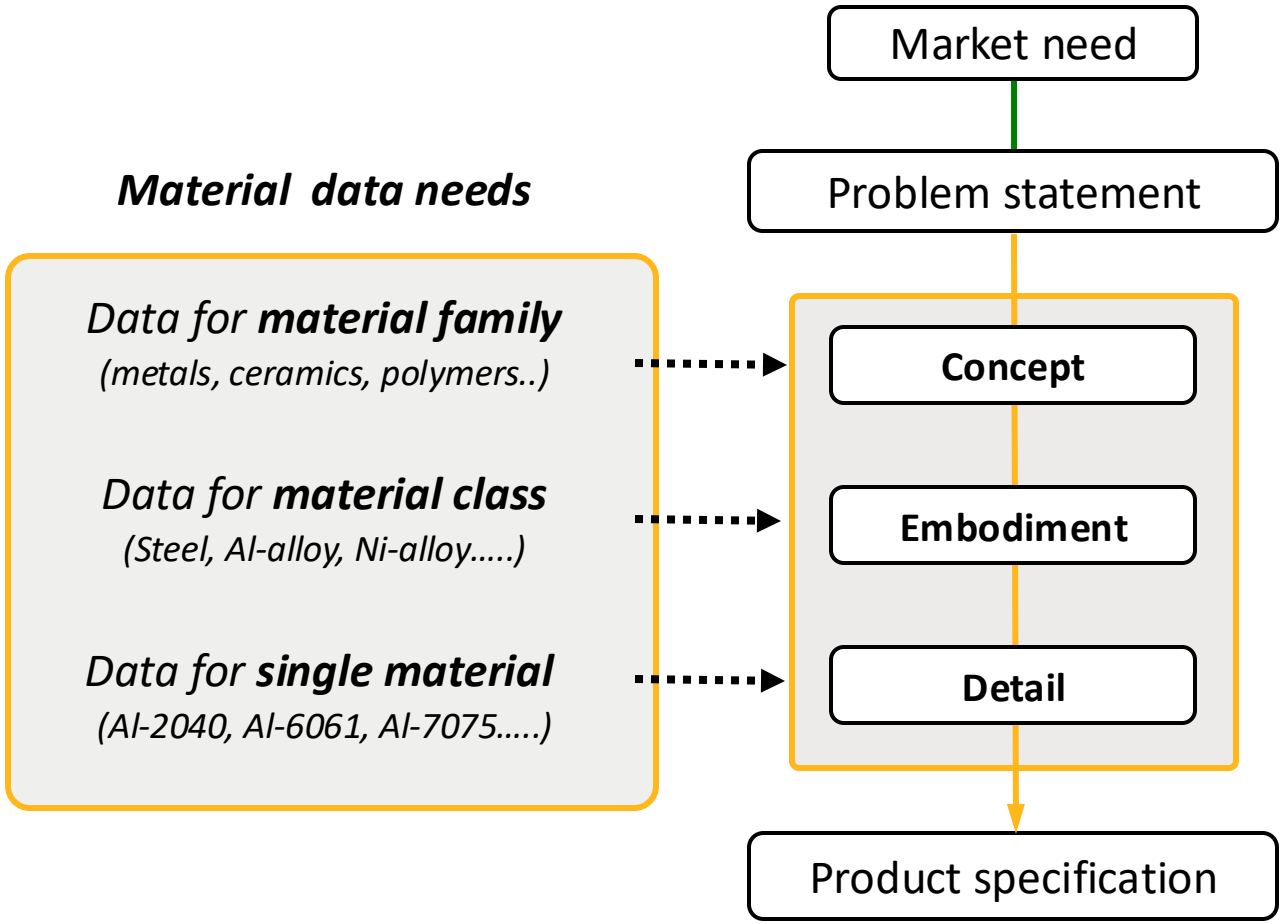
Outline of lecture unit

- Linking **materials** to **design**
- The **selection strategy:**

  Translation – Screening – Ranking - Documentation

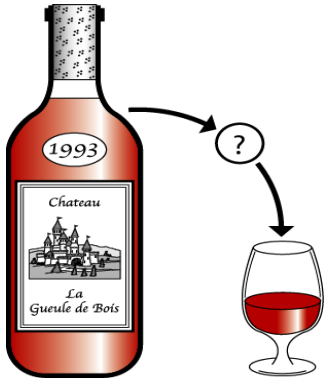
- The **Ansys Granta EduPack software selection toolbox**
  - ***Limit stages***
  - ***Graph stages***
  - ***Tree stages***
- **Material indices** do the job

