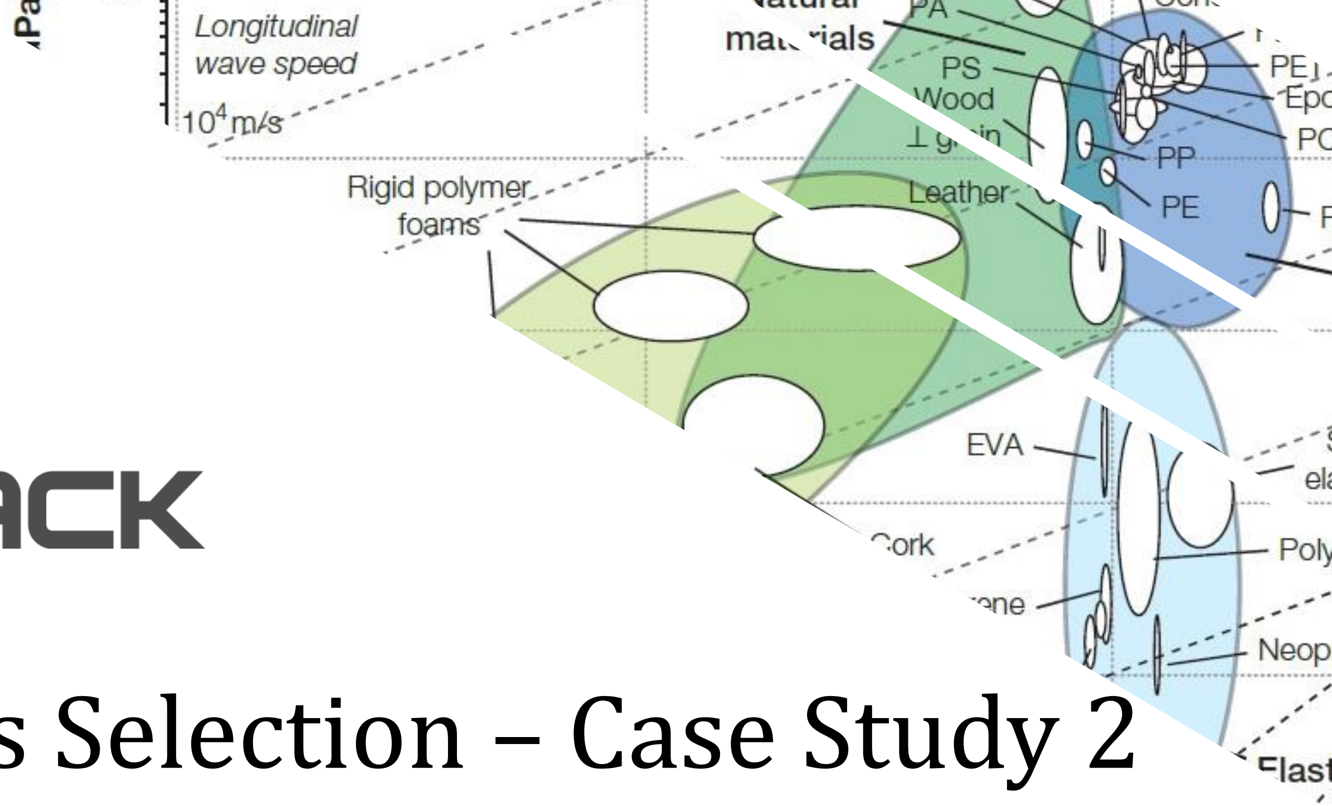

Materials Selection – Case Study 2
Advance Properties and Concepts

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Monday, 05 November 2018

Outline

- ***Case Study 13: Load-limited design, Energy-limited design and Deflection-limited design***
- ***Case Study 14: Safe Pressure Vessels***

Multiple constraints

- ***Case Study 14': Light pressure Vessels with MULTIPLE CONSTRAINT APPROACH***

Theory: Method of the weight factor

Theory: Enhanced Digital Logic (EDL)

