Manufacturing Technologies

Lecture 1 – Introduction and materials selection

Prof. Yves Bellouard
Galatea Lab, STI/IEM
https://galatea.epfl.ch/

EPFL

Contact

- **Pour me contacter** / yves.bellouard@epfl.ch
- **Bureaux**
  - La plupart du temps: Neuchâtel / MC A1 288 (Microcity)
  - De temps en temps: Lausanne **(sur rendez-vous, mercredi matin)** / ME B2 433 / ME B2 425
  - Limited mobility until end of March

Vos assistants 2025

- **Martin** Lentz / martin.lentz@epfl.ch
- **Antoine** Duret / antoine.duret@epfl.ch
- **Camar** Cheyto / camar.cheyto@epfl.ch

Etudiants-assistants:

- **Samm** De Bruyn / samm.debruyn@epfl.ch
- **Alexandre** Van Nam Dao / alexandre.dao@epfl.ch

Format du cours / Evaluation

- Les transparents seront en **anglais**…
- Le cours est donné en **français**…
- **Six questionnaires durant le semestre**
  - Une semaine sur deux
  - **10%** de la note finale / (moyenne des *quatre* meilleurs questionnaires)
- **Examen écrit**
  - **40%** de la note finale
- **Projet intégré à faire en cours (‘reverse engineering’)**
  - **50%** de la note finale répartie comme suit:
    - *40% - rapport*
    - *10% - 5 min vidéo tutorielle courte.*
- **Quatre heures** hebdomadaires sur 14 semaines

➢ ***Cours** / 13h15 – 15h00 in **PO 01***

➢ ***Exercices** / **Project** / 15h15 –17h00 in **PO 01***

Support pour le cours

- **Moodle** / Mise-à-jour avant le cours de la semaine
- **Ouvrages conseillés:**
  - **Materials Selection in Mechanical Design** / M.F. Ashby / Elsevier / Lien bibliothèque EPFL
  - **Manufacturing Engineering & Technology** / M.C. Shaw, P.K. Wright, S. Kalpakjian / Pearson Ed / Lien bibliothèque EPFL
- Beaucoup de resources sur Internet (Youtube // How things are made? etc.) – **Soyez curieux !**

Overall planning for the class

MICRO-301 - Manufacturing Technologies Course	2025

Lecturers	Prof. Yves Bellouard (YB) / Prof Vivek Subramanian (VS)	
TAs	Antoine Duret, Martin Lentz, Camar Cheyto	Lecture given in French
Etudiants assistants	Samm de Bruyn, Alexandre Van Nam Dao	Lecture given in English

Room	PO 01	13h15 - 15h00		15h15 - 17h00	
#	Date	Lecture content	Lecturer	Suggested exercises	Revese engineering project
1	19-Feb	Introduction	YB	Exercise I	Learning objectives
2	26-Feb	Surfaces	YB	Exercises II-IV	
3	05-Mar	Laser manufacturing	YB	Quiz I	Session 1
4	12-Mar	Metal forming	YB	Exercises V-IX	
5	19-Mar	Casting and molding	YB	Quiz II	Session 2
6	26-Mar	Conventional machining	YB	Excercises X-XIII	
7	02-Apr	Unconventional machining process	YB	Quiz III	Session 3
8	09-Apr	Polymers and related processing methods	YB	Exercises XIV-XV	
9	16-Apr	Manufacturing economics and process monitoring	YB	Quiz IV	Session 4
	23-Apr	Pâques			
10	30-Apr	Assembly processes	YB	Exercises XVI-XXI	
11	07-May	Electronics integration	VS	Quiz V	Session 5
12	14-May	Multiscale integration / packaging	VS	Exercises XXII-XXIV	
13	21-May	Introduction to additive manufacturing	YB	Quiz VI	Session 6
14	29-May	Sustainability and life cycle analysis	YB		Session 7
15	05-Jun	Deadline for submitting the report			

Updated 18/02/2025

English course (Optional)

- Barbara Althaus
- Kristin Andrikopoulos

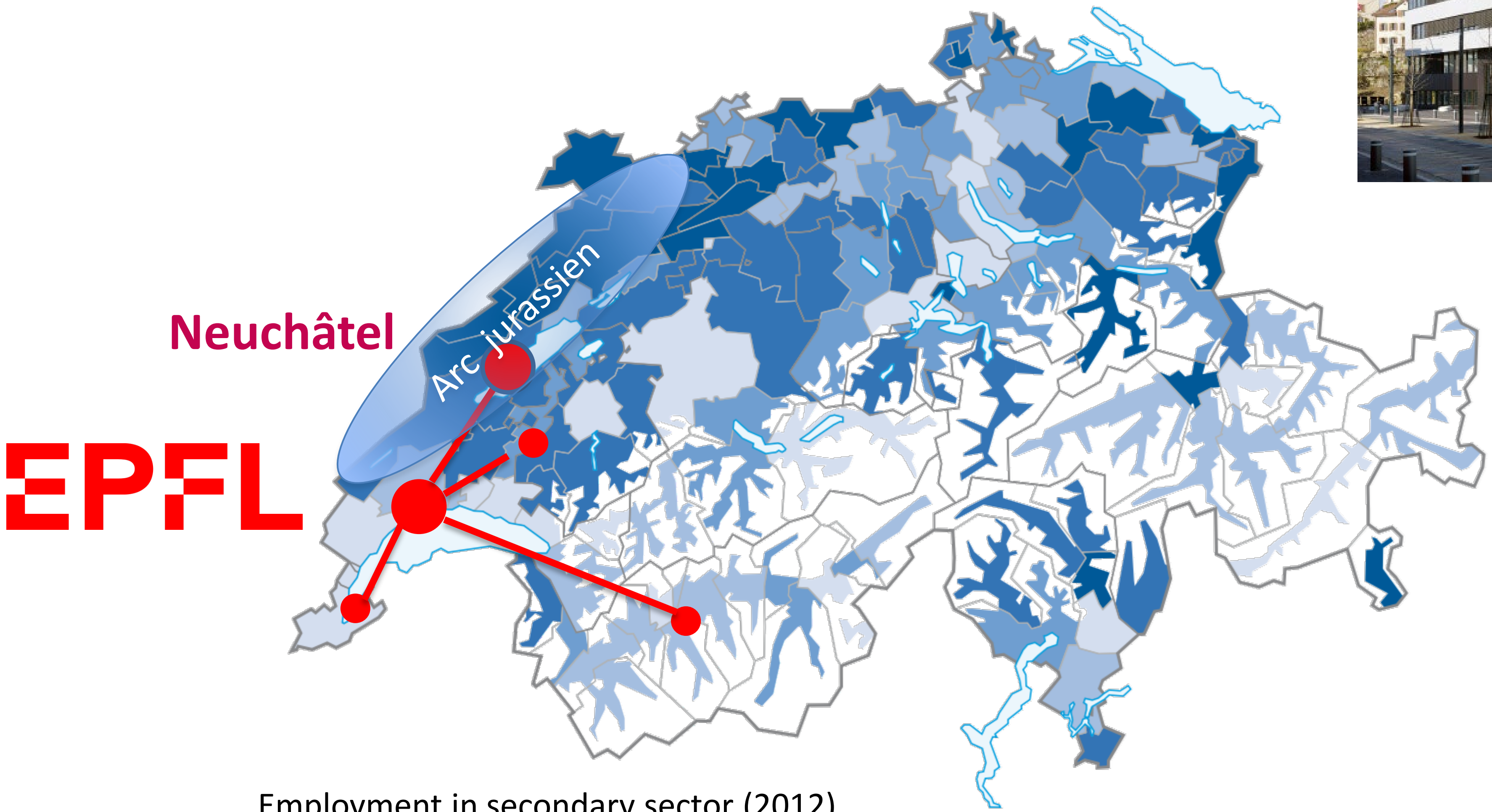
A unique opportunity not only to improve your English skills while applying in a technological context!

Engage in a discussion over sustainability in manufacturing

Importance of manufacturing in Switzerland and beyond…

- High number of jobs in the country **(~ 20 %** is more or less related to it)
- **'Swiss expertise'**
- Strong push worldwide (initiatives in Europe, USA, Asia, …)
- ***This is not 'old science'*** – Hot research topic…

Major manufacturing groups active in watchmaking and Medtech >75% of jobs in highly specialized SMEs



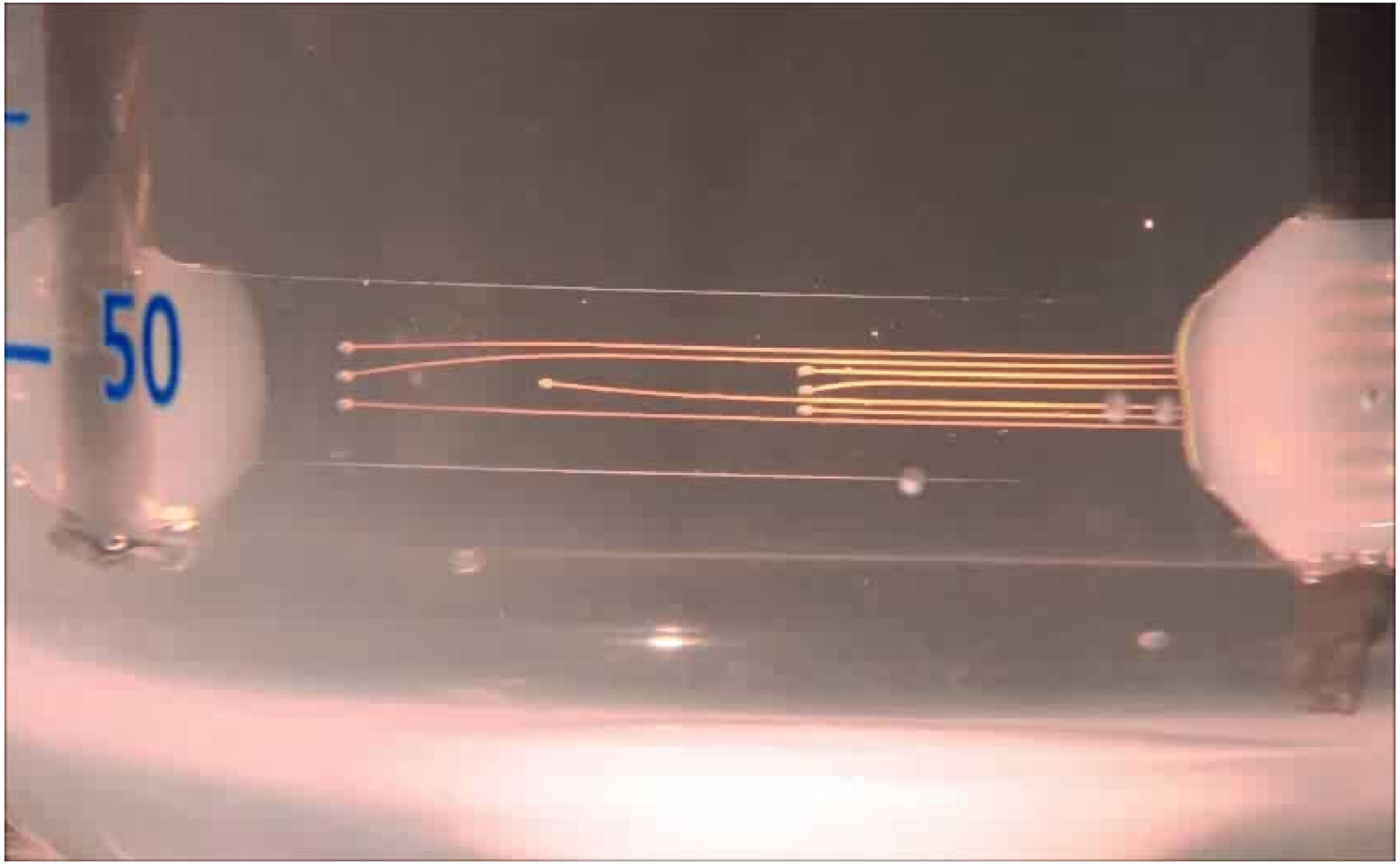
Employment in secondary sector (2012)

< 22,0 | 22,0 - 28,9 | 29,0 - 35,9 | 36,0 - 42,9 | ≥ 43,0

Source: Federal Office of Statistics, February 2015

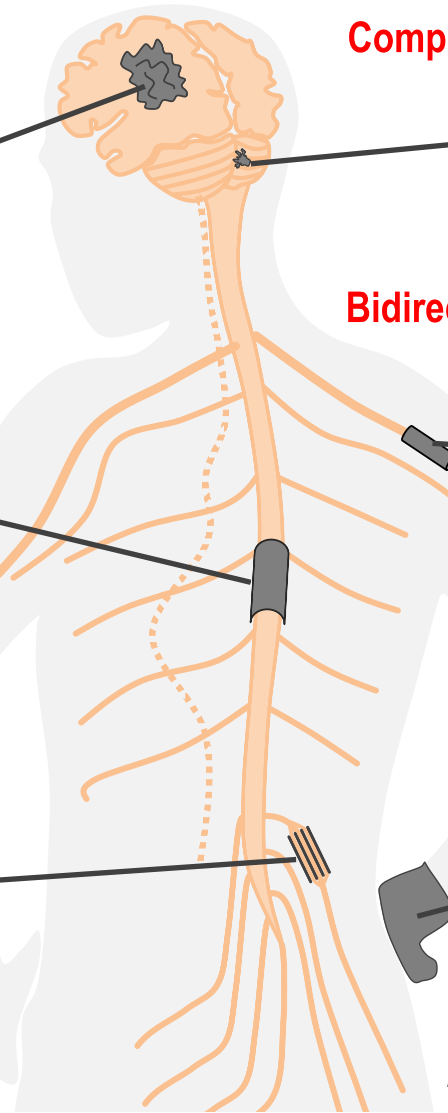
A few illustrative examples of manufacturing research @ EPFL

Mastering 'undeformable material' deformation …



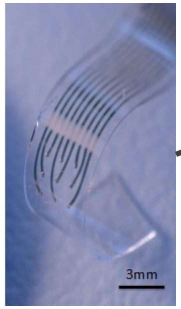
Prof. S. Lacour's lab

... enables new field of soft bioelectronic Interfaces

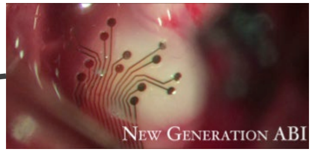


Electrocorticography

Science | 2015 |
Nature Medicine | 2016 |

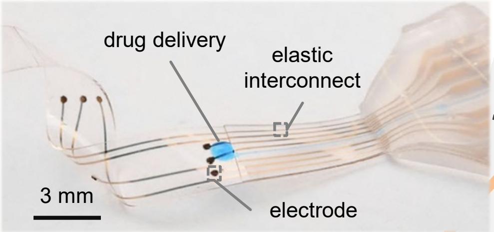


Compliant auditory brainstem implants

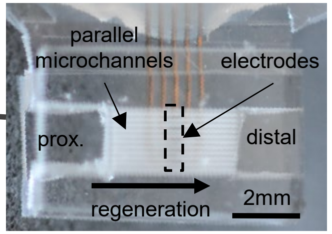


J. Mat. Chem. | 2015 |

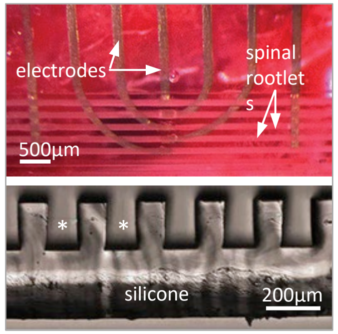
Electronic dura mater



Bidirectional regenerative microchannel electrodes



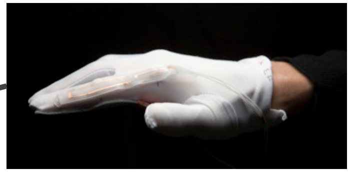
Nature Scientific Reports | 2015 |

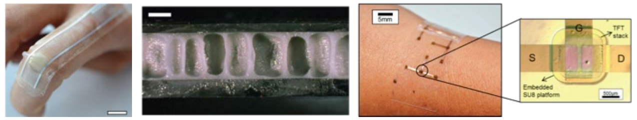


Microchannel spinal root electrodes

Science Trans. Medicine | 2014 |

Wearable Electronic skin





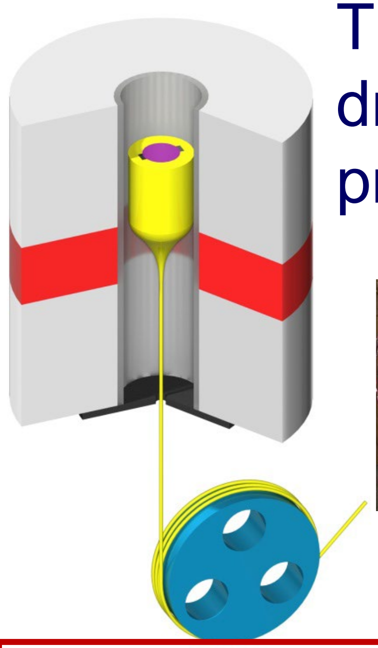
Adv. Mat. | 2012; **Adv. Funct. Mat.** | 2015; **Adv. Mat.** | 2016