The design process

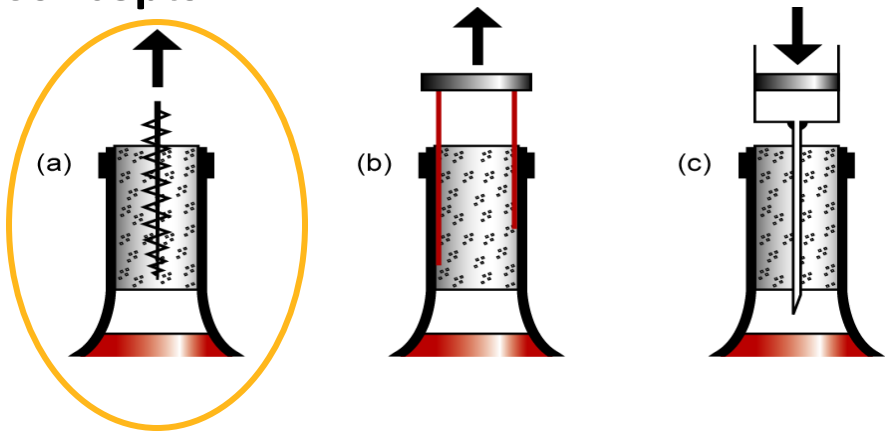


Need – Concept – Embodiment

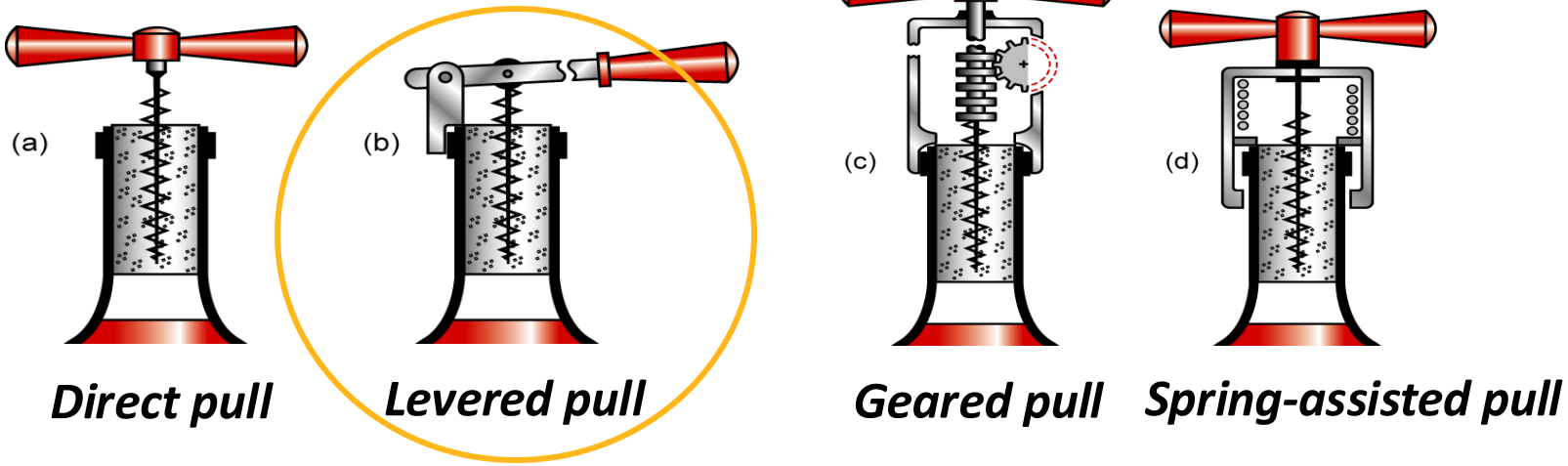
Need



Concepts



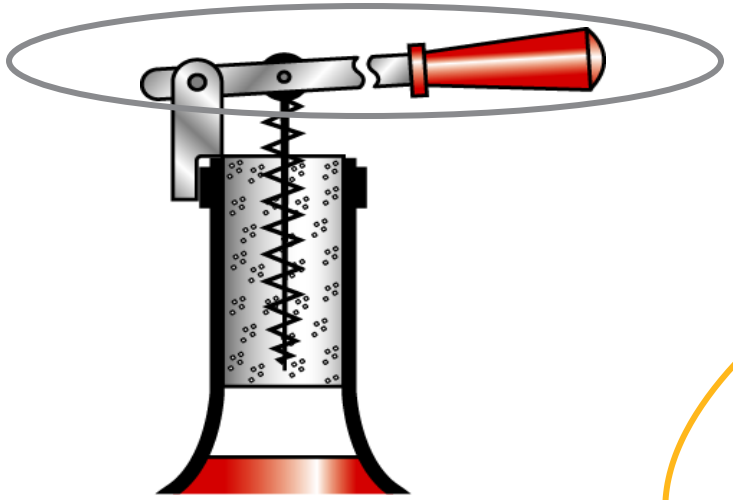
Embodiments



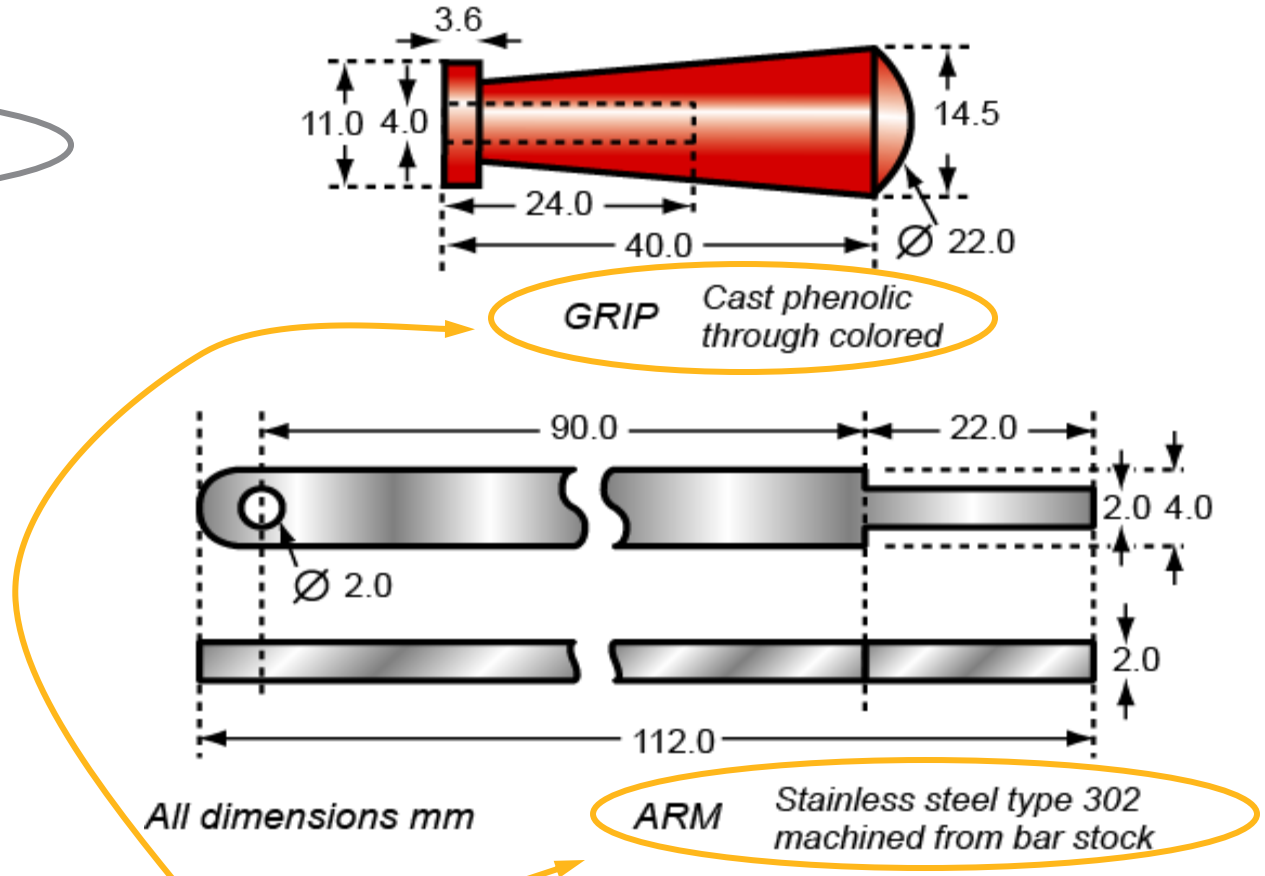
Direct pull ***Levered pull*** ***Geared pull*** ***Spring-assisted pull***

Embodiment – detail

Embodiment



Detail



How are those choices made?

The selection strategy: materials

Design requirements:

expressed as

Constraints *and*

Objectives

Data:

Material attributes

Process attributes

Documentation

Able to be molded

Water and UV resistant

Stiff enough

Strong enough

As cheap as possible

(As light as possible)

Comparison engine

- **Screening**
- **Ranking**
- **Documentation**

Density

Price

Modulus

Strength

Durability

Process compatibility

More…….

Final selection

Translation is important

Translation: *"express design requirements as constraints and objectives"*

Design requirements

Typical Constraints

What essential conditions must it meet ?

- ***Be strong enough***
- ***Conduct electricity***
- ***Tolerate 250˚C***
- ***Be able to be cast***

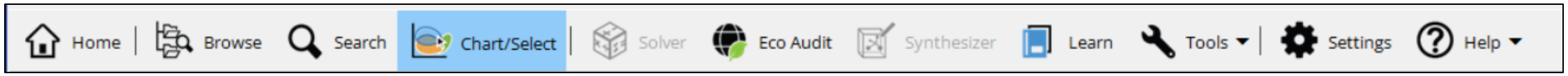
Typical Objectives

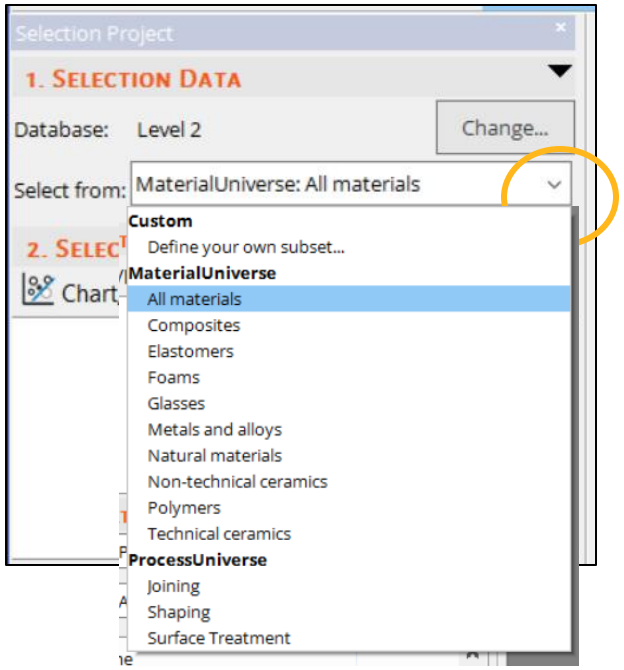
What measure of performance is to be maximized or minimized ?

