Aalto University
School of Engineering

MEC-E1070 Selection of Engineering Materials

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Learning objectives for this Lecture

Knowledge and Understanding

Knowledge and understanding of the design process using **Material Indices**

Skills and Abilities

Ability to use GRANTA EduPack to apply **screening** and **ranking** to material properties

Values and Attitudes

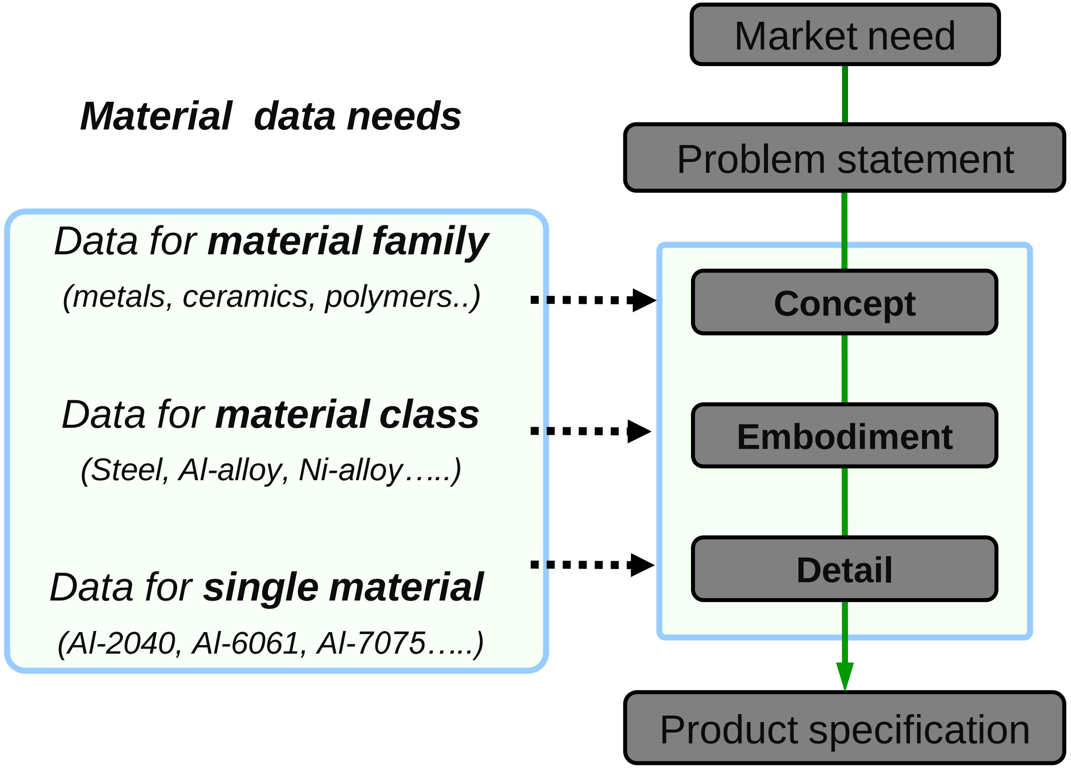
Appreciation of design-led decision-making using GRANTA EduPack tools

Resources

- Text: *“**Materials Selection in Mechanical Design**”,* 4th edition by M.F. Ashby, Butterworth Heinemann, Oxford, 2016, Chapters 3-5
- 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, 4 and 5.