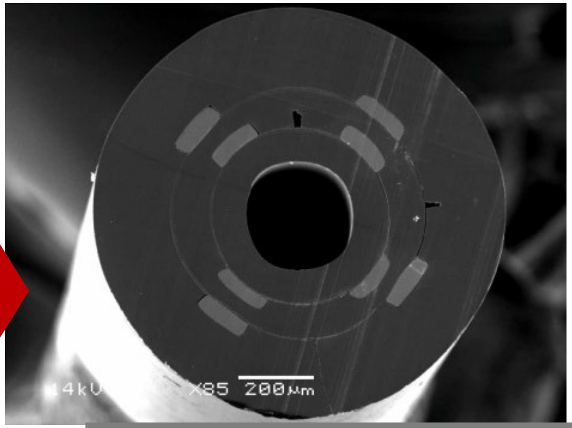
(Profs. S. Lacour's lab / & Courtine's lab)

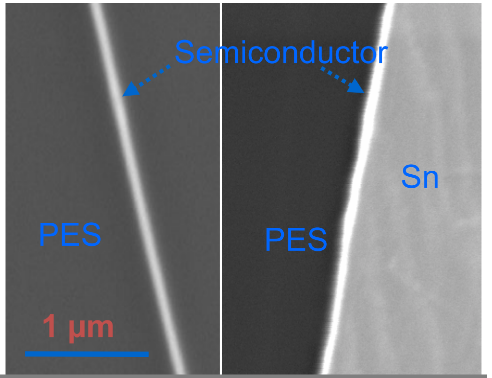
Multi-material functional fibers

(Prof. Fabien Sorin's lab.)

Thermal drawing process

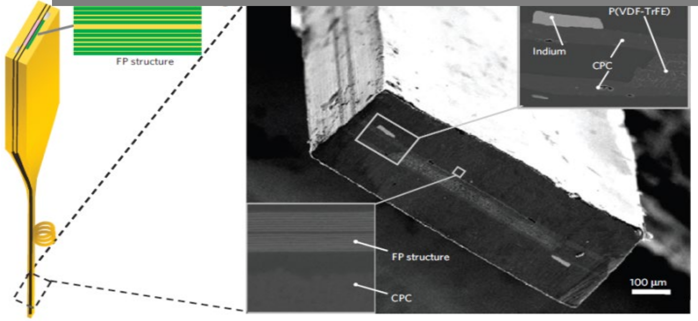


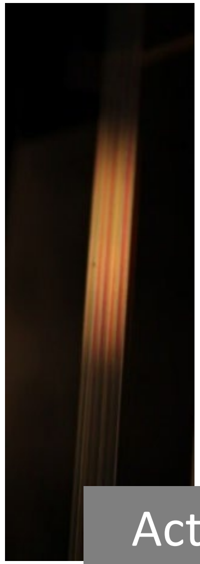


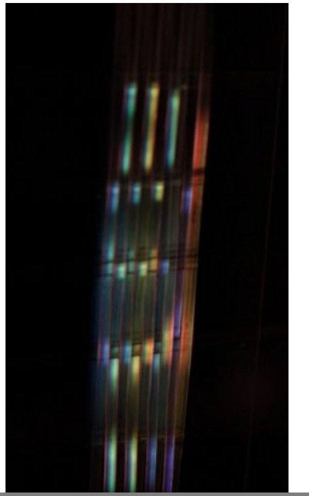


Electronic and Optoelectronic fibers:
Energy harvesting and storage

Piezoelectric and piezo-resistive fibers



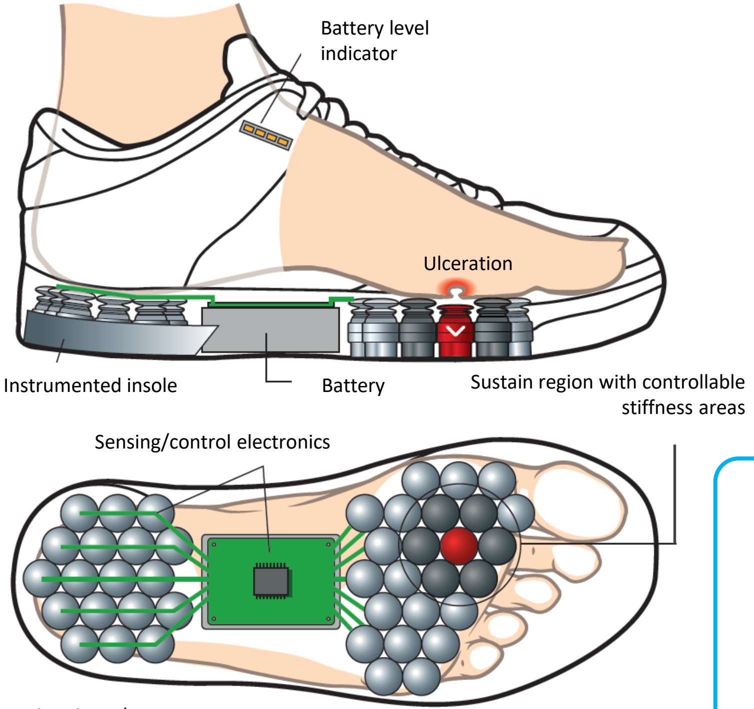




Active and passive emissive photonic fibers

3D Printing-enables intelligent footwear…

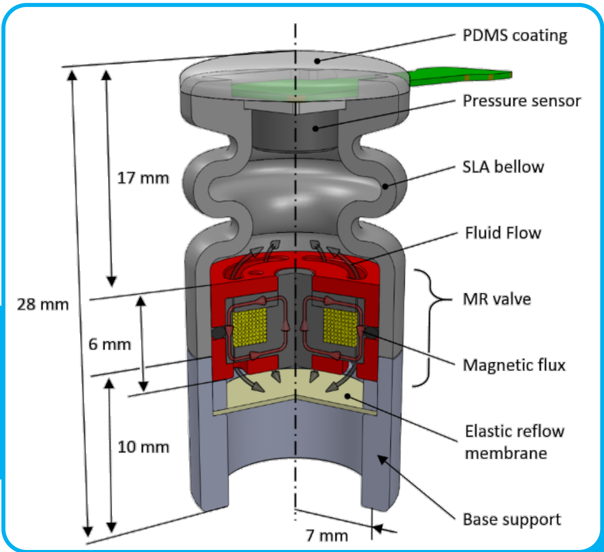
Offloading principle



Pascal Coderay/EPFL, 2016

Smart insole – Realized noncept

A. Herzog/EPFL, 2016

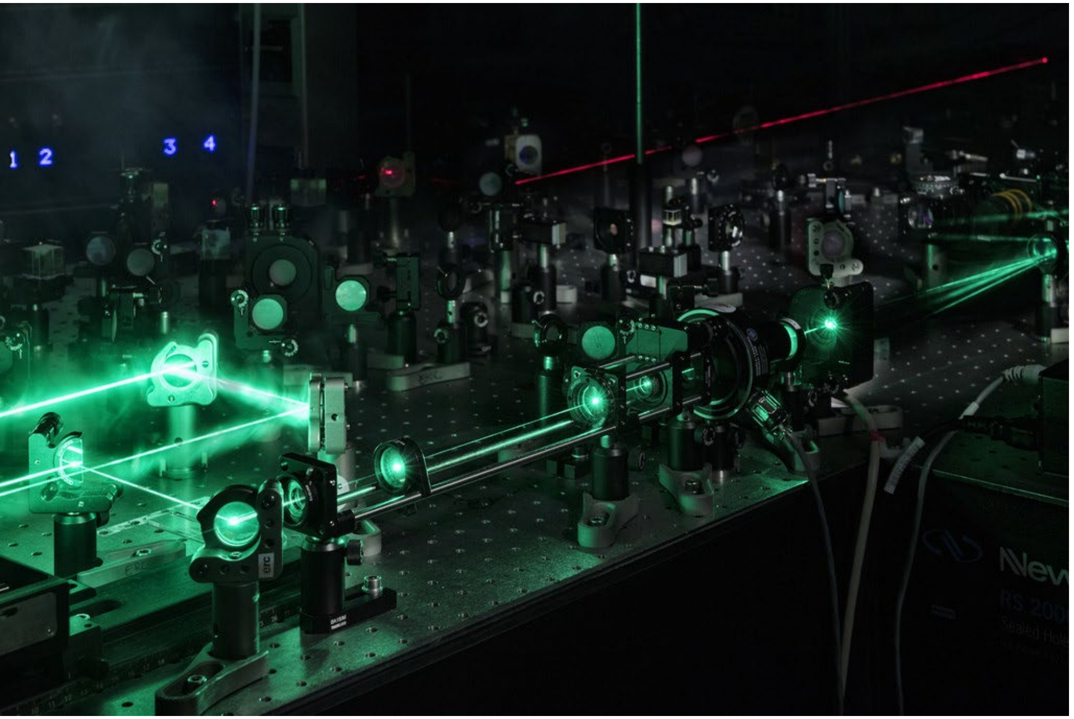


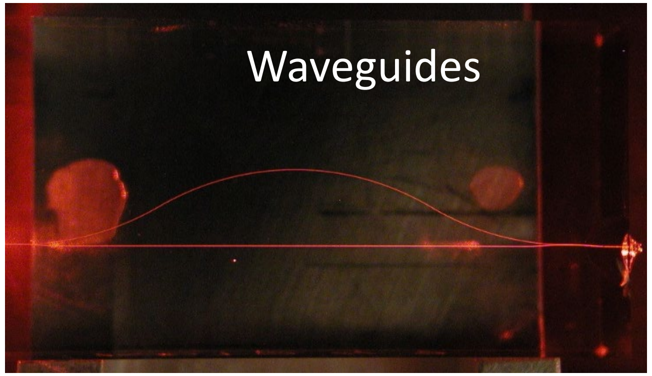
Miniature MR (Magneto-Rheological) Shock Absorber

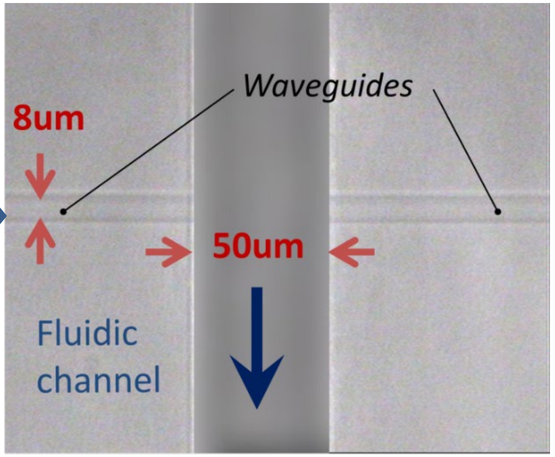
- High miniaturization level
- Low complexity (13 parts)
- Low power consumption (≈ 100 mW)
- High sustainable load (up to 60 N)

HUG Hôpitaux Universitaires de Genève

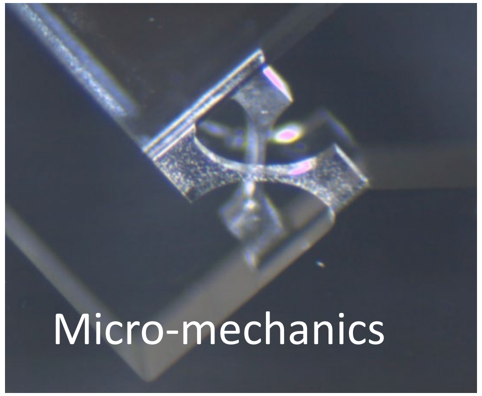
Ultrafast laser processing enables direct-write systems...



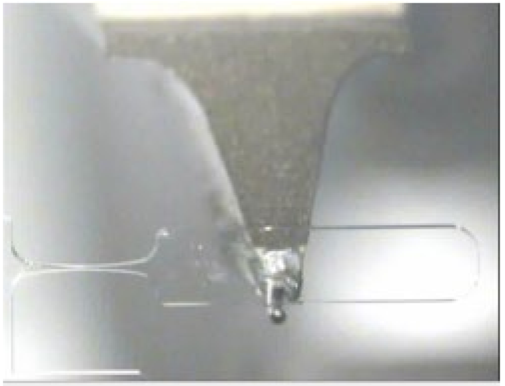


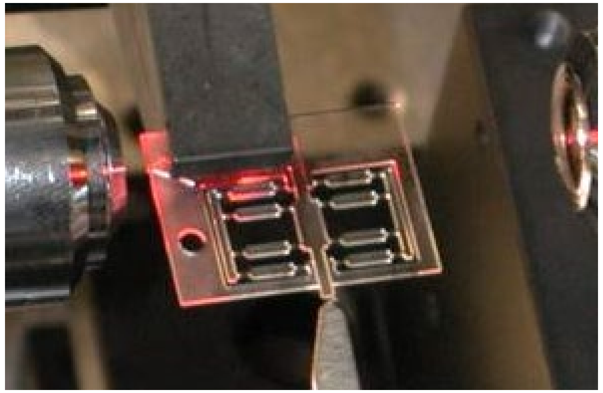


Lab-on-a-chip



Sensors





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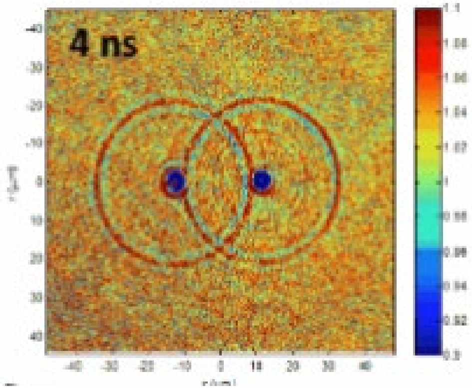
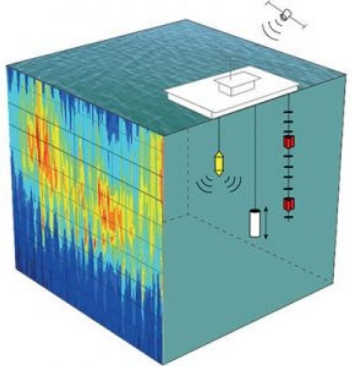
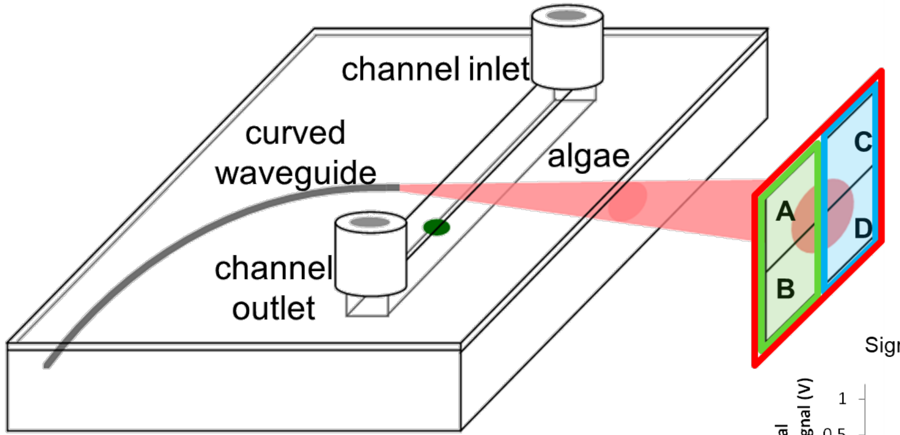
https://galatea.epfl.ch/