- ***Mass***
- ***Volume***
- ***Eco-impact***
- ***Cost***

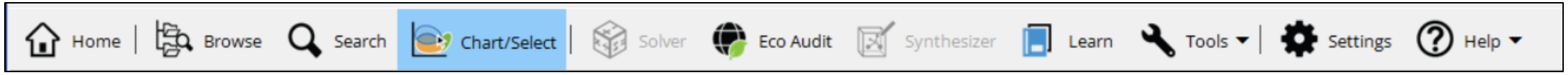
Screening: *"use constraints to eliminate materials that can't do the job"*

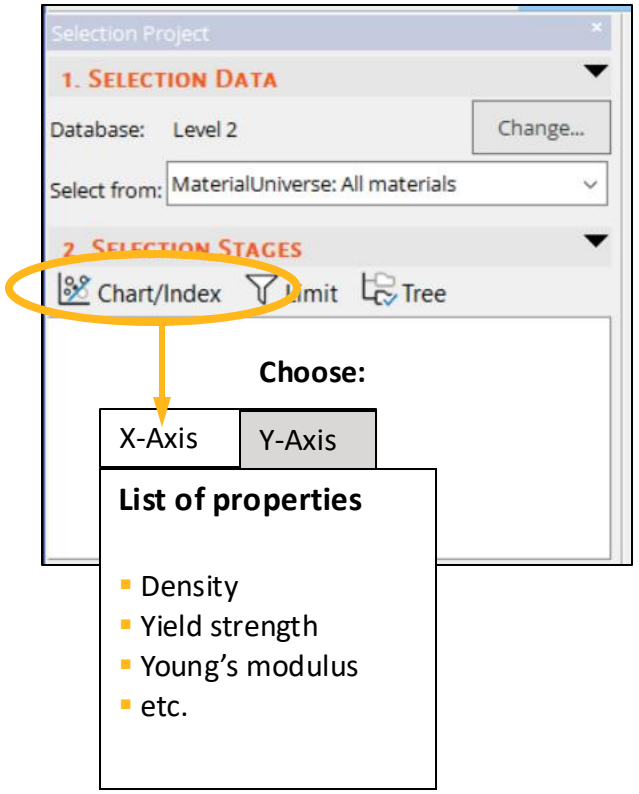
Creating Charts – choosing materials to plot

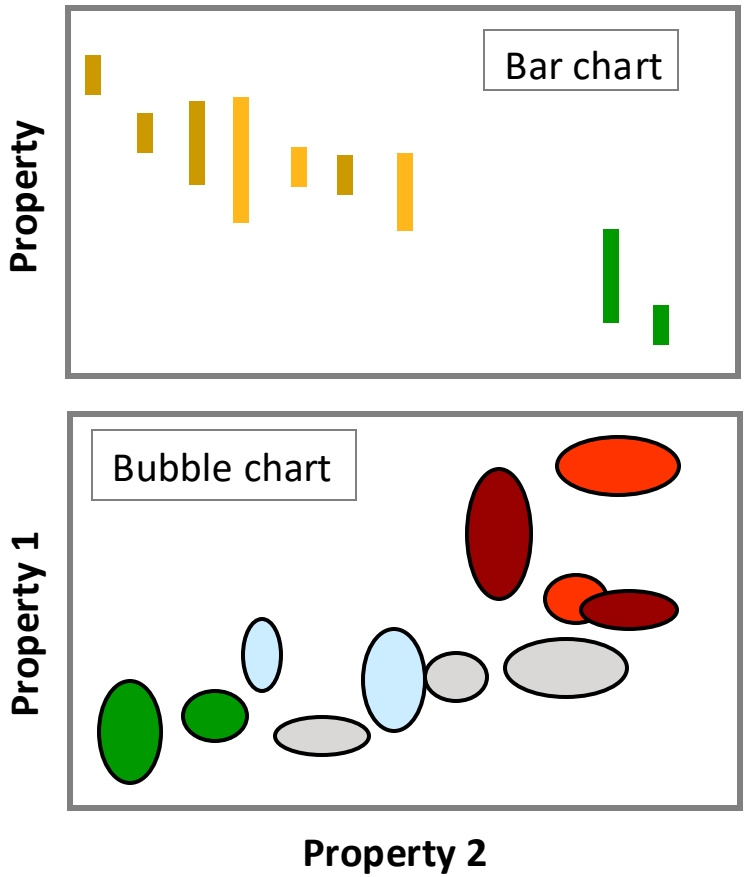




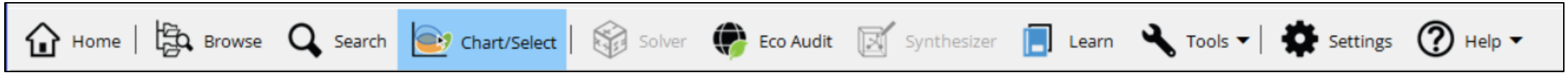
Creating Charts – single property charts