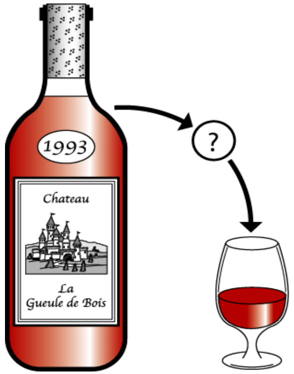
The design process

Material data needs

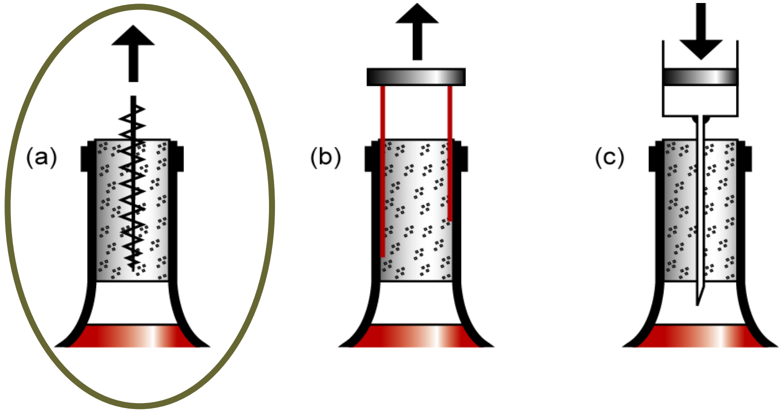


Need – Concept – Embodiment

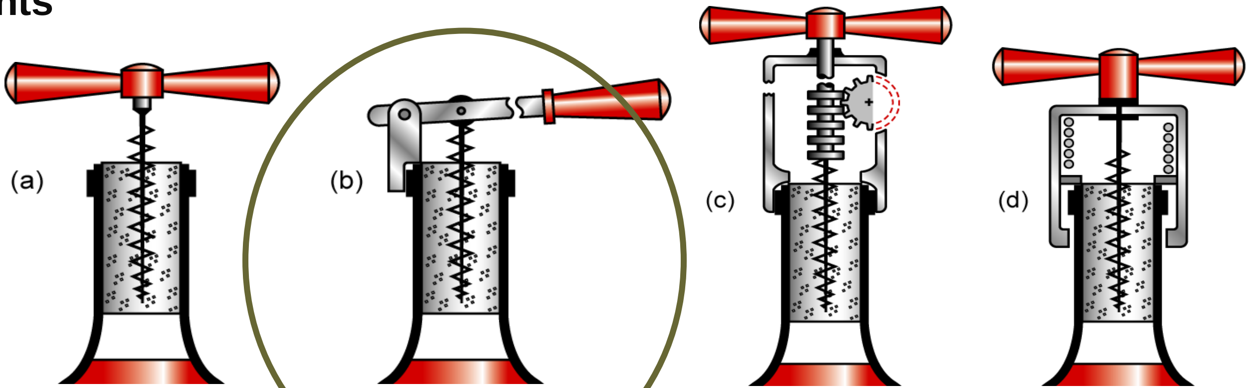
Need



Concepts



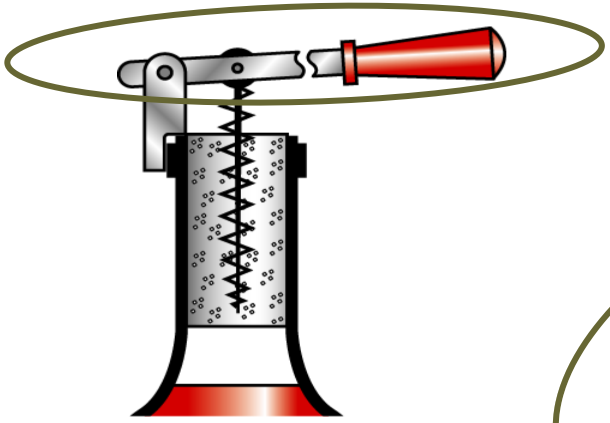
Embodiments



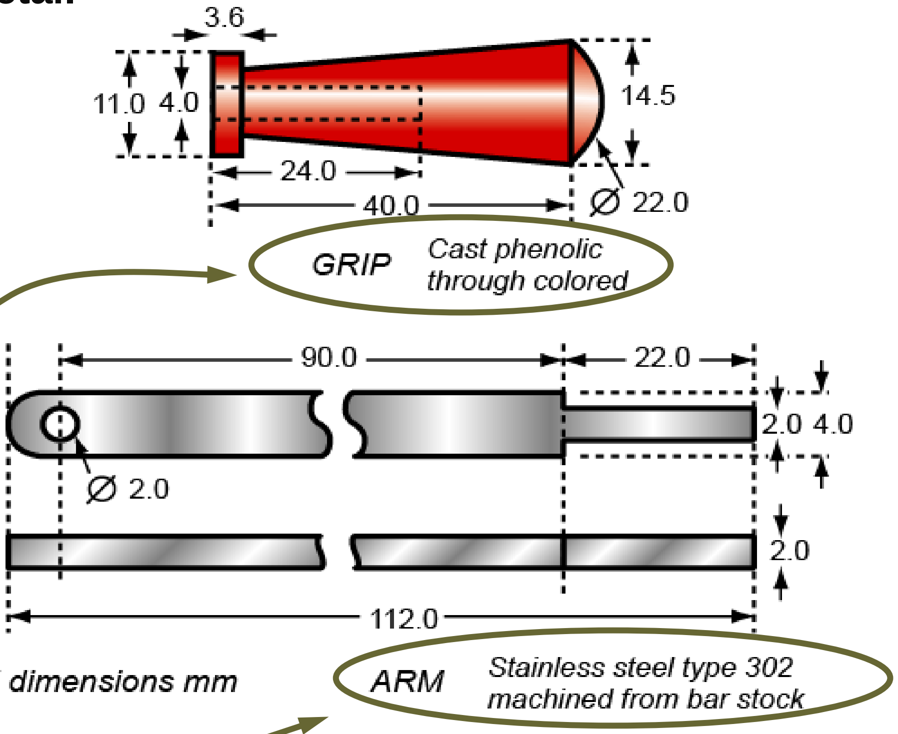
Direct pull *Levered pull* *Geared pull* *Spring-assisted pull*

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”*

What is a "material index"?

Component performance is limited by either:

- a single material property **e.g. tensile strength**, $\boxed{\sigma_{ts}}$
- a material property group, **e.g. modulus / density**, $\boxed{E / \rho}$

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

To maximize performance:

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

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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