Prof. Yves Bellouard

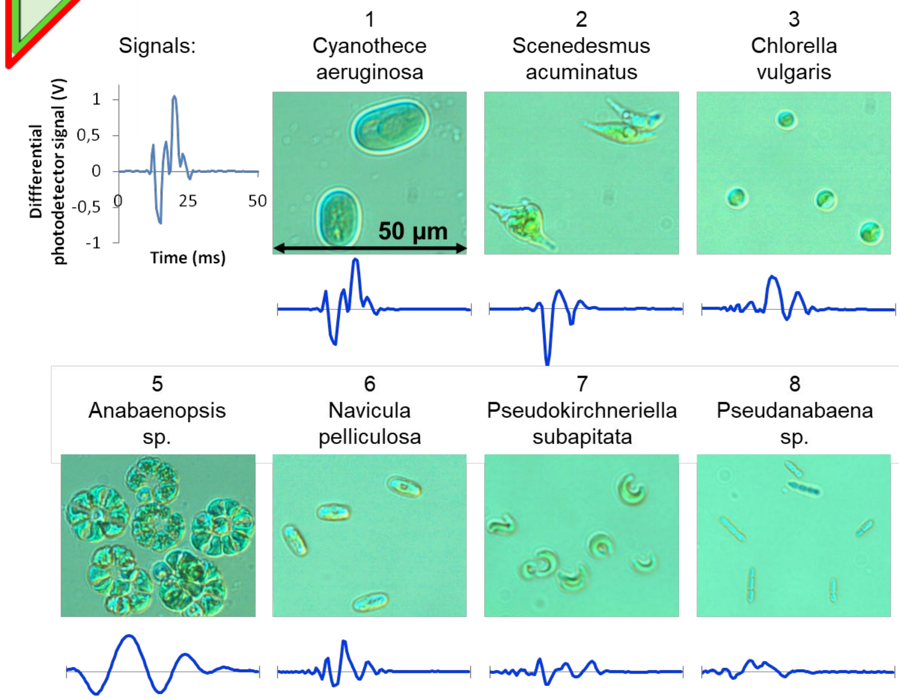




Algae population monitoring



Optofluidics chip



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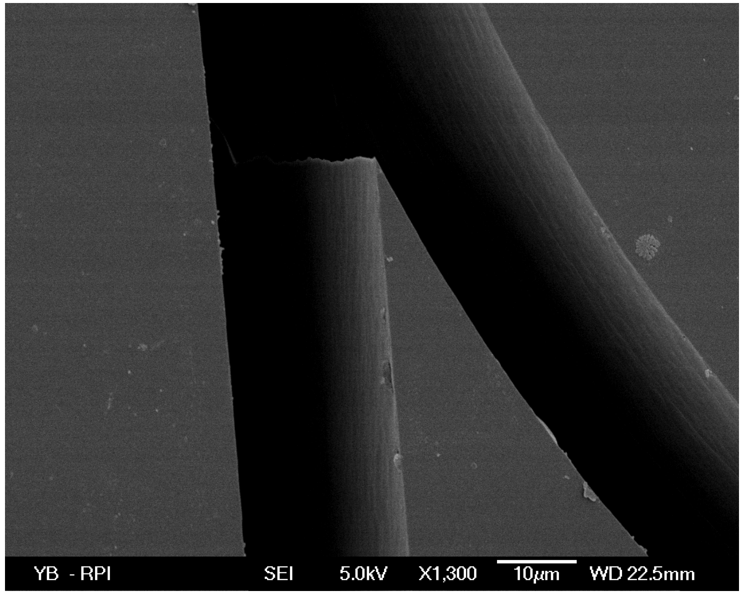
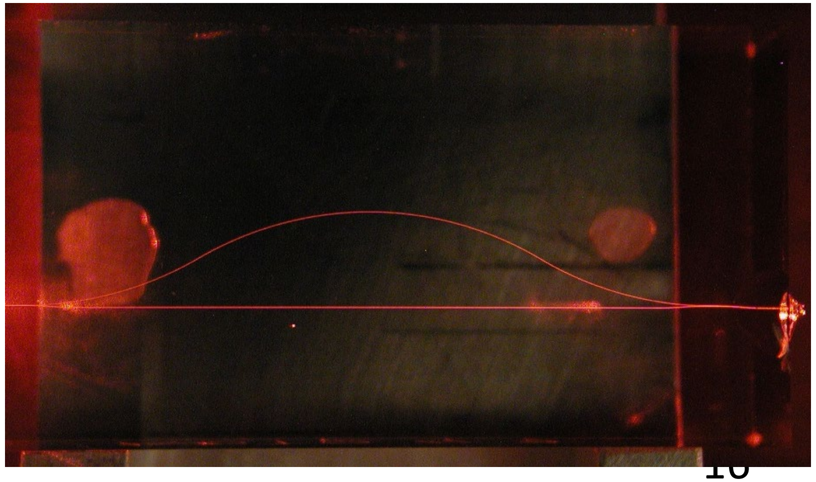
Fluidic channels



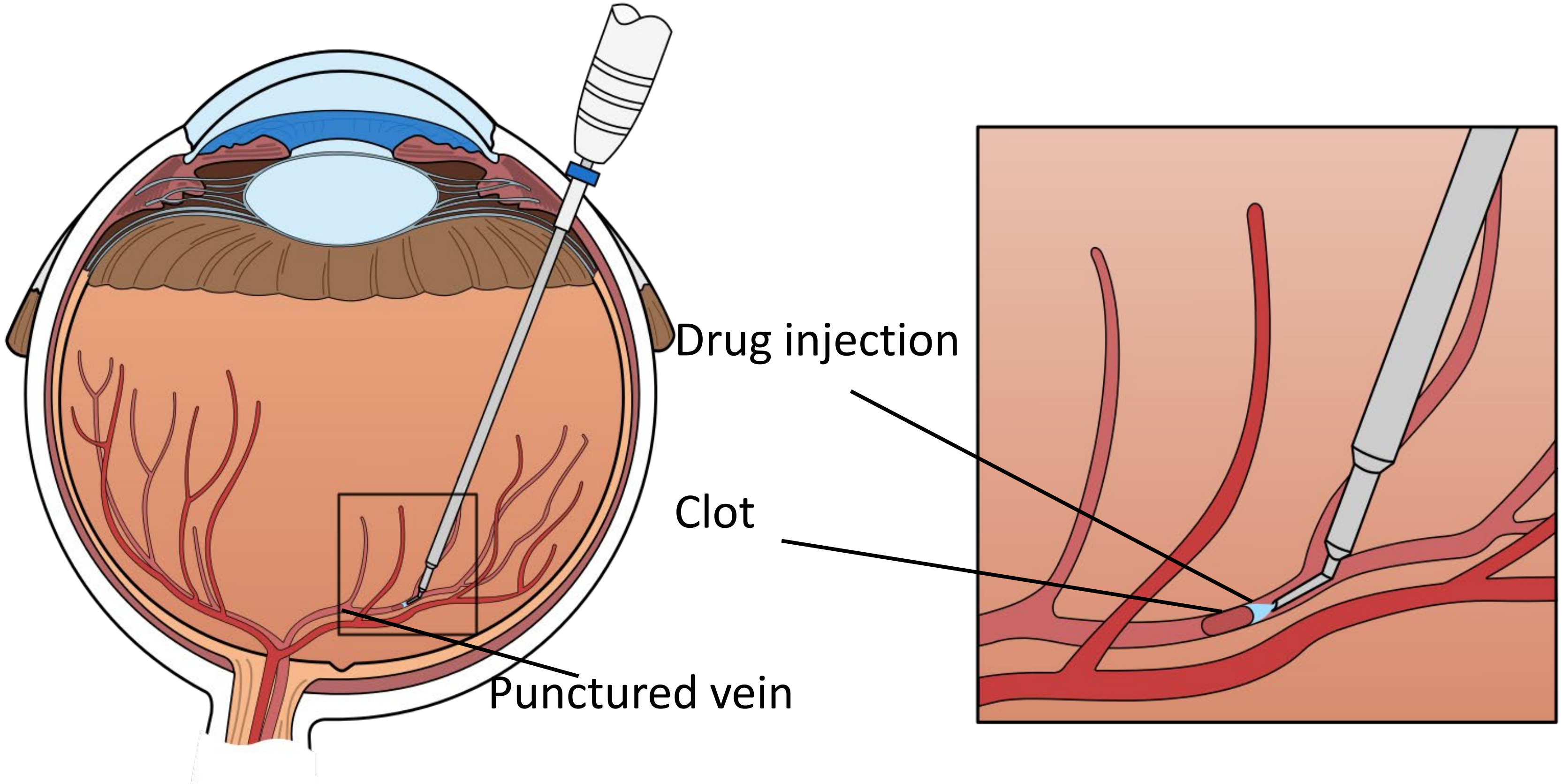
Optical waveguides

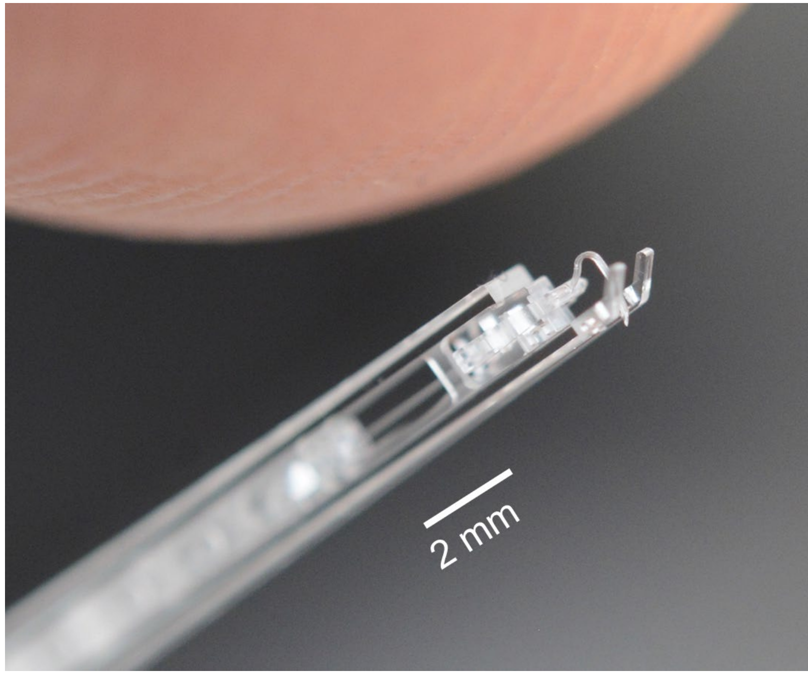


eawag aquatic research

UNIVERSITÉ DE GENÈVE

Illustration: Retinal vein canulation





Hôpital ophtalmique Jules-Gonin

FEMTOprint
3D printing for glass microdevices

INSTANT-LAB

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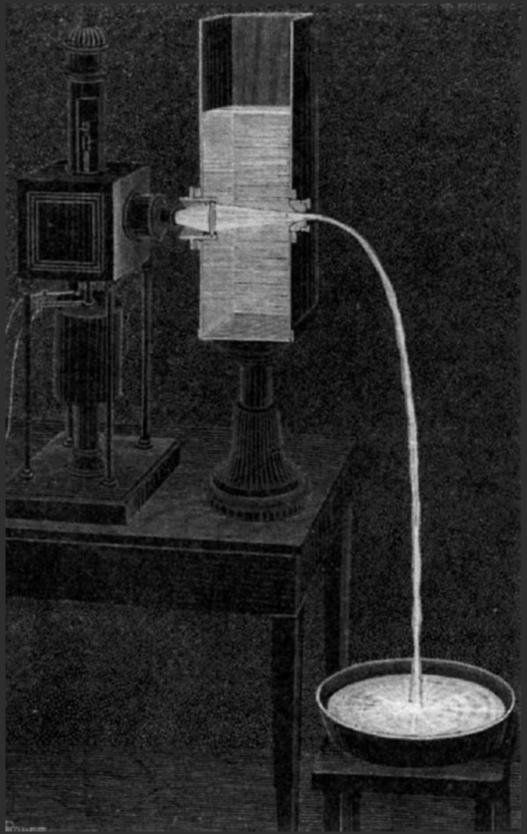
Manufacturing is an enabler for product innovations…

From a concept…



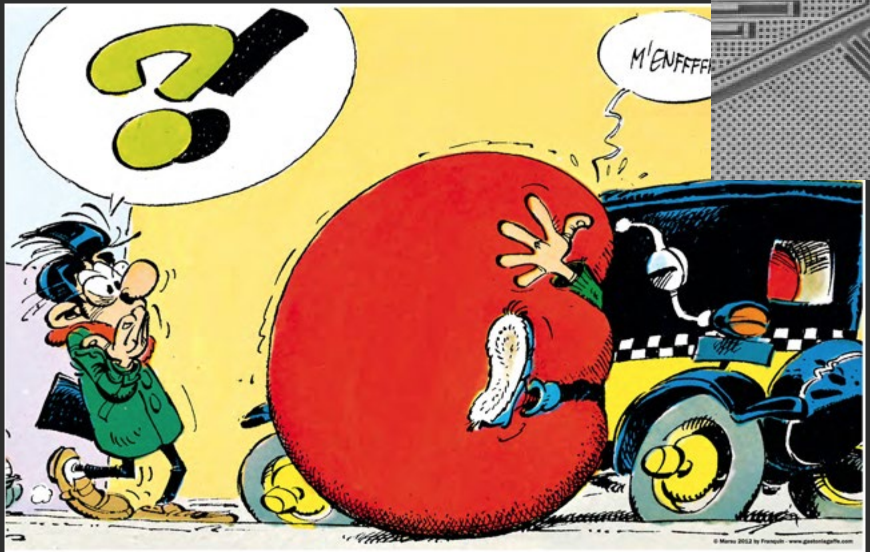
(Colladon 1842)

(Fiber drawing tower, ORC, Univ. of Southampton)

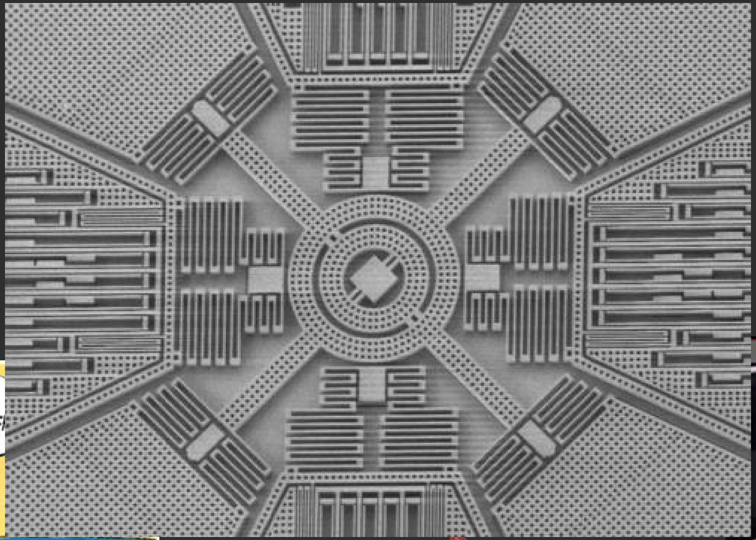
… to a mass product

Manufacturing is an enabler for product innovations…

From a concept…



(Franquin, 70s, Dargaud)

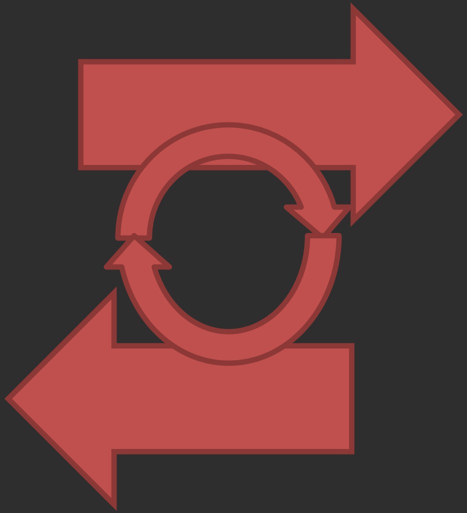


… to a product

The tool or the idea, which comes first?