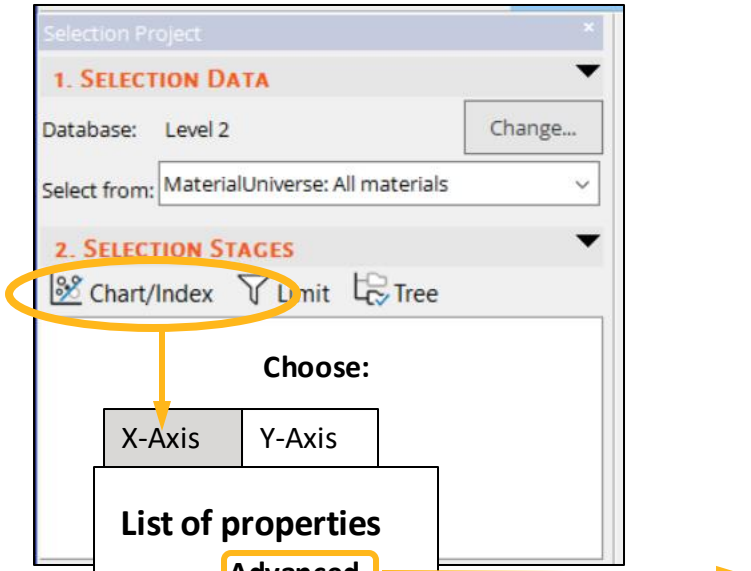


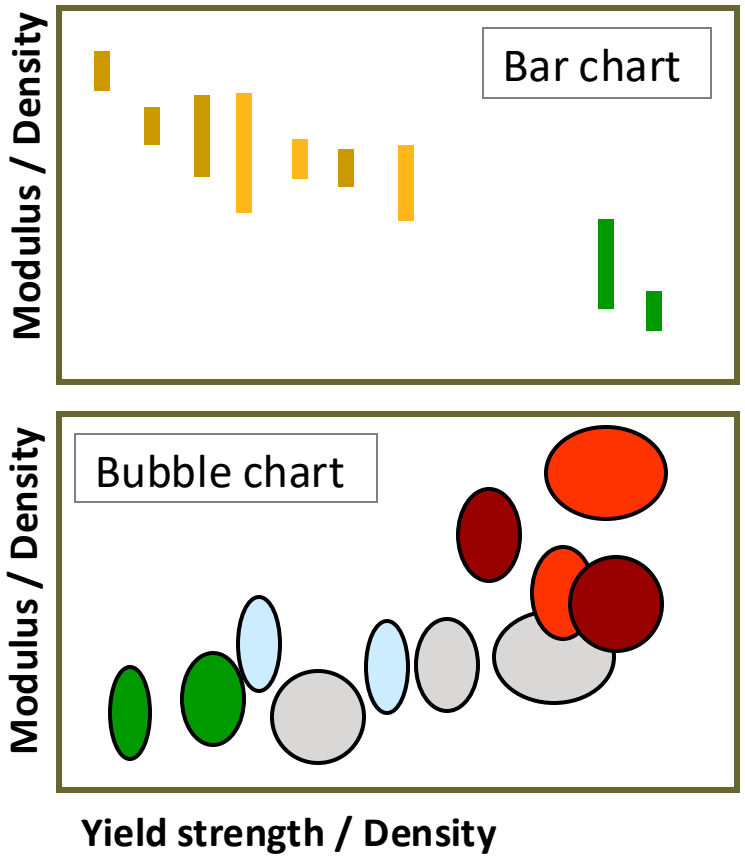




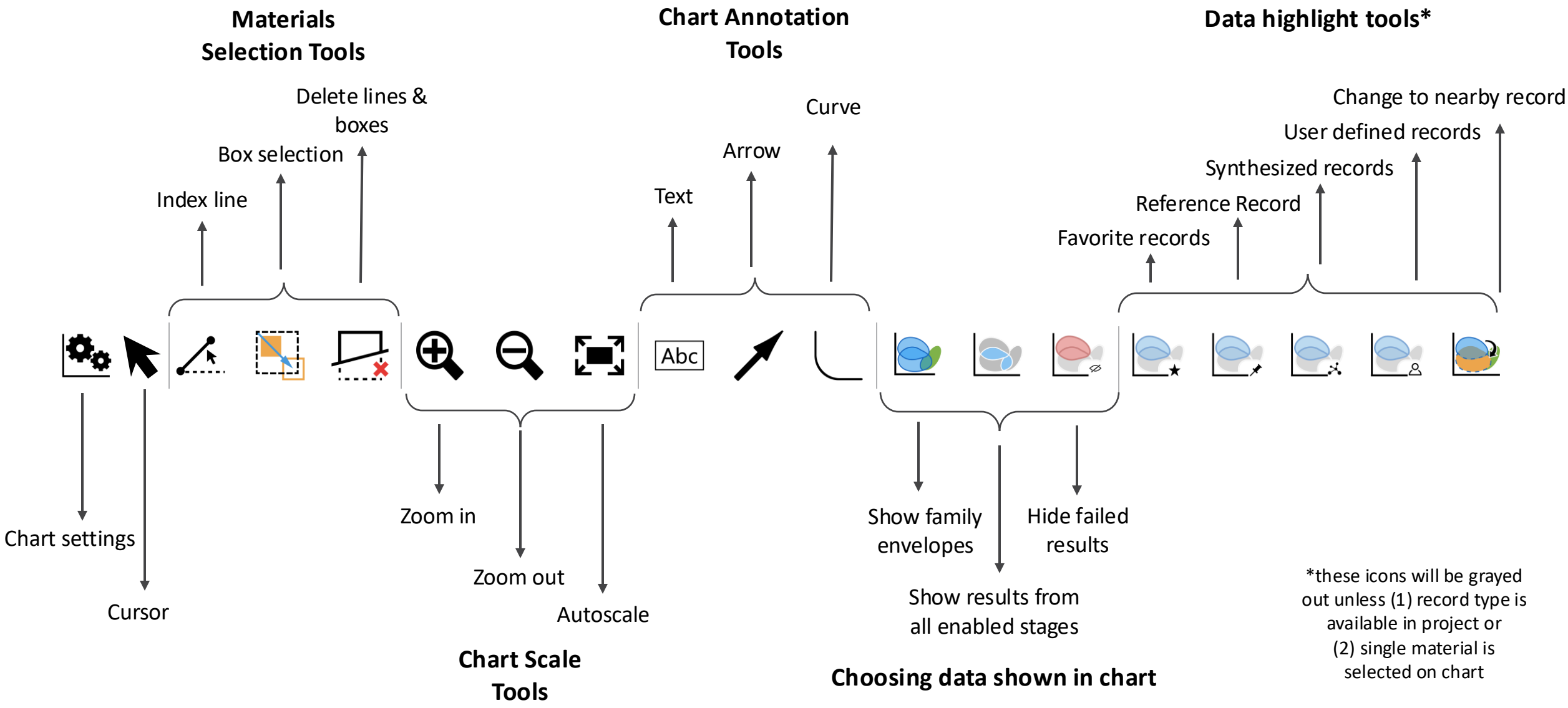
Creating Charts – advanced property charts





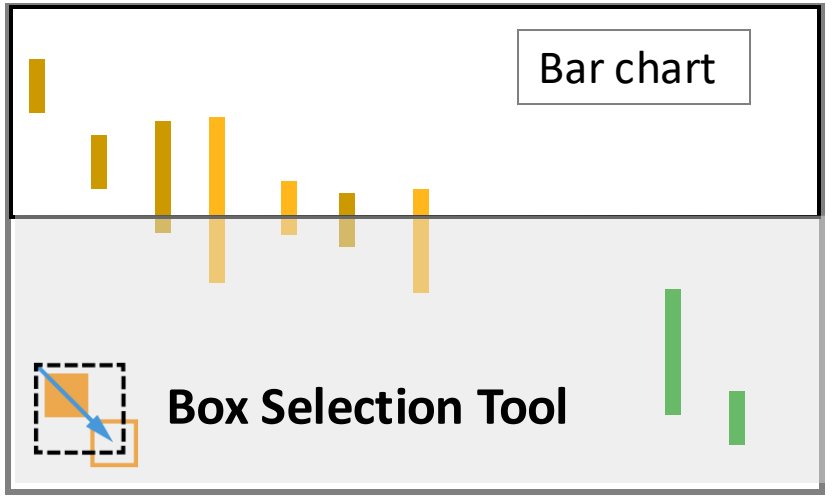


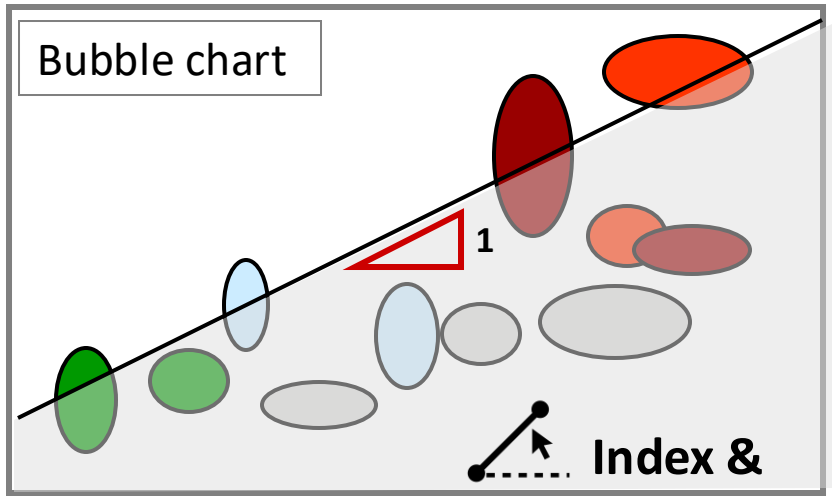
The Chart tool bar



*these icons will be grayed out unless (1) record type is available in project or (2) single material is selected on chart