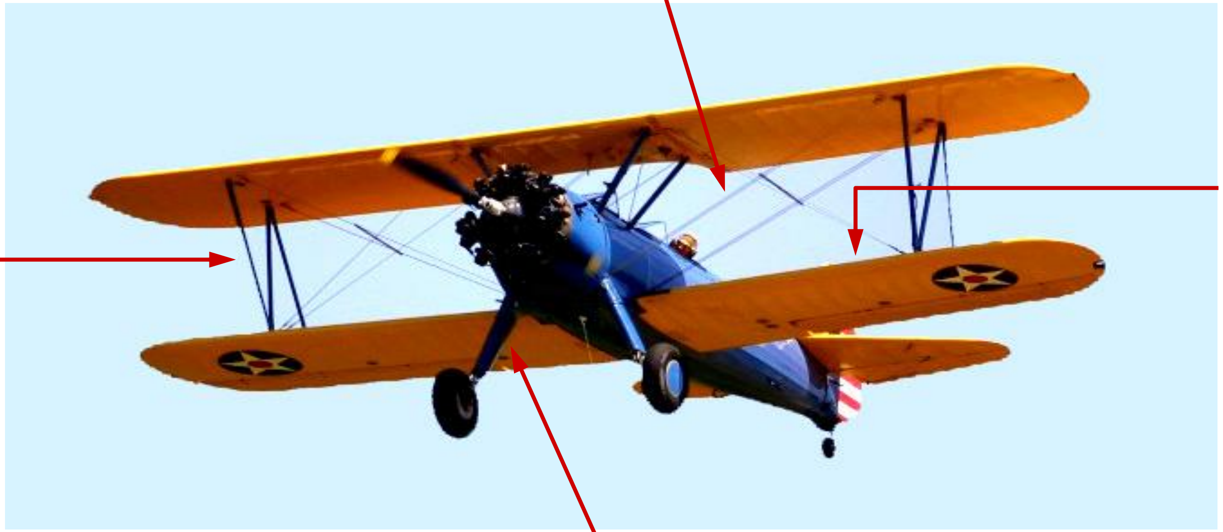
Minimum weight design - indices

Tensile ties

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

Compression strut

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



Main spar - beam

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

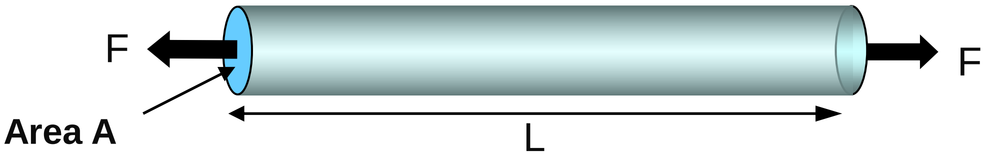
Undercarriage - bending and compression

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

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

Index for a strong, light tie-rod

Strong tie of length L and minimum mass



Function — *Tie-rod*

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

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

$$\boxed{F/A < \sigma_y}$$

Objective — ***Minimize mass m:***

$$\boxed{m = A\,L\,\rho}$$