From the tool …

… to the idea?



… to the tool?

From the idea…

~ -21 000 BC

(sources: Hominidés.com, Wiki)

Course overall learning objectives

- **Understand** how process, design, and materials are closely linked together and interdependent
- **Learn about** existing manufacturing processes
- **Understand** the underlying physical principles and evaluate process limitations
- **Be able** to make a proper choice for a manufacturing process for a given problem

Emphasis on physical processes...

- Understanding **physical processes** behind manufacturing enables you to:

  ✓ *Be aware* of the theoretical limits of a given process

  ✓ *Be able to have a critical look* at what manufacturers propose / cost related to manufacturing

  ✓ *Develop a generic understanding* of manufacturing

  ✓ *Activate prior knowledge* acquired in the bachelor phase

Today's learning objectives

- Appreciate how **design / materials / process** are **interlinked**
- An introduction on **material selection process**
- Learn about **Ashby plots** as one method for **selecting material**

Bottles…

Plastic…

(Source Wisegeek)

Metal…

(Source SIGG)

Glass…

(Source DIYhomedecorguide.com)

Why choosing these materials?

Many possible (and valid) reasons…

- … reusable and durable (metal)
- … recyclable (polymers, glass, metal)
- … One-time use (polymers, glass)
- … inert (ex. for chemistry) (polymers, glass)
- … long term storage (glass)
- …. elegant (ex. perfumes, etc.) (glass)
- … cost
- … optical properties (etc.)

Comes from product specifications 'Cahier des charges'

How SIGG bottles are made?

https://youtu.be/J_Rnf_aKd-0

How plastics bottles are made?

https://youtu.be/lWMZ1Pmh7uM

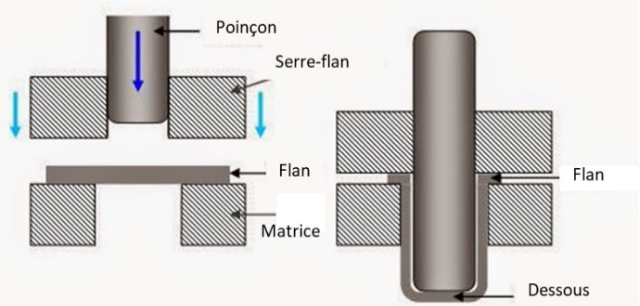
A choice of material determines which process can be used…

(Sigg Bottle)

Metals (Aluminum)

Embossing

Metal forming

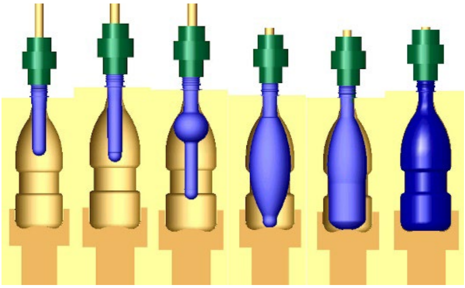


(source CEAL Aluquebec)

Plastics (PET)

Molding (preform)

blow molding



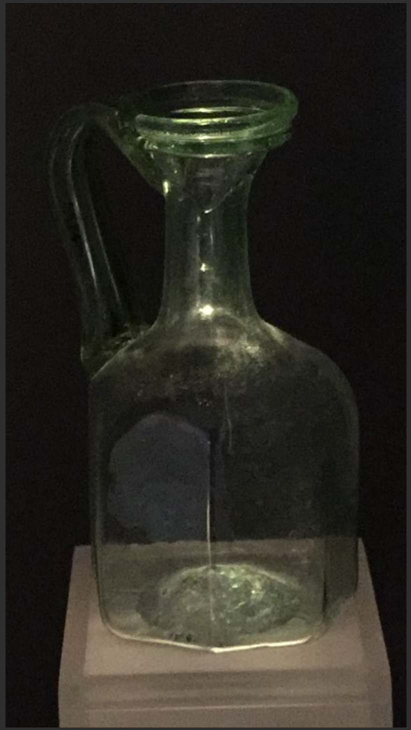
(source Wiki)

Glass: an historical note...

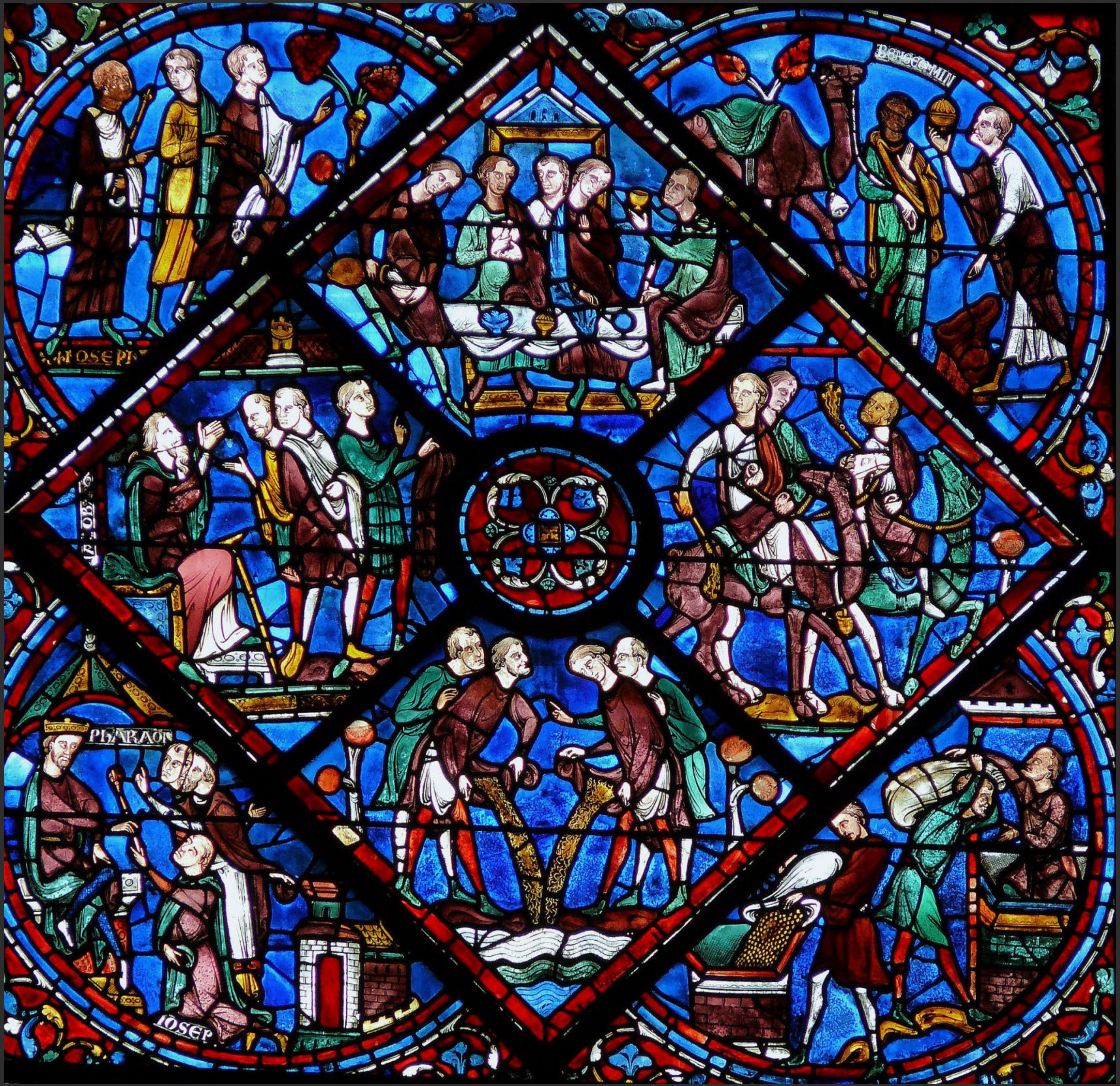
(source carionmineraux.com)

- Since when do we process glass?
  - Processing natural glass (Obsidian) < 11000 BC
  - Molding glass – Mesopotamia, probably ~ 1250 BC
  - Glass blowing (Phoenician? Roman around 1st century BC)

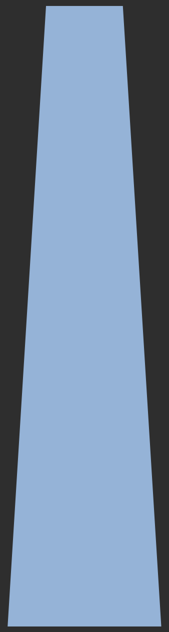
(source YB, Thessoliniki, 3rd c BC)



(source YB, Thessoliniki, 1 c. AD)



Does glass flow?



(Cathedral of Chartres,
~1200 AD, Picture from Mossot)

1/ The physics argument…

$$\log\eta = \log\eta_0 + \frac{B}{(T - T_0)}$$

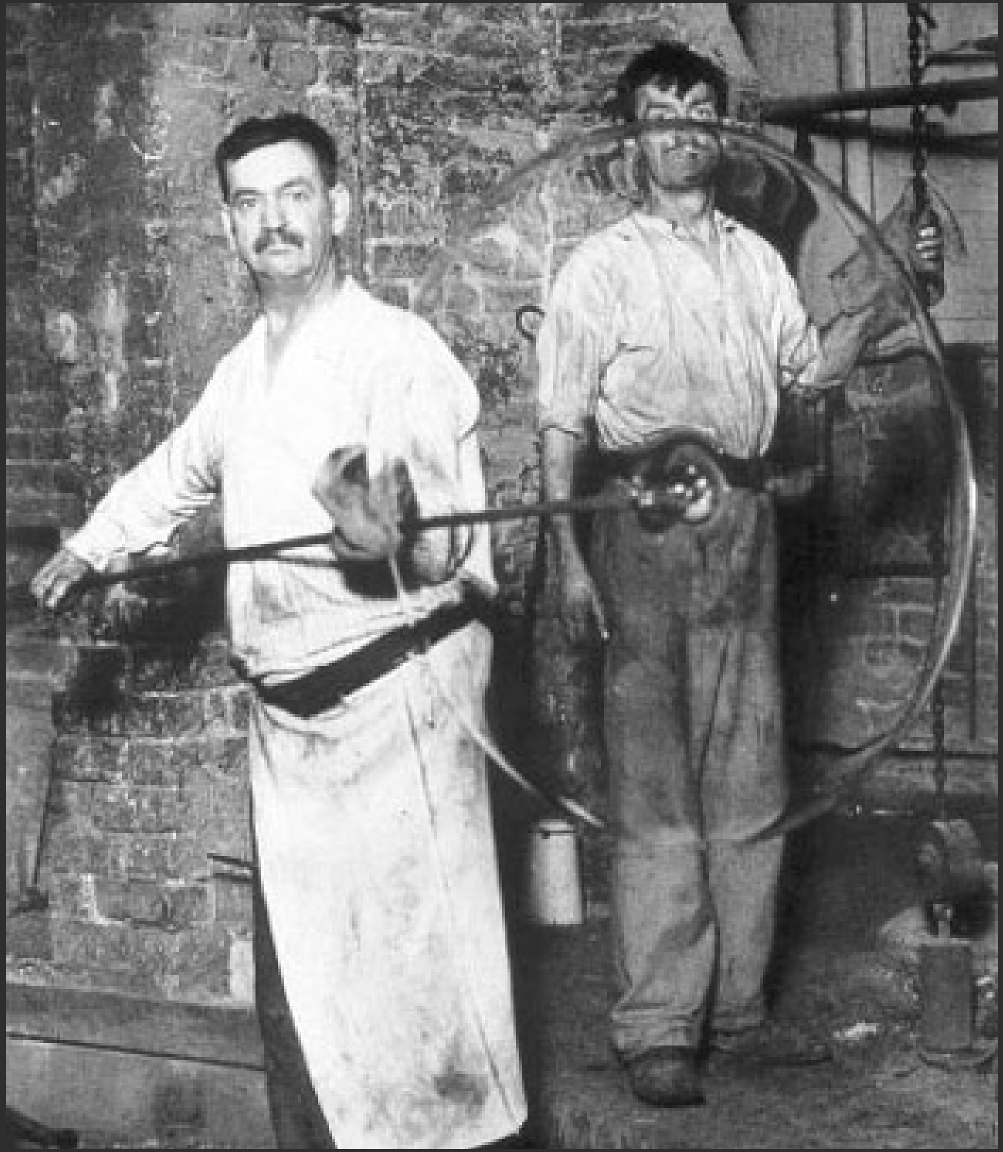
Vogel-Fulcher-Tamman law

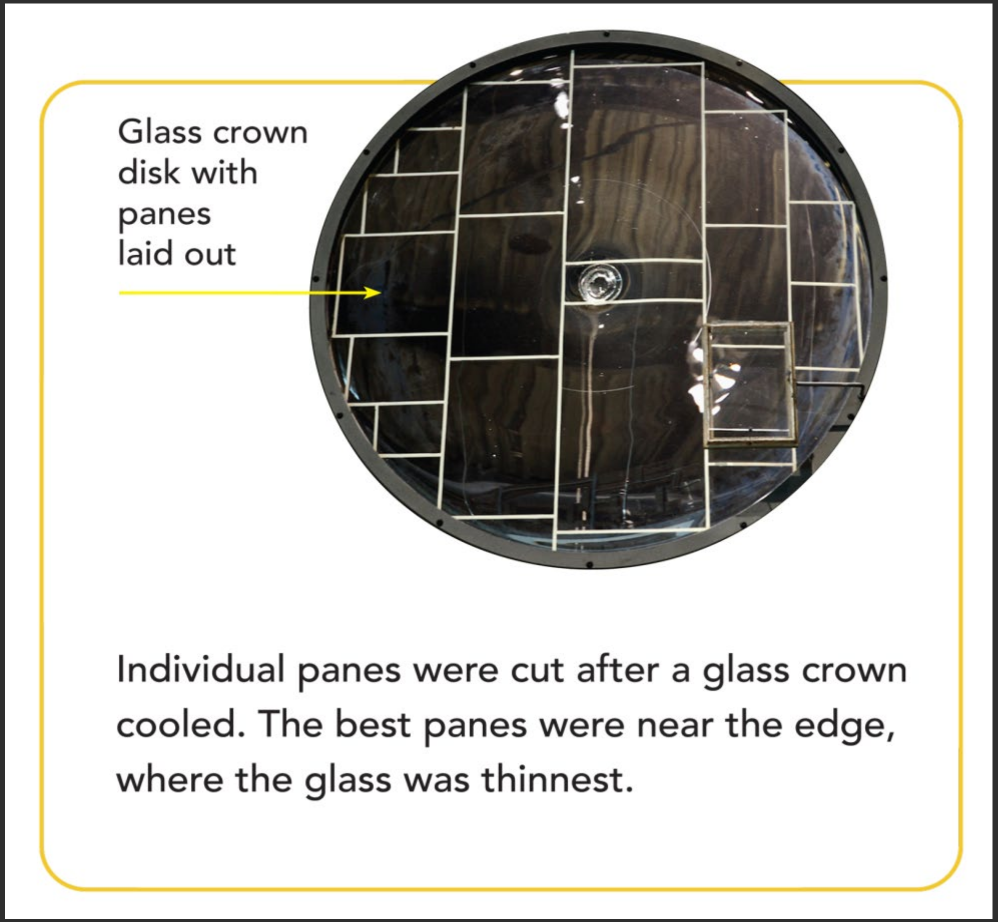
Assuming ultra-high viscosity still has a meaning, it would take about 10^{32} years! (age of the universe: ~ 10^{10} years)

…or hold the glass above 400 deg C, and for 800 yrs to see a flow, that would account for the bevel observed in the cathedral glasses.