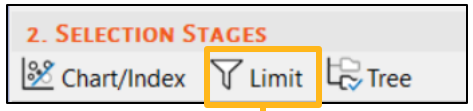
Screening with a CHART STAGE

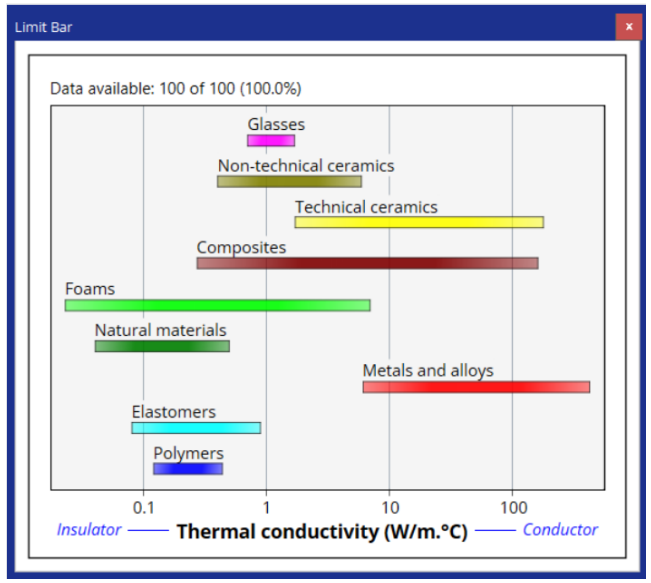


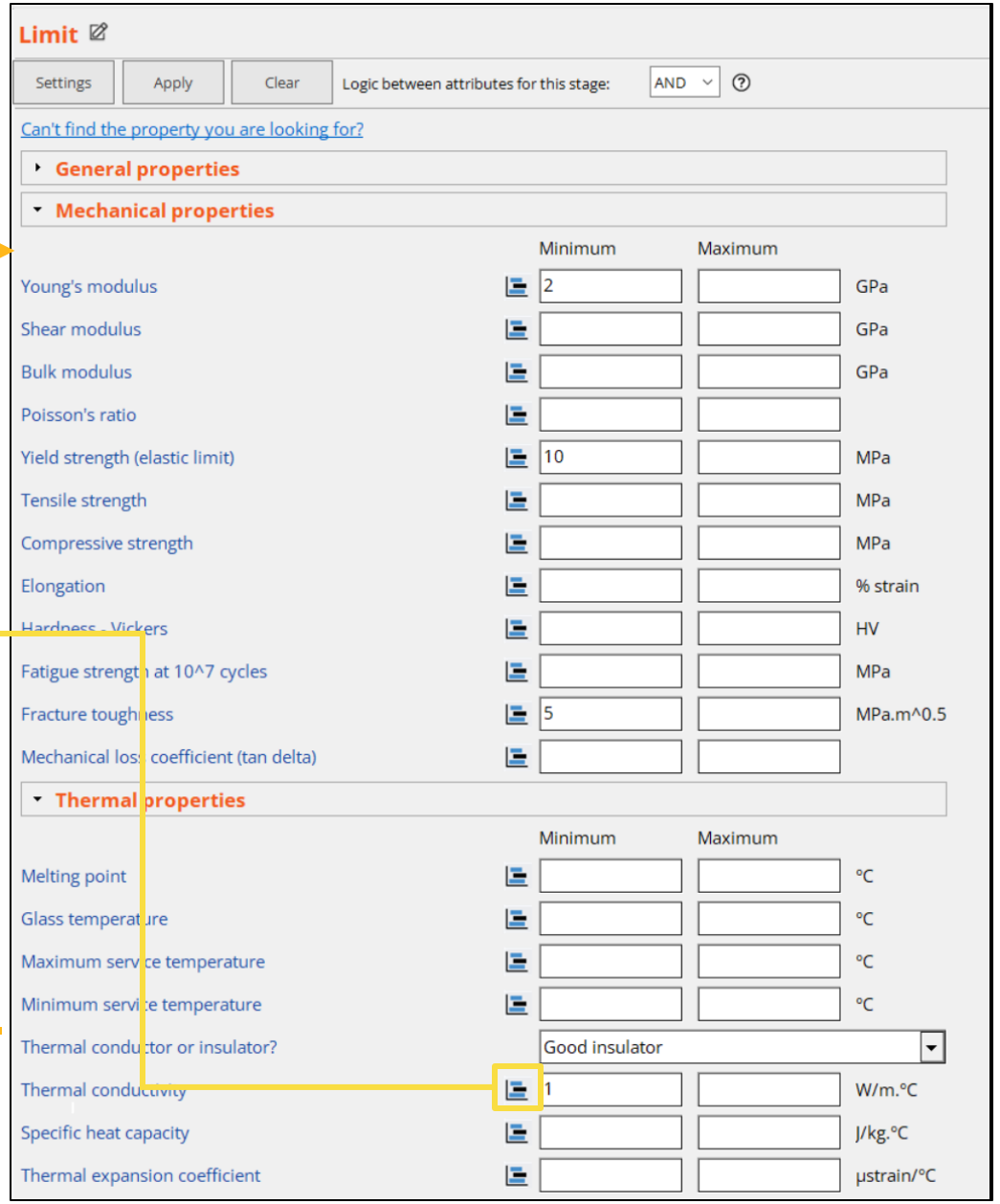


Results	*Ranking*	
X out of 100 pass	*Prop 1*	*Prop 2*
Material 1	2230	113
Material 2	2100	300
Material 3	1950	5.6
etc...		

Screening with a LIMIT STAGE

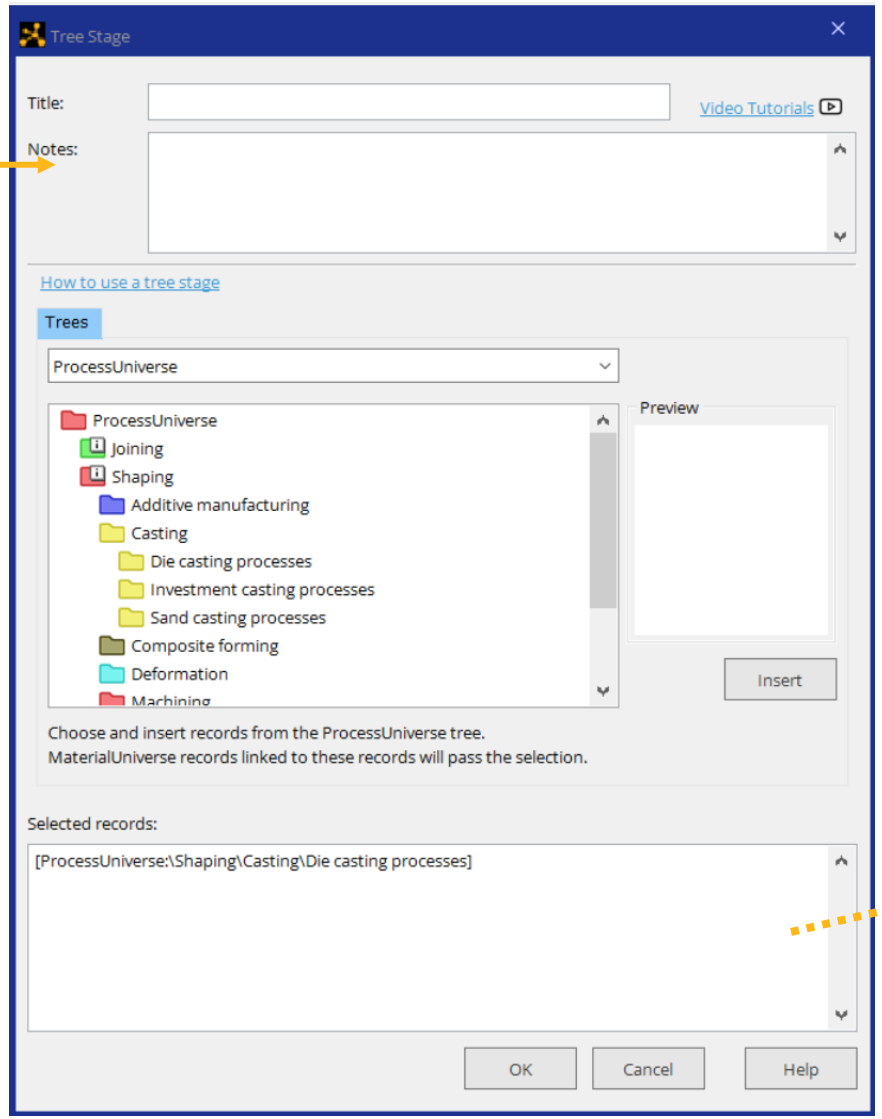






Results	***Ranking***	
X out of 100 pass	***Prop 1***	***Prop 2***
Material 1	2230	113
Material 2	2100	300
Material 3	1950	5.6
etc...		