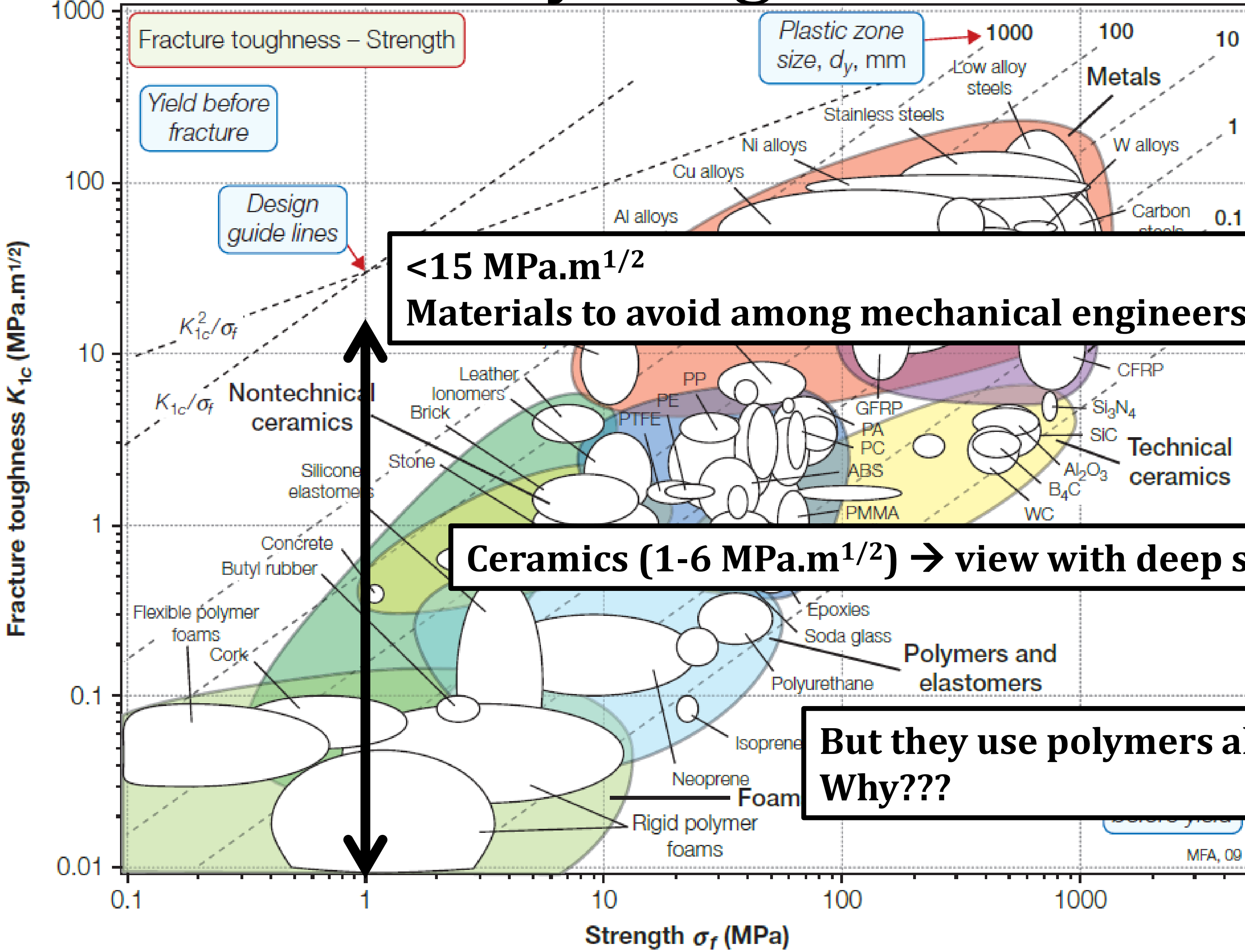
- ***Case Study 15: Precision devices***
- ***Case Study 16: Long Span Transmission line***
- ***Case Study 17: Light Cable***
- ***Case Study 18: Kiln Walls***
- ***Case Study 19: Insulation for Short-Term isothermal containers***
- ***Case Study 20: Process for a Can***

Secret slides : Kubota case

The Fracture-limited design

Fracture-limited design is important to control crack propagation

Ashby Diagrams



<15 MPa.m$^{1/2}$
Materials to avoid among mechanical engineers

Ceramics (1-6 MPa.m$^{1/2}$) → view with deep suspicion

But they use polymers all the time
Why???

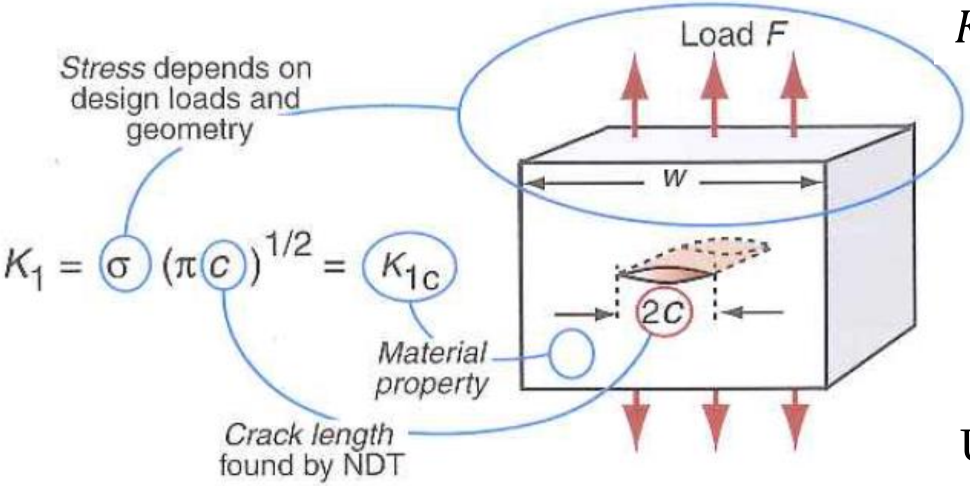
The Fracture-limited design

The resistance of a material to the propagation of a crack is measured by its plane-strain fracture toughness value (K_{1c})