Zanotto, "Do cathedral glasses flow?," American Journal of Physics 66, 392–395 (1998).

Crown glass process





(Source: Corning museum)

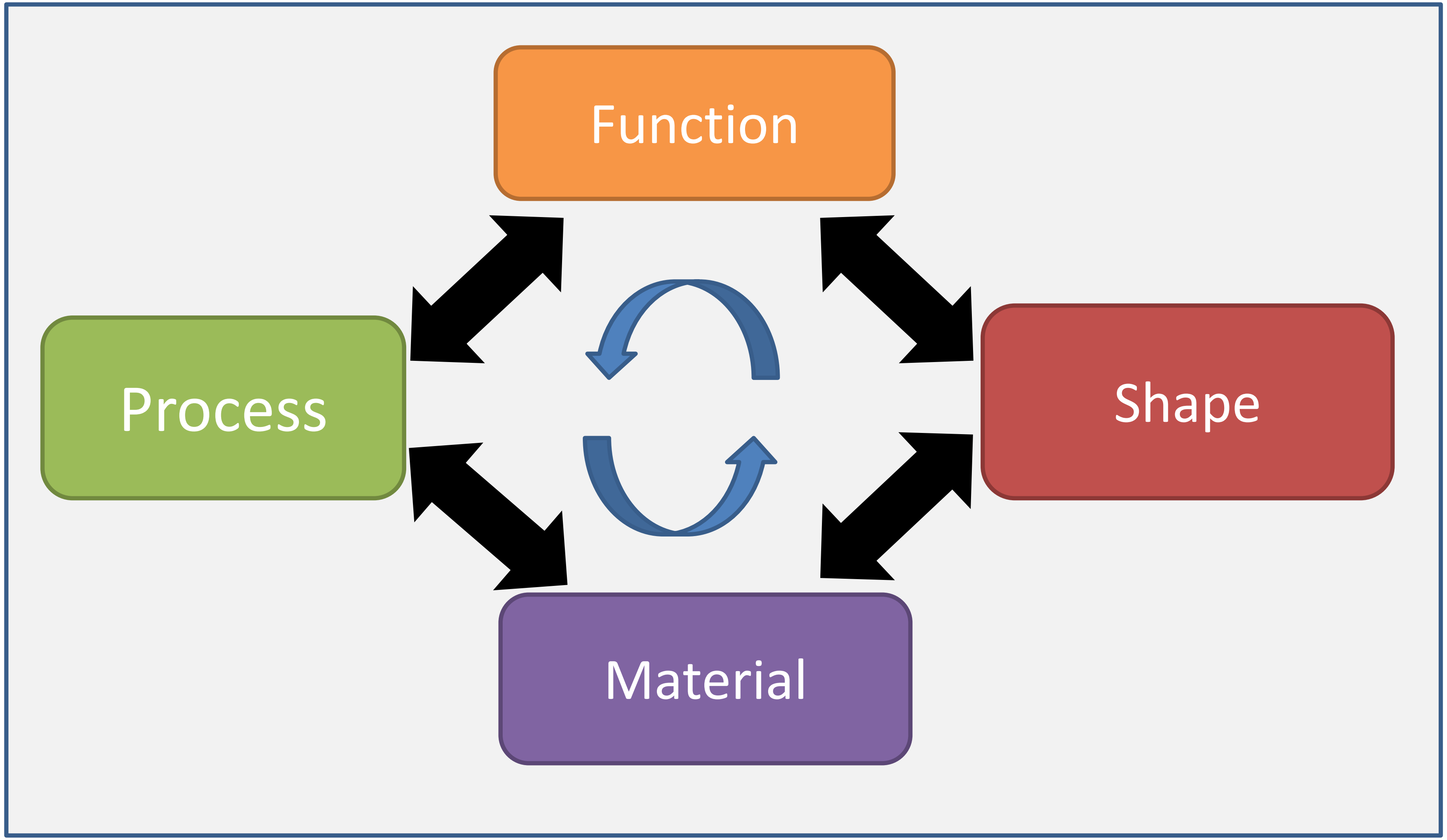
“Glass in Architecture and Decoration” by Raymond McGrath & A.C. Frost, 2nd Edition, London, 1961 [1937], p. 75

2/ The archeological argument: more ancient glass, why they did not flow, then?…

Roman cup (400 AD)
Antikensammlung München

Roman glass (between 351-400 AD), Cadiz, Spain

‘A PART’



How do we choose a material for a given function?

- What criteria?
- What methodology?
- How to make an optimal choice?

Method based on M. F. Ashby plots

Materials properties versus function?

- Mechanical → *Young modulus, Elastic limit, Toughness, Damping (loss coefficient), etc.*
- Thermal → *Melting point, thermal conductivity, thermal expansion, heat conductivity*
- Electrical → *Resistivity, Dielectric properties, Breakdown voltage*
- Optical → *Refractive index, (absorptivity)*

Design related Material properties

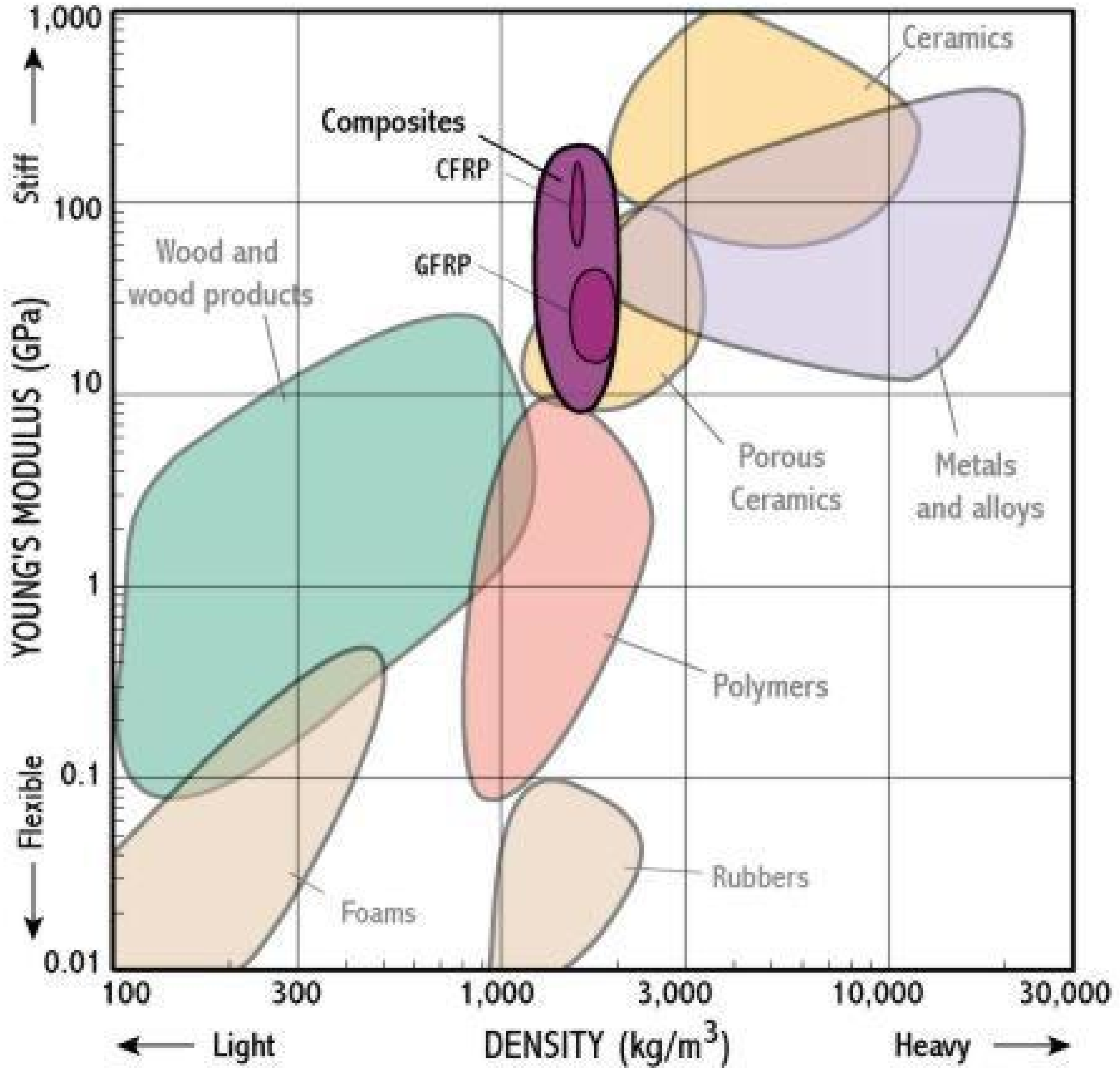
Class	Property	Symbol and Units
General	Density	ρ (kg/m^3 or Mg/m^3)
	Price	C_m (\$/kg)
Mechanical	Elastic moduli (Young's, shear, bulk)	E, G, K (GPa)
	Yield strength	σ_y (MPa)
	Tensile (ultimate) strength	σ_{ts} (MPa)
	Compressive strength	σ_c (MPa)
	Failure strength	σ_f (MPa)
	Hardness	H *(Vickers)*
	Elongation	ε (–)
	Fatigue endurance limit	σ_e (MPa)
	Fracture toughness	K_{1c} (MPa.m$^{1/2}$)
	Toughness	G_{1c} (kJ/m^2)
	Loss coefficient (damping capacity)	η (–)
	Wear rate (Archard) constant	K_A MPa^{-1}
Thermal	Melting point	T_m (°C or K)
	Glass temperature	T_g (°C or K)
	Maximum service temperature	T_{max} (°C or K)
	Minimum service temperature	T_{min} (°C or K)
	Thermal conductivity	λ (W/m.K)
	Specific heat	C_p (J/kg.K)
	Thermal expansion coefficient	α (K^{-1})
	Thermal shock resistance	ΔT_s (°C or K)
Electrical	Electrical resistivity	ρ_e (Ω.m or $\mu\Omega$.cm)
	Dielectric constant	ε_r (–)
	Breakdown potential	V_b (10^6 V/m)
	Power factor	P (–)
Optical	Refractive index	n (–)
Eco-properties	Embodied energy	H_m (MJ/kg)
	Carbon footprint	CO_2 (kg/kg)

(M.F. Ashby, Material selection in mechanical design,
Elsevier, 2011)

Quiz?

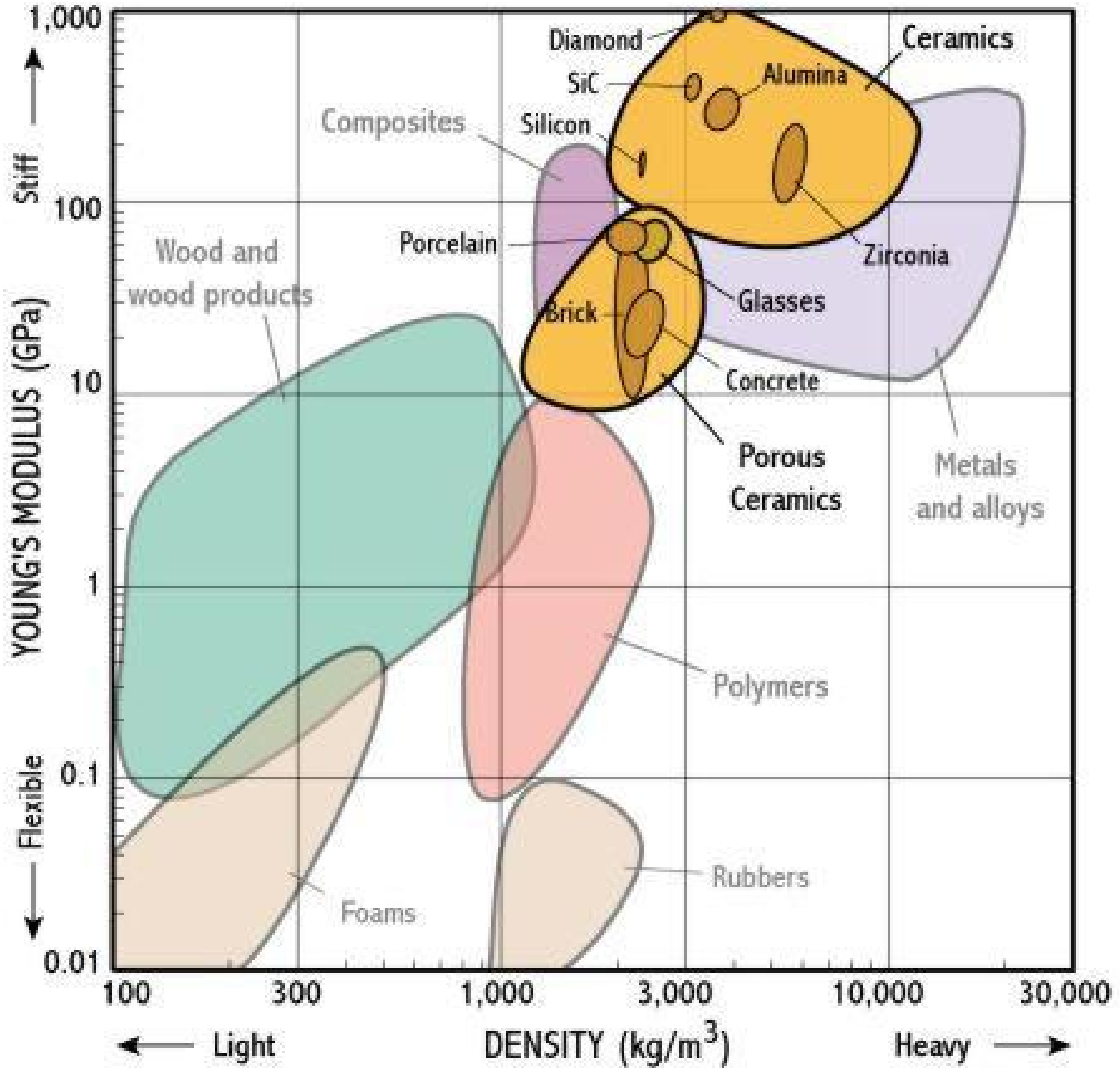
- Highest Young modulus material?
- Heaviest material?
- Highest stiffness/weight ratio materials?
- Lowest stiffness/weight ratio materials?