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

Performance metric

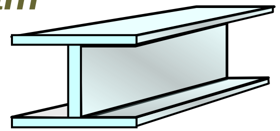
$$\mathbf{m} = \mathbf{F\,L}\left(\frac{\boldsymbol{\rho}}{\boldsymbol{\sigma_y}}\right)$$

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

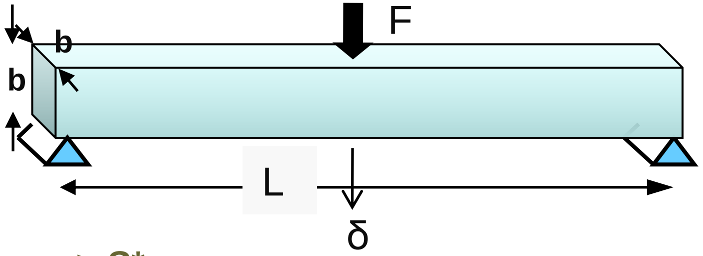
Index for a stiff, light beam

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:

$$\boxed{S = \frac{F}{\delta} = \frac{C\,E\,I}{L^3} = \frac{C\,E\,A^2}{12L^3}}$$

Objective

Minimize mass m:

$$\boxed{m = A\,L\,\rho}$$

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 $M = \left(\dfrac{E^{1/2}}{\rho}\right)$

Ranking, using charts

Light stiff beam:

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

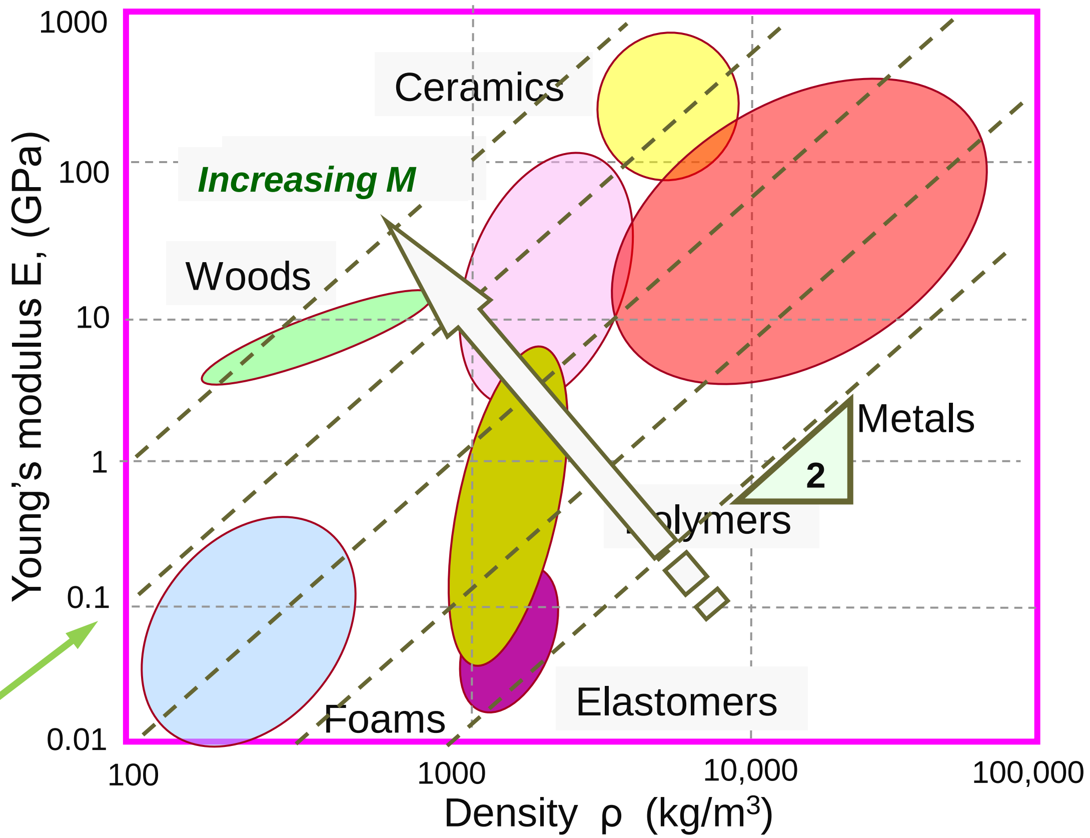
Rearrange:

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

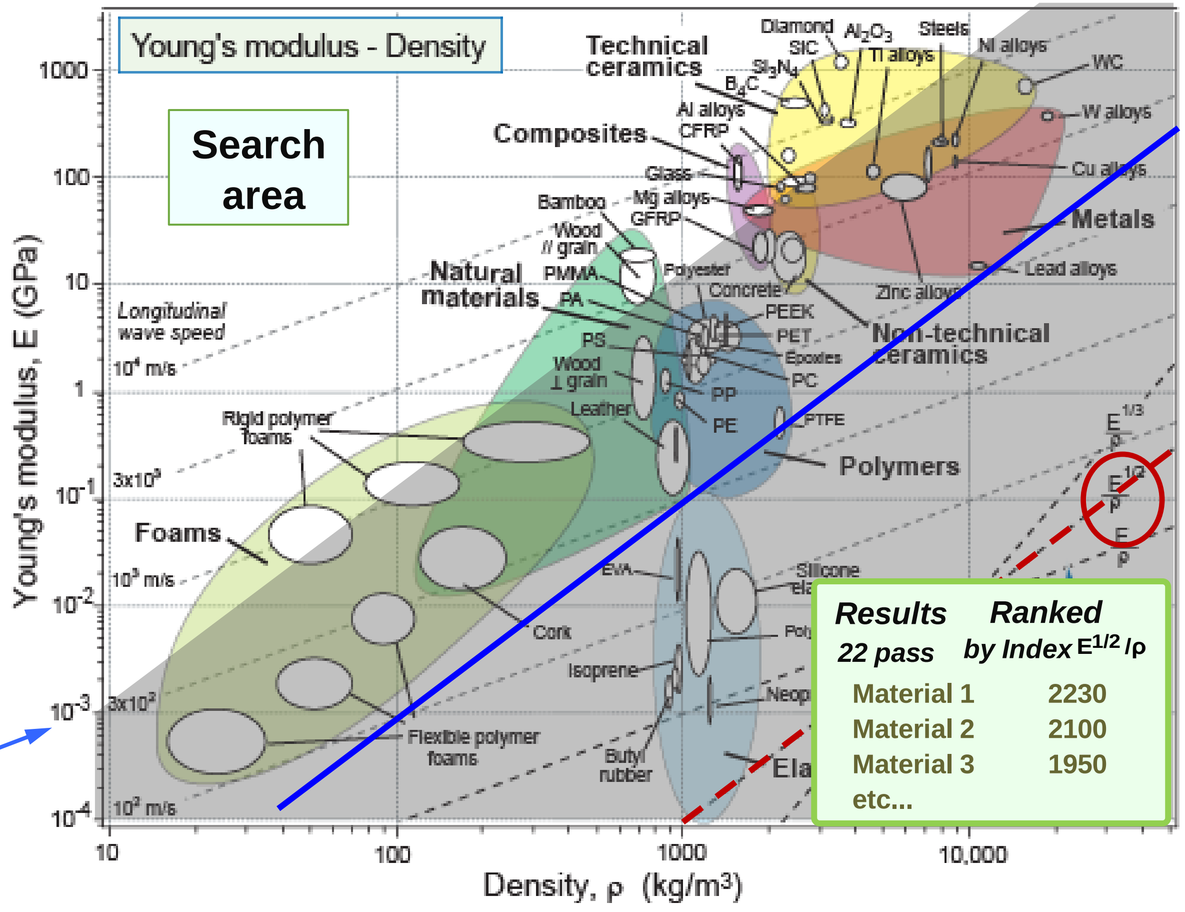
Take logs:

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

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 ***22 pass***

Ranked by Index $E^{1/2}/\rho$

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

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