Screening with a TREE STAGE



Materials that can be die-cast

Results

X out of 100 pass

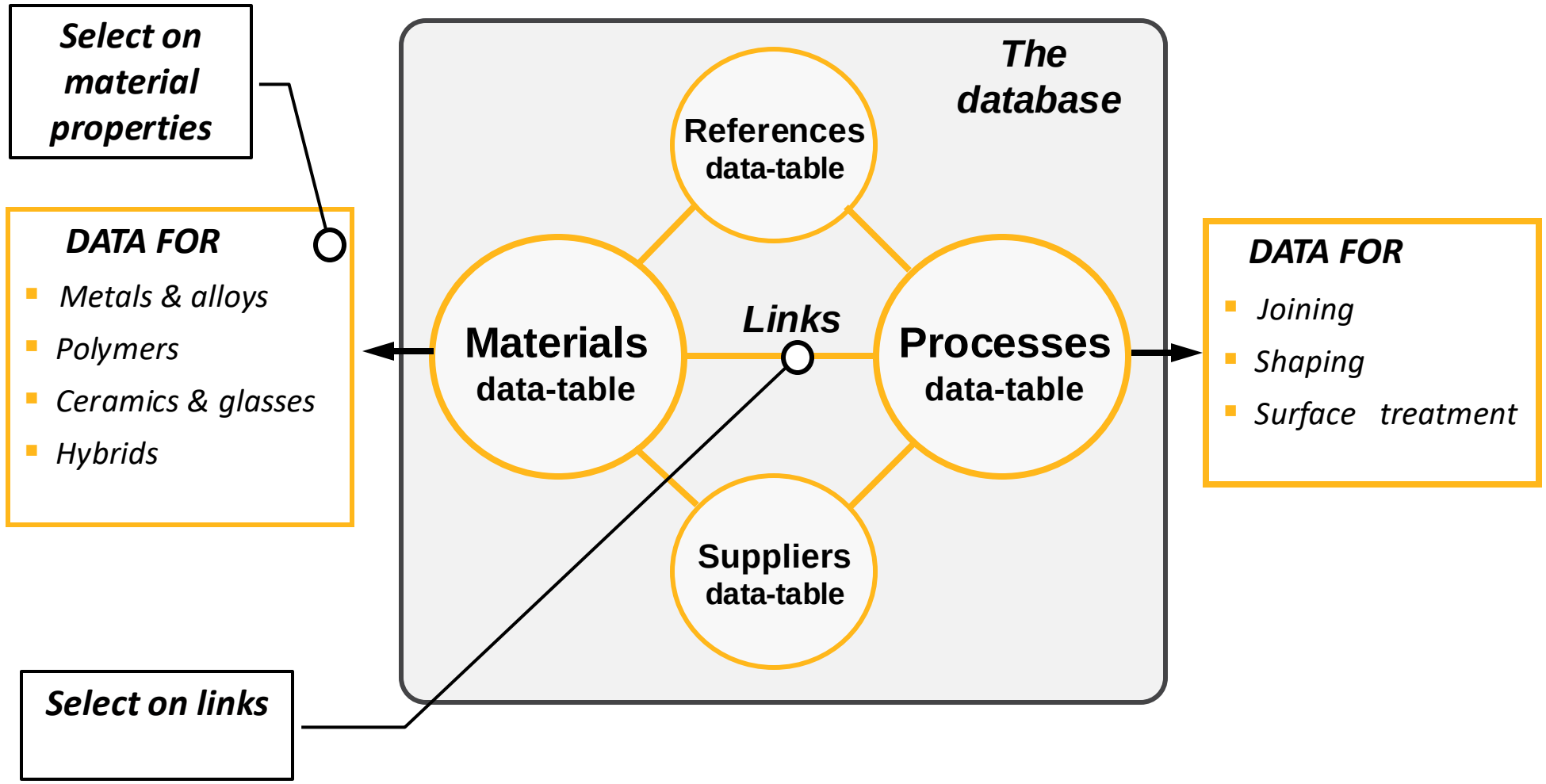
Material 1

Material 2

Material 3

etc...

Selection on links



What is a “material index”?

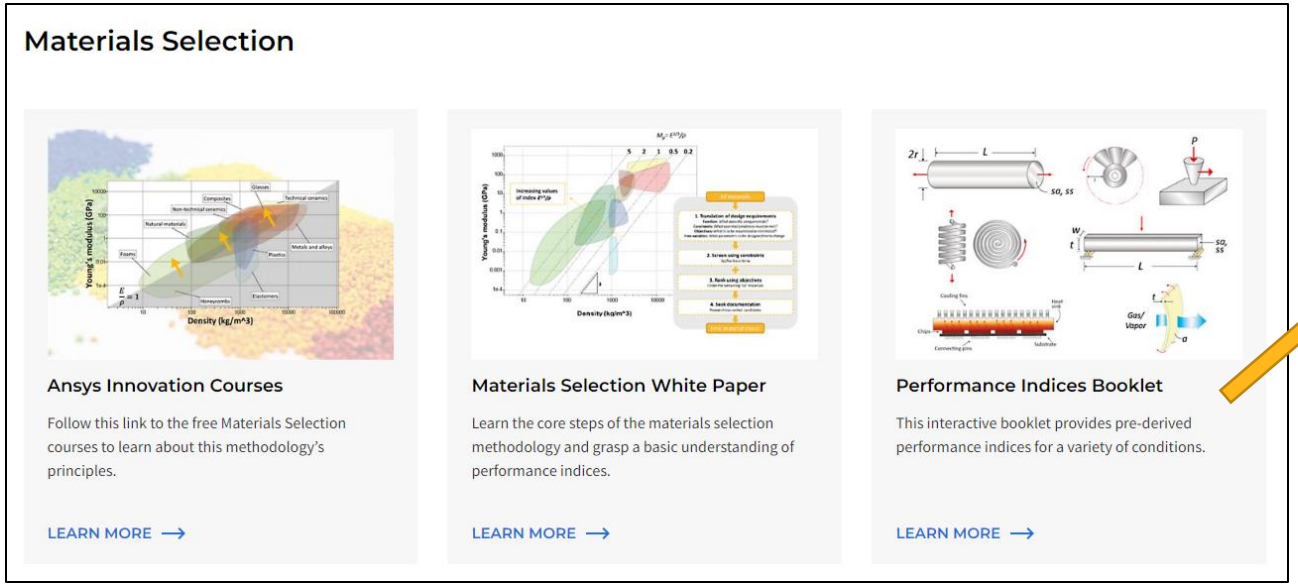
Component performance is limited by either:

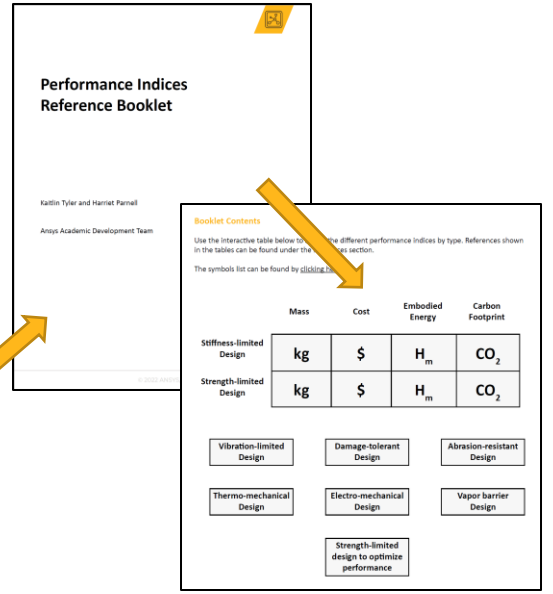
- a single material property **e.g. tensile strength**, σ_{ts}
- a material property group, **e.g. modulus / density**, E / ρ

*The **material index** for the design*

To maximize performance:

- First apply all **constraints**
- Then select materials with the **biggest or smallest index**