Ashby's plot



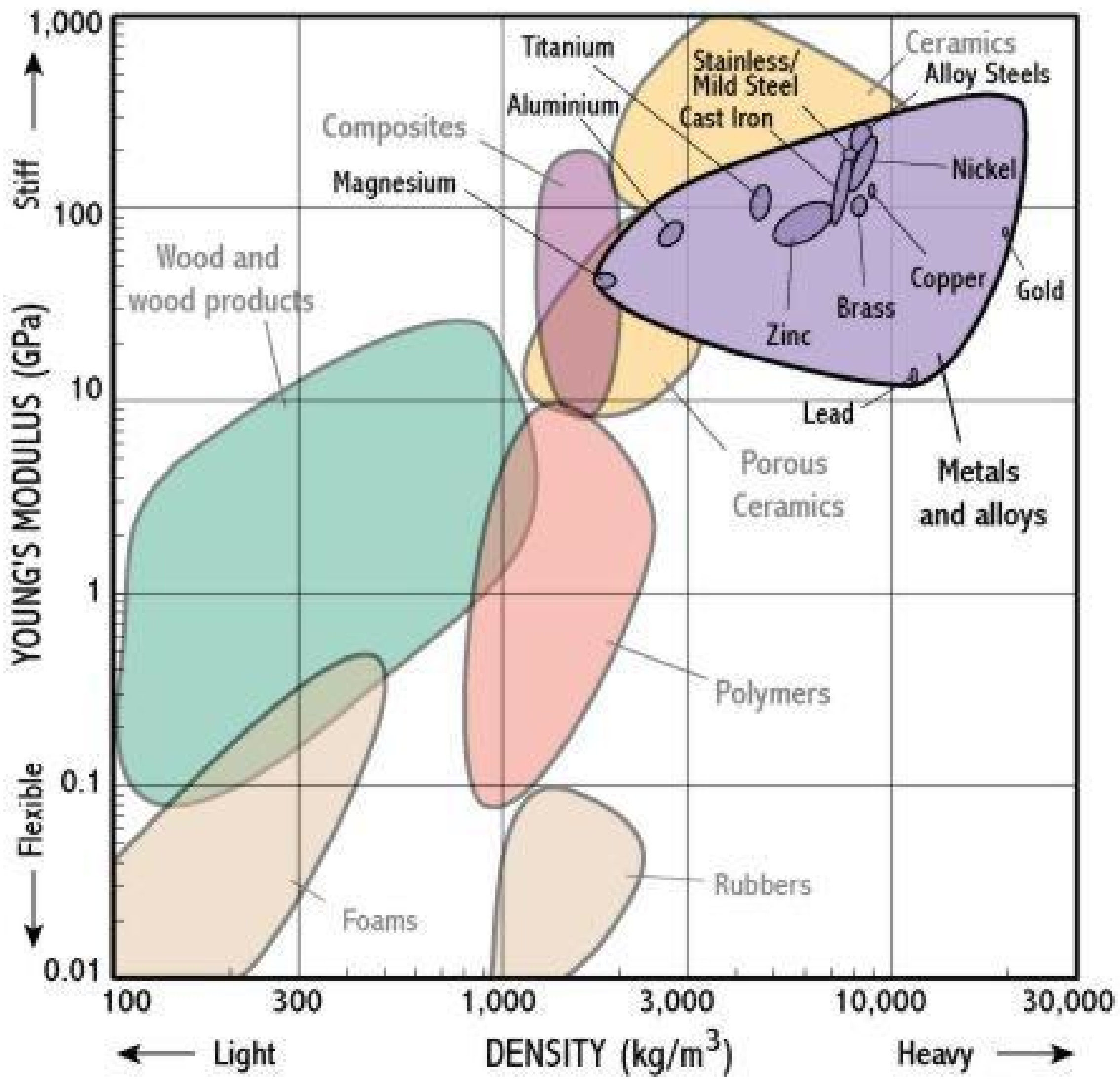
(source Cambridge University)

Ashby’s plot



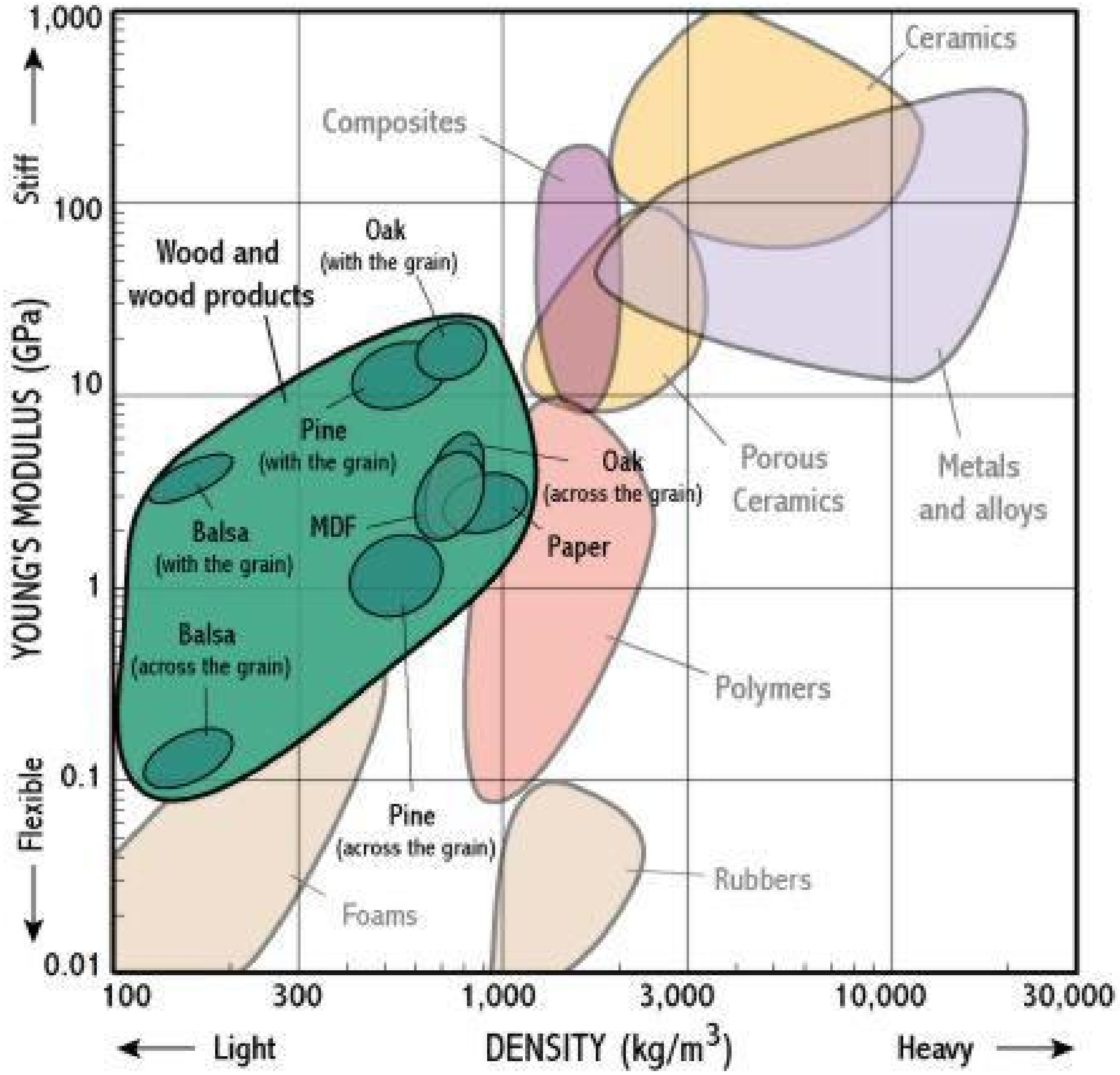
(source Cambridge University)

Ashby's plot



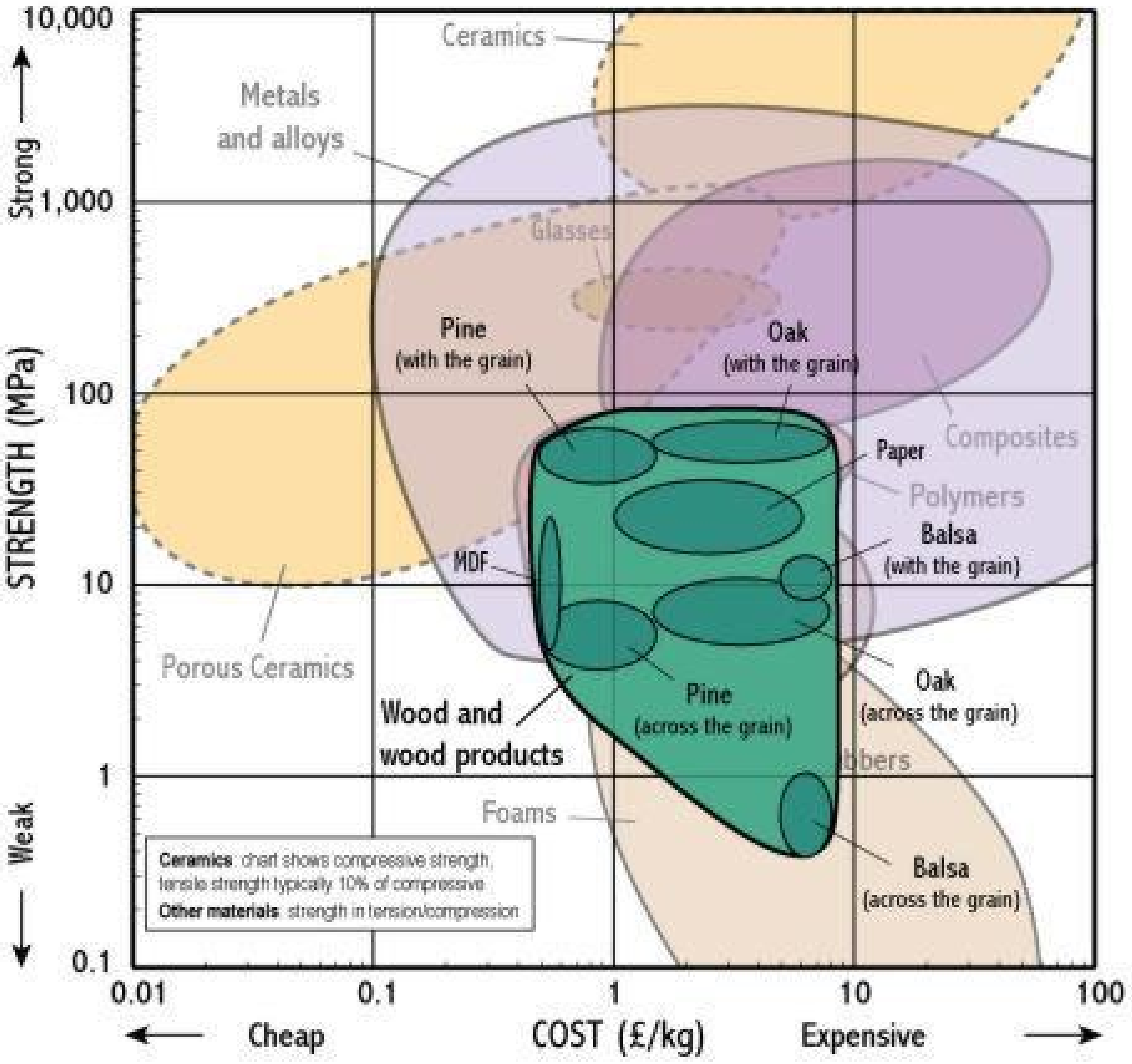
(source Cambridge University)

Ashby's plot



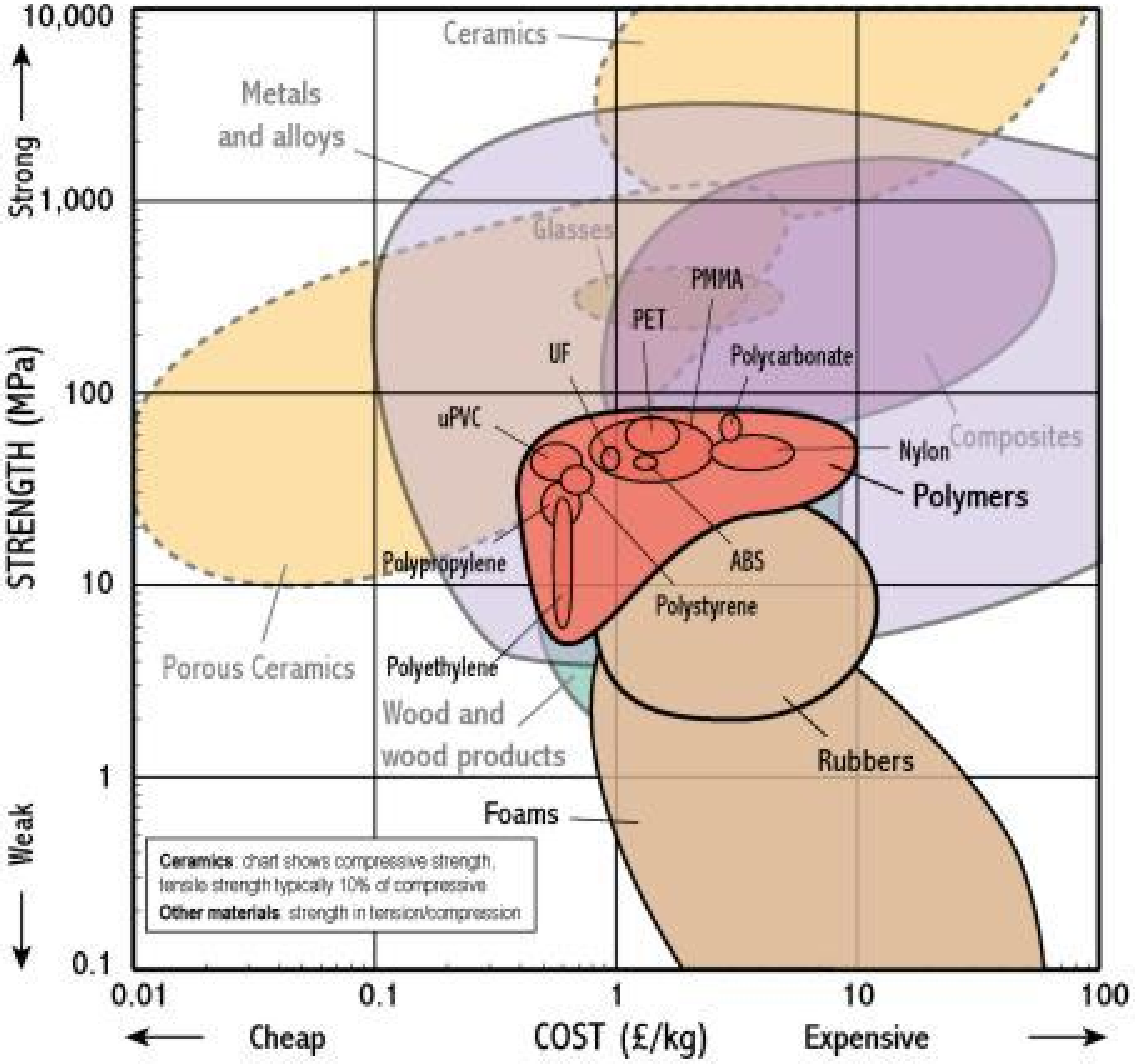
(source Cambridge University)

Cost vs strength



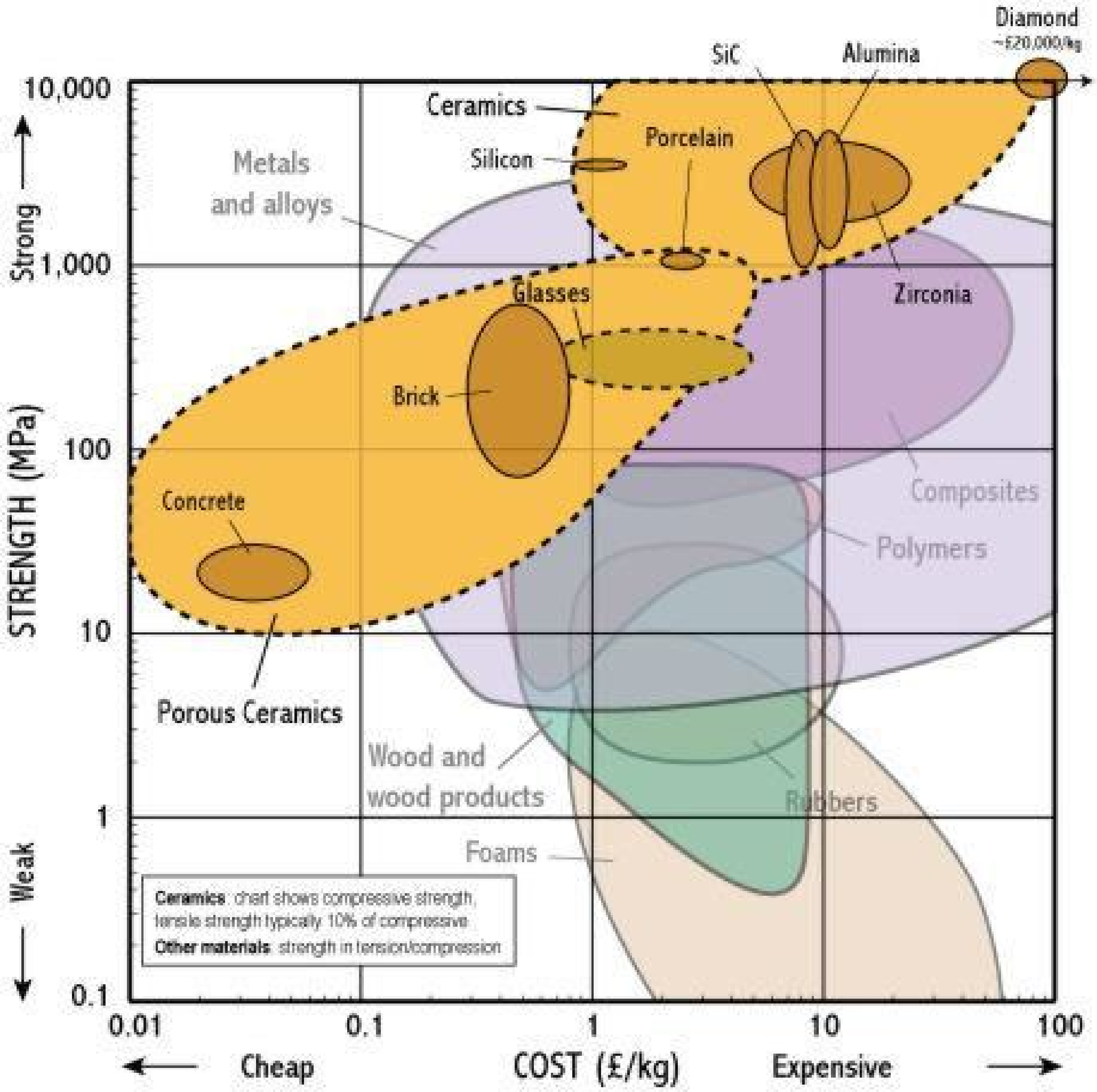
(source Cambridge University)

Cost vs strength



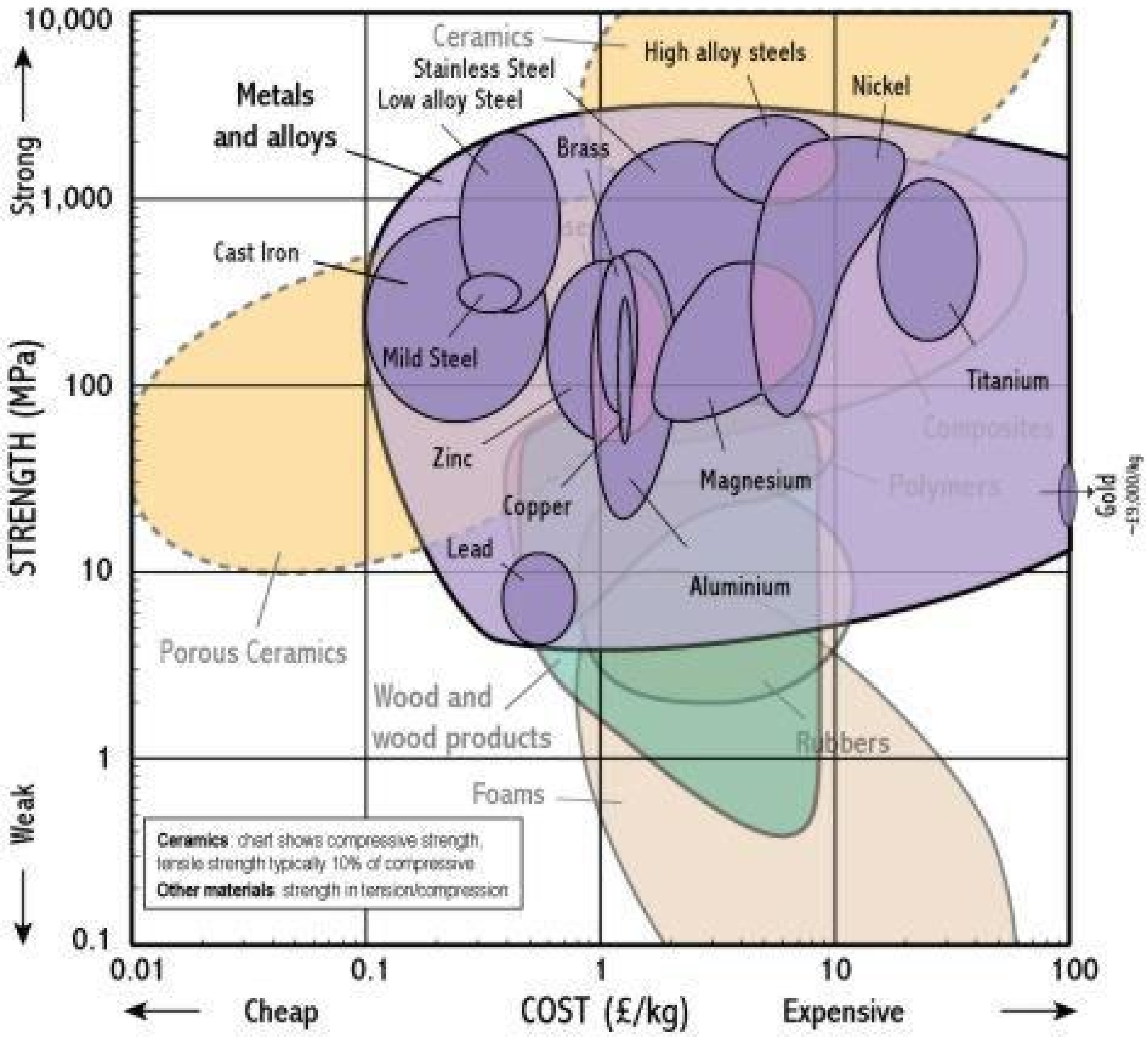
(source Cambridge University)

Cost vs strength



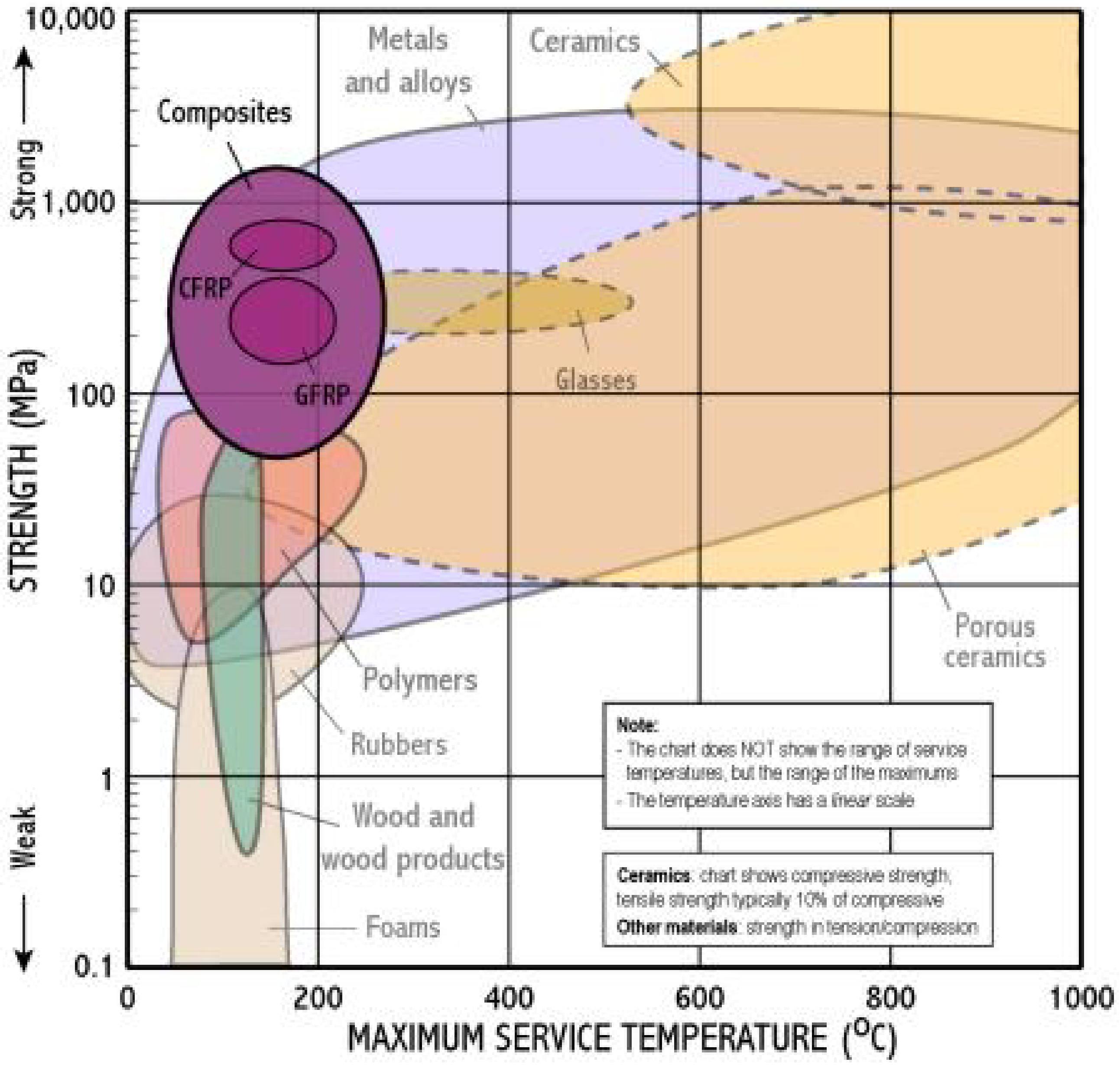
(source Cambridge University)

Cost vs strength

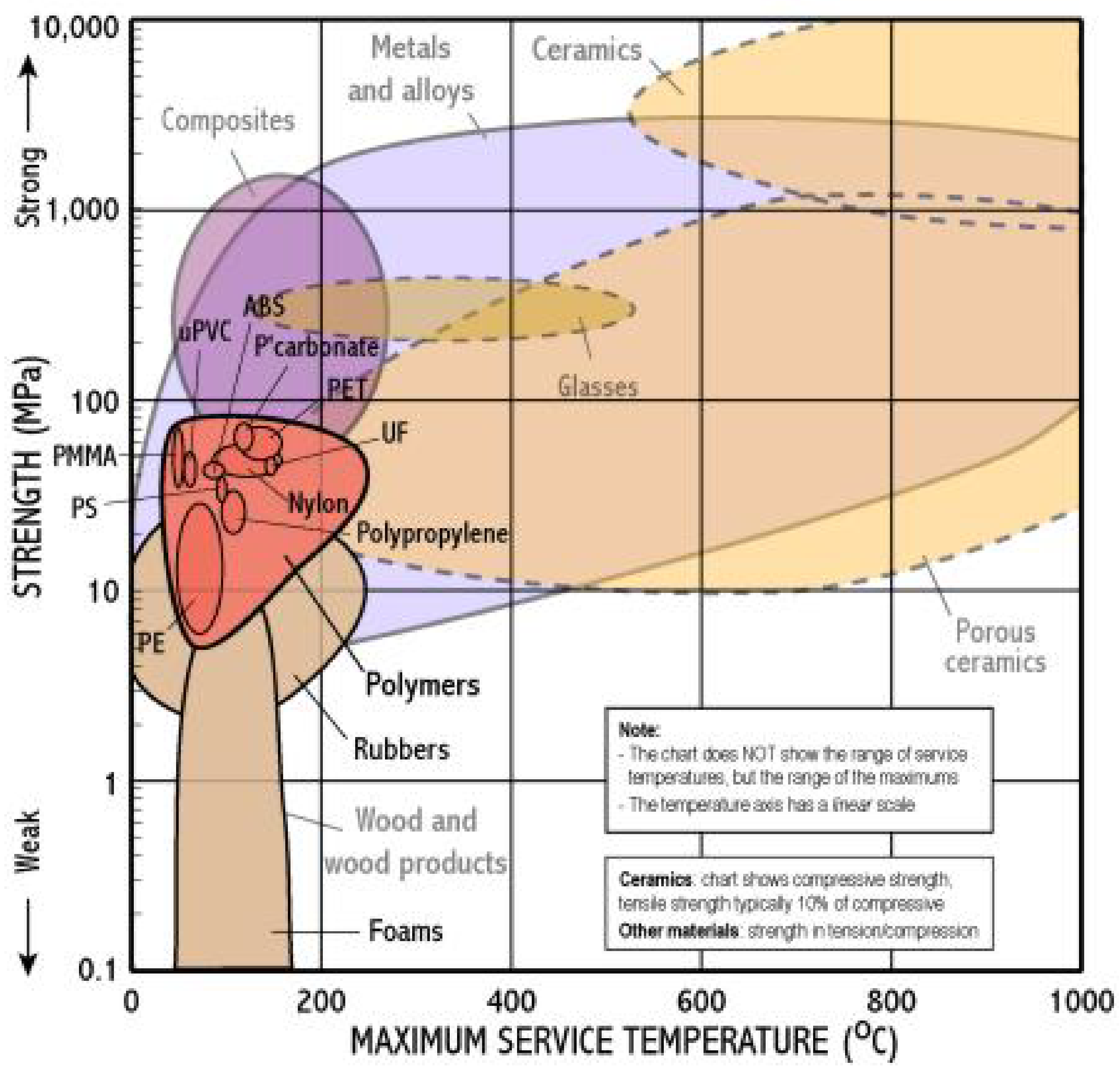


(source Cambridge University)

Strengh vs service temperature

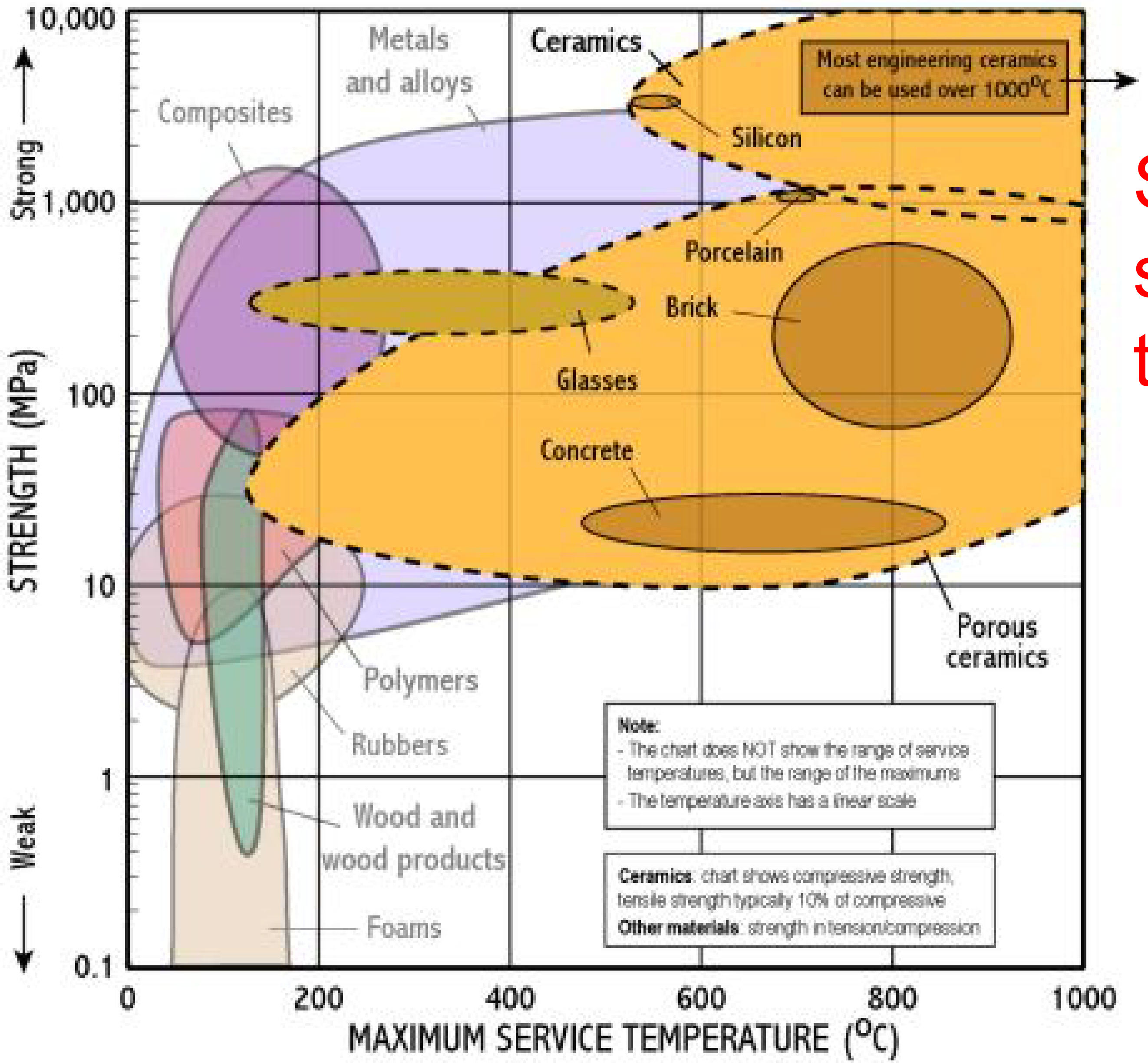


(source Cambridge University)