Simple one-property indices

Protective visor for motorcyclists

Design requirement

Constraints

- Transparent - of optical quality
- Able to be molded

Objective

- As tough as possible – maximize fracture toughness K_{1c}

The material index: choose material with largest K_{1c}

Alternative objective

- As cheap as possible – minimize material cost C_m

The material index: choose material with smallest C_m

Minimum weight design - indices

Tensile ties

$$\left(\frac{\sigma_y}{\rho}\right)$$

Compression strut

$$\left(\frac{E^{1/2}}{\rho}\right)$$

Main spar - beam

$$\left(\frac{E^{1/2}}{\rho}\right)$$

Undercarriage - bending and compression

$$\left(\frac{\sigma_y^{2/3}}{\rho}\right)$$

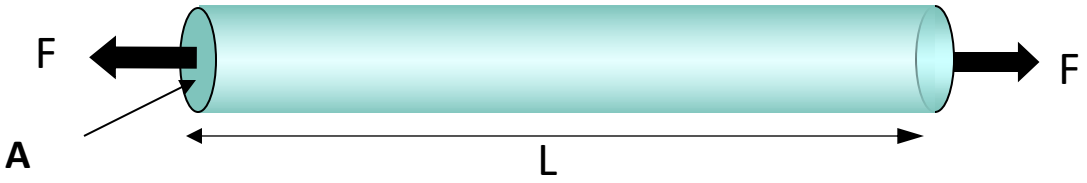
E = Young's modulus
ρ = Density
σ_y = Yield strength

Index for a strong, light tie-rod

Function

Tie-rod

Strong tie of length L and minimum mass



Constraints

- ***Length L is specified***
- ***Must not fail under load F***

Objective

***Equation for constraint on A*:**

$$F/A < \sigma_y$$

Minimize mass m:

$$m = A\,L\,\rho$$

m = mass
A = area
L = length
ρ = density
σ_y = yield strength

Performance metric

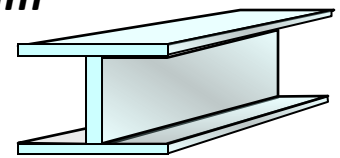
$$\mathbf{m} = \mathbf{F}\,\mathbf{L}\left(\frac{\boldsymbol{\rho}}{\boldsymbol{\sigma}_\mathbf{y}}\right)$$

Chose materials with largest $M = \left(\frac{\sigma_y}{\rho}\right)$

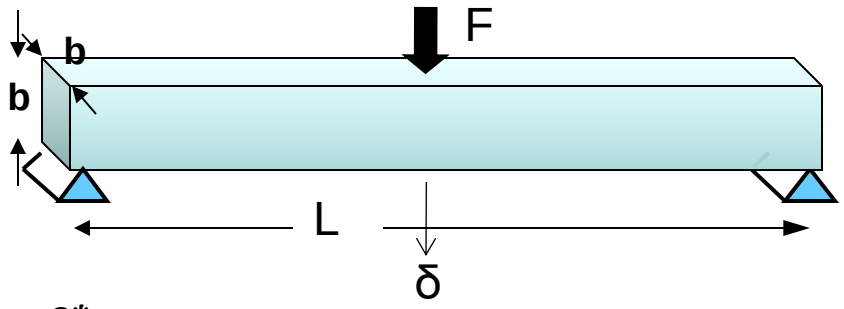
Index for a stiff, light beam

Function

Beam



Stiff beam of length L and minimum mass



Square section, area $A = b^2$

Constraints

- ***Length L is specified***
- ***Must have bending stiffness > S****

Equation for constraint on A:

$$S = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CEA^2}{12L^3}$$

Objective

Minimize mass m:

$$m = A L \rho$$

m = mass
A = area
L = length
ρ = density
S = stiffness (F/δ)
This beam: $\delta = FL^3/CEI$
C = constant (here, 48)
E = Young's modulus
I = second moment of area
($I = b^4/12 = A^2/12$)

Performance metric

$$m = \left(\frac{12L^5 S^*}{C}\right)^{1/2} \left(\frac{\rho}{E^{1/2}}\right)$$

Chose materials with largest $M = \left(\frac{E^{1/2}}{\rho}\right)$

Ranking, using charts

Light stiff beam:

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

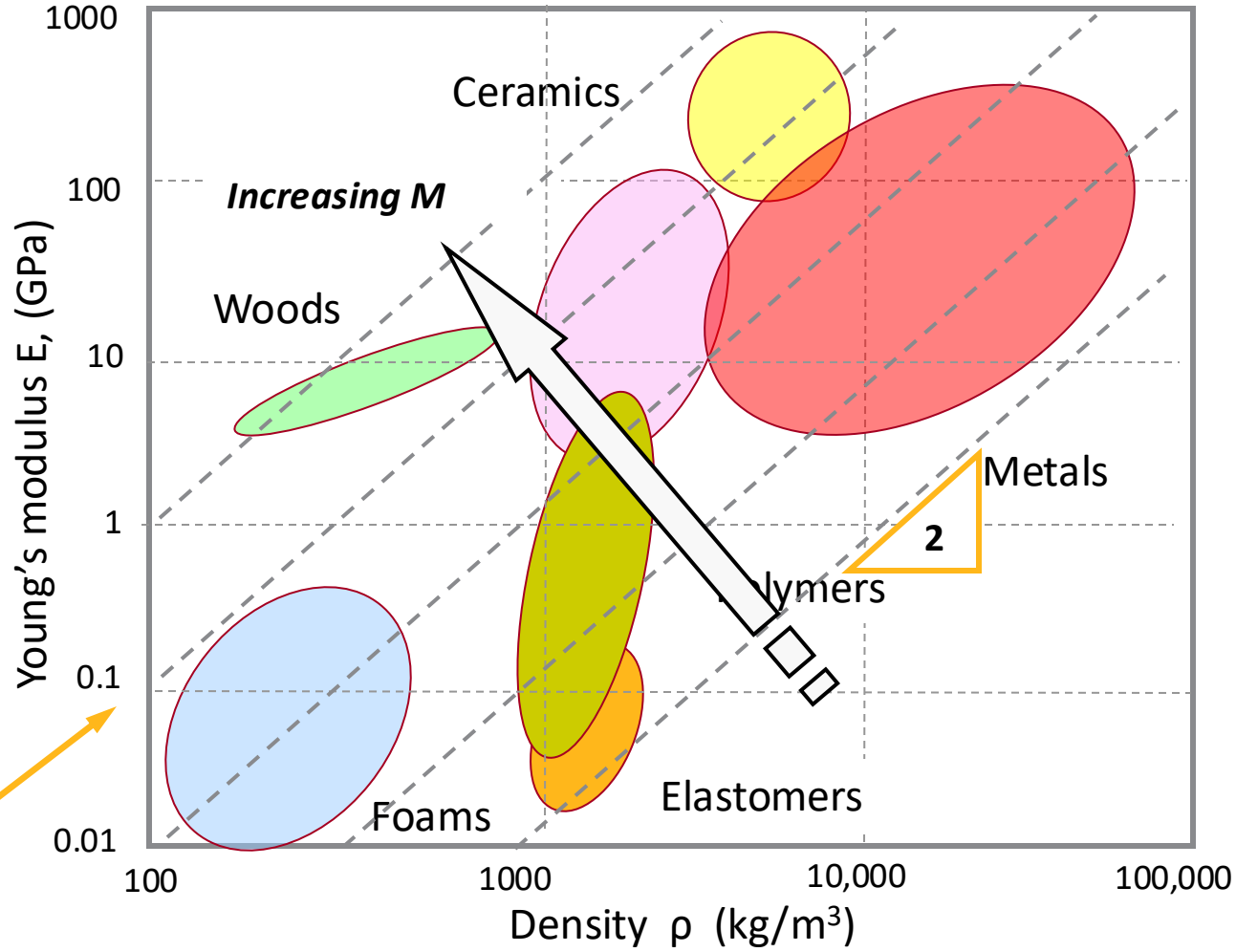
Rearrange:

$$E = \rho^2 M^2$$

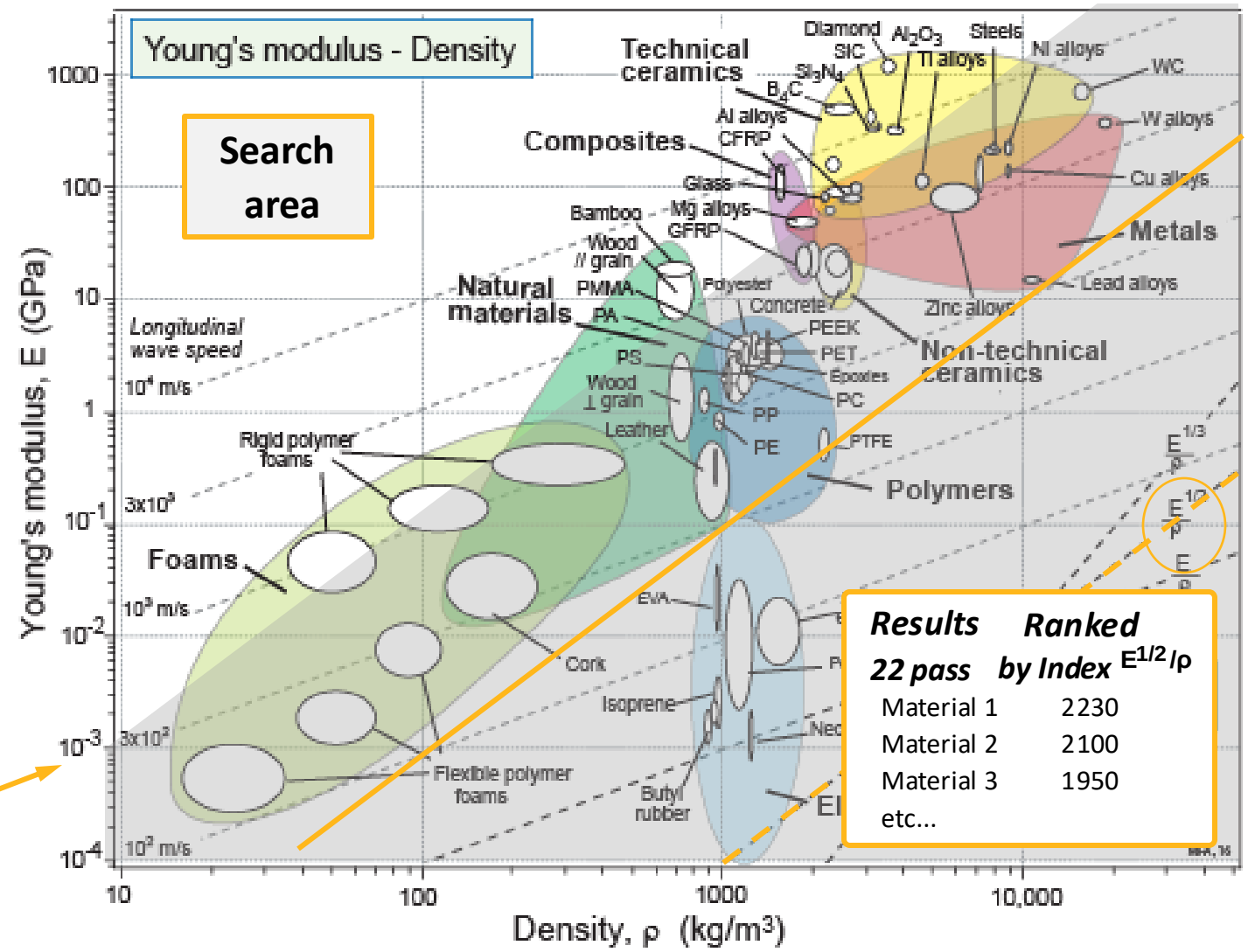
Take logs:

$$\text{Log } E = 2 \log \rho + 2 \log M$$

Function	*Index*	*Slope*
Tie	E/ρ	*1*
Beam	$E^{1/2}/\rho$	*2*
Panel	$E^{1/3}/\rho$	*3*



Selection using index in a bubble chart



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

Results ***Ranked***

22 pass ***by Index*** $E^{1/2}/\rho$

Material 1	2230
Material 2	2100
Material 3	1950
etc...	

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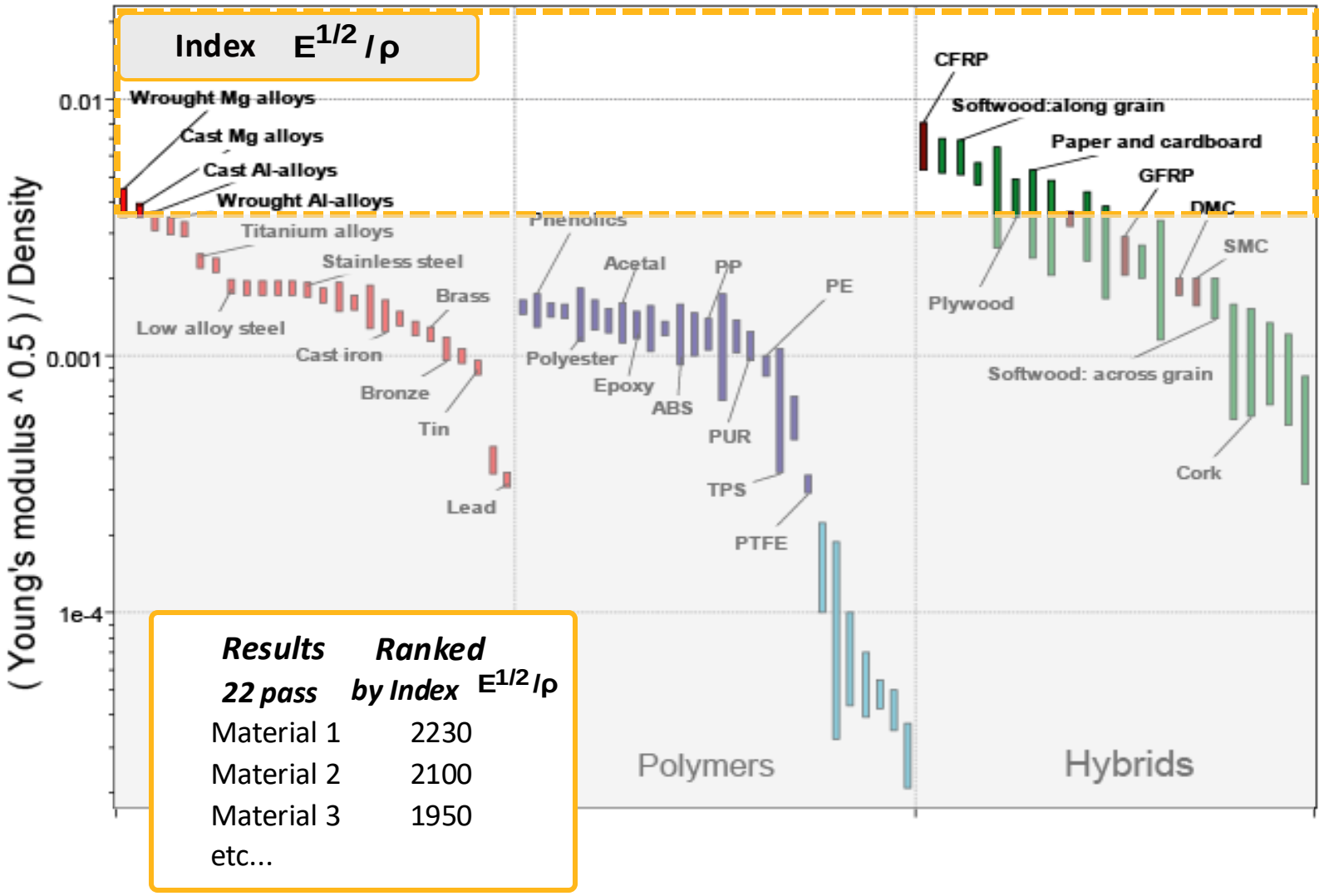
Selection using index directly on chart axis



Results 22 pass	*Ranked by Index* $E^{1/2}/\rho$
Material 1	2230
Material 2	2100
Material 3	1950
etc...	

Documentation: the pedigree

Documentation: *"now the number of candidates is small, explore their character in depth"*

Handbooks

Specialized databases

The Internet

Suppliers' data sheets

Summary

- **The selection strategy:**

Translate - Screen - Rank - Documentation

- The Granta EduPack software allows Screening using **'Limit – Chart – Tree stages'** in any number and sequence

- The progression:

Data

(Numbers, text)

Visualization

(understanding the data)

Selection

(using the data)

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