Strengh vs service temperature

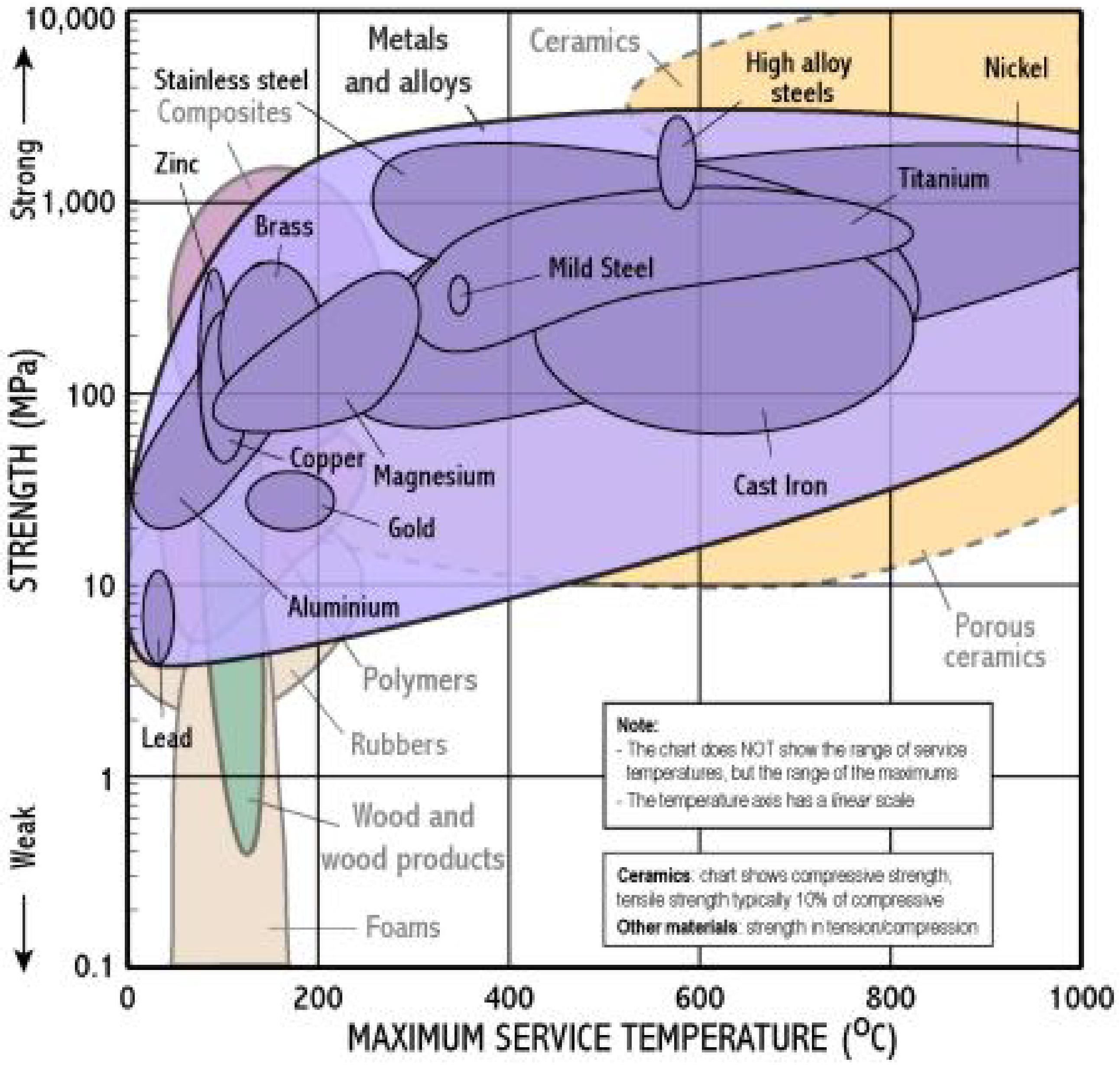
(source Cambridge University)



Strengh vs service temperature

(source Cambridge University)

Strengh vs service temperature



(source Cambridge University)

Many other plots...

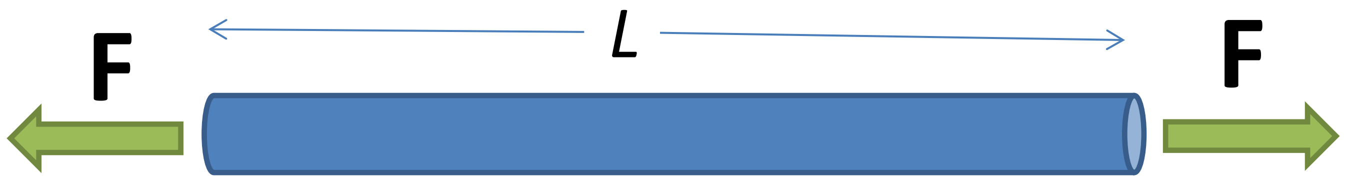
- Young's modulus - Density
- Young's Modulus - Cost
- Strength - Density
- Strength - Toughness
- Strength - Elongation
- Strength - Cost
- Strength - Max service temperature
- Electrical resistivity - Cost
- Recycle Fraction - Cost
- Etc…

Ashby's method

- **'Translation':** *express design requirements as constraints & objectives*
- **'Screening':** *eliminate materials that cannot do the job*
- **'Ranking':** *find the materials that do the job best*
- **'Supporting information':** *explore pedigrees of top-ranked candidates*

Illustration

What *material parameters* should we optimize to *minimize the mass* of a tie of length L and achieve the *maximum strength* in tension?



Objective function: ‘minimize the mass’ and ‘maximize strength’

Design parameter: length of the tie (L)

Free parameter: Area (A)

Methodology: pose the problem

- **Step 1:** Pose the problem
  - ‘Minimizing mass’

$$m = \overbrace{\rho}^{\textit{Material parameter}}\underbrace{L}_{\text{Design parameter}}\underbrace{A}_{\text{Free variable}}$$

Methodology: pose the problem

- **Step 1** (follow): Define the problem
  - Maximum strength in tension

Free variable

$$\sigma = \frac{F}{A} \rightarrow F_{\max} = \boxed{\sigma_{\max}}\boxed{A}$$

Material data

- **Step 2:** Eliminate free variables to define an objective function

Design parameter

$$\frac{m}{F_{\max}} = \boxed{\left(\frac{\rho}{\sigma_{\max}}\right)}\boxed{L}$$

Material data

Define an optimization problem

- Minimizing mass while achieving the highest strength is equivalent to looking for a material that maximizes:

$$C = \left(\frac{\sigma_{\max}}{\rho} \right)$$

(in which C is a constant)

- In an log-log Ashby plot, this is a family of straight line of slope 1.

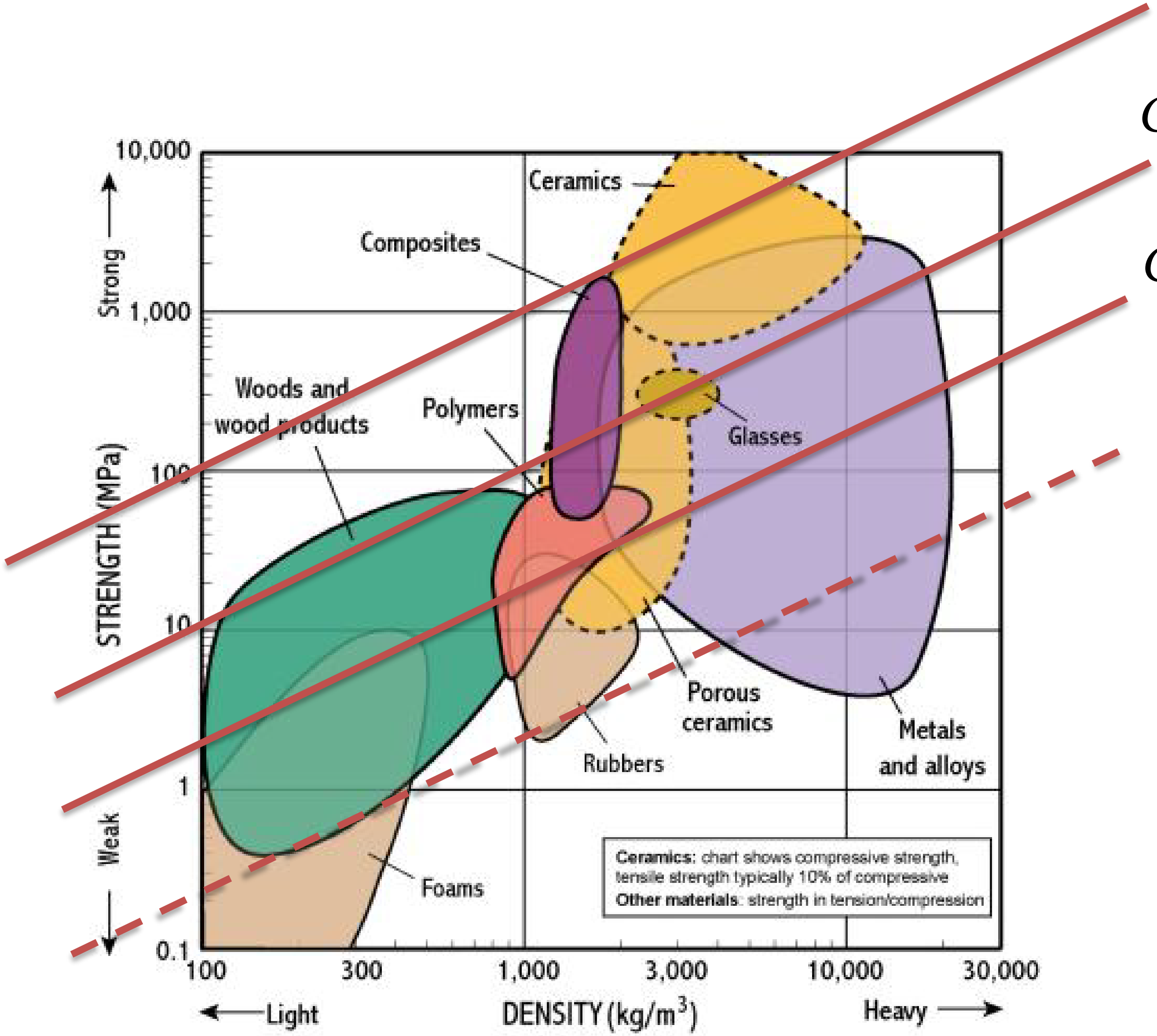
$$\log(\sigma_{\max}) = \log(\rho) + \log(C)$$

Visualize on a Ashby's material selection plot

$$C_1 = \left(\frac{\sigma_{\max}}{\rho}\right)$$

$$C_2 = \left(\frac{\sigma_{\max}}{\rho}\right)$$

$$C_3 = \left(\frac{\sigma_{\max}}{\rho}\right)$$

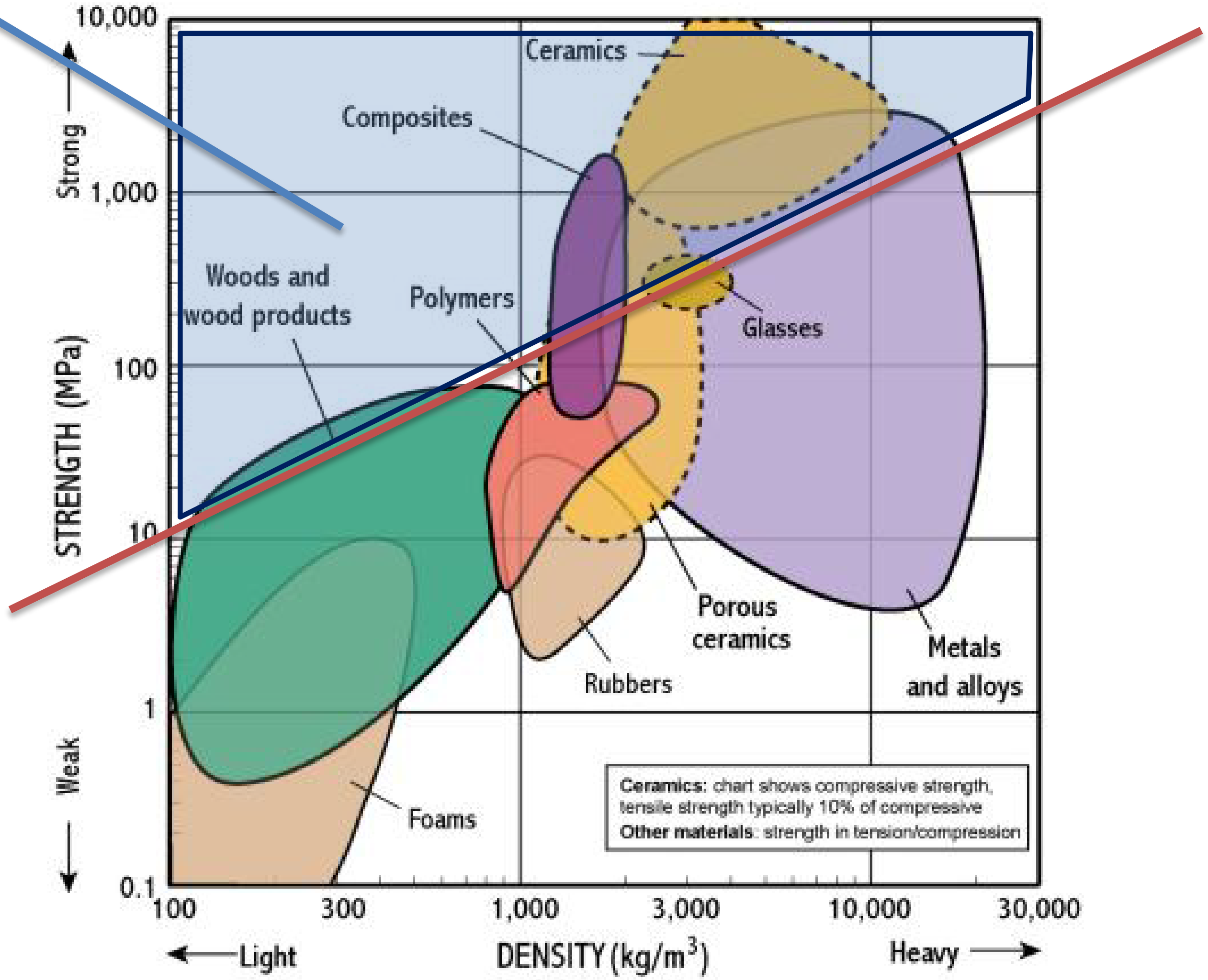


(source Cambridge University)

Visualize on a Ashby's material selection plot

Materials that may fulfil the condition

$$C_2 = \left(\frac{\sigma_{max}}{\rho}\right)$$



(source Cambridge University)

Mutliple solutions to a given problem: ex. Bamboo vs steel

Steel scaffolding

Bamboo scaffolding

Hong Kong (source LABC, UK)

Final remarks on Ashby's opmitization approach

- The final selection will be triggered by additional considerations, such as:
  - A minimum Young modulus
  - Manufacturability / Sustainability
  - Durability
  - Cost
  - Etc.

→ *A multi-parameters optimization problem with multiple possible solutions!*

'Lexique manufacturing'

English (UK) > French

- Metal embossing: *Emboutissage profond*
- Metal forming: *Mise en forme des métaux / formage*
- Molding (Moulding): *Moulage*
- Blow molding (Blow moulding): *Moulage par soufflage*
- Scaffold / Scaffolding: *Echaffaudages*