When a brittle material is deformed,
it deflects elastically until it fractures.
The stress at which this happens is:

$$\sigma_f = \frac{K_{1c} \cdot C}{\sqrt{\pi \cdot a_c}}$$

<u>σ_f *by definition,*</u>
<u>*To consider all the stresses*</u>



NDT = non-destructive testing

K_1 = stress intensity factor
$K_{1c} = K_1$ → crack propagates

Usually C=1
a_c = the length of the largest crack

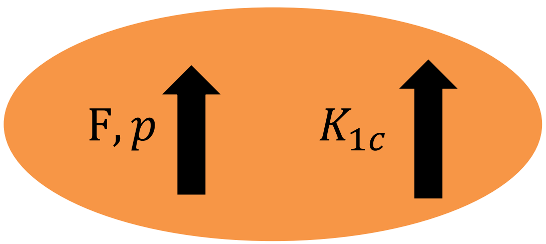
Case Study 13: Load-limited design

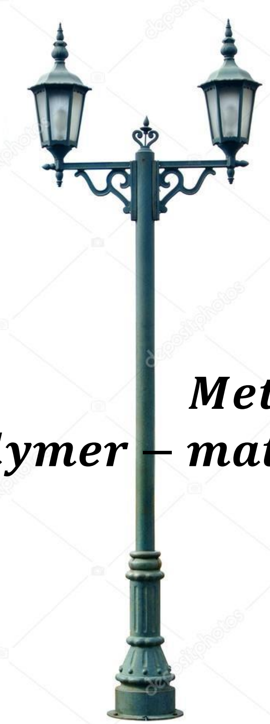
Objective	• Minimize the volume (mass, cost)
Constraints	• Design load specified
Free Variables	• Choice of material

Carry a specified load or pressure without fracturing?

Easy

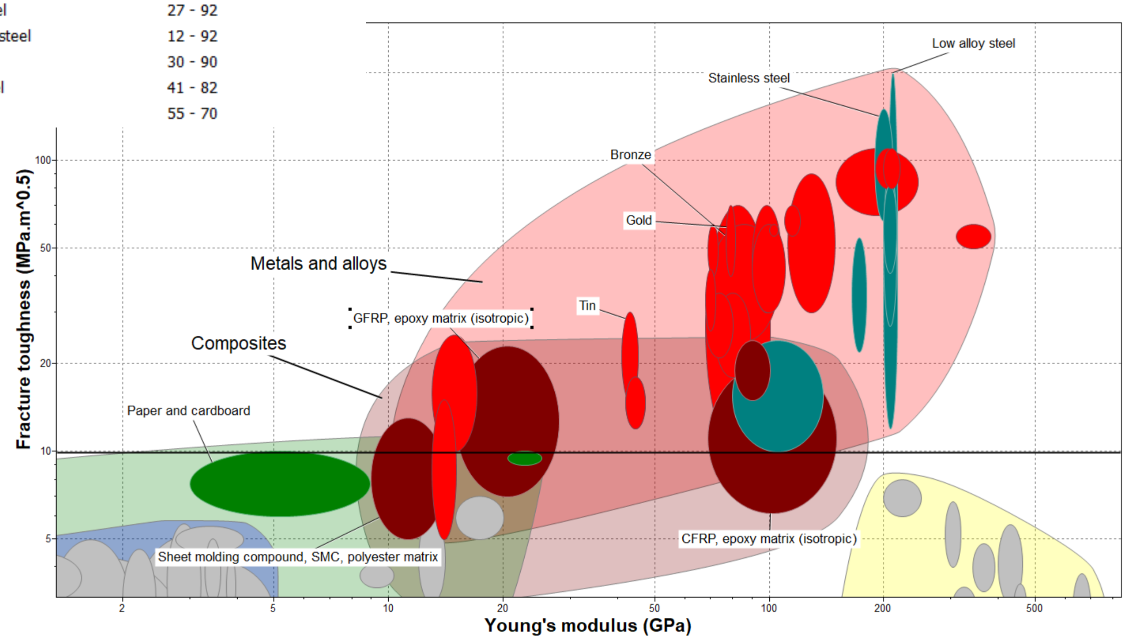
$$\sigma_f = \frac{K_{1c} \cdot C}{\sqrt{\pi \cdot a_c}}$$





Metals, polymer – matrix composites

Name	Fracture toughness (MPa....
Low alloy steel	14 - 200
Stainless steel	62 - 150
Nickel	80 - 110
Nickel-chromium alloys	80 - 110
Nickel-based superalloys	65 - 110
High carbon steel	27 - 92
Medium carbon steel	12 - 92
Copper	30 - 90
Low carbon steel	41 - 82
Titanium alloys	55 - 70



Case Study 13:
Energy-limited design

Objective	• Minimize the volume (mass, cost)
Constraints	• Design energy specified
Free Variables	• Choice of material

Springs

Containment systems for turbines

Flywheels

$$\begin{cases} \sigma_f = \dfrac{K_{1c} \cdot C}{\sqrt{\pi \cdot a_c}} \\ W_{el} = \dfrac{{\sigma_y}^2}{2E} \end{cases}$$

Elastic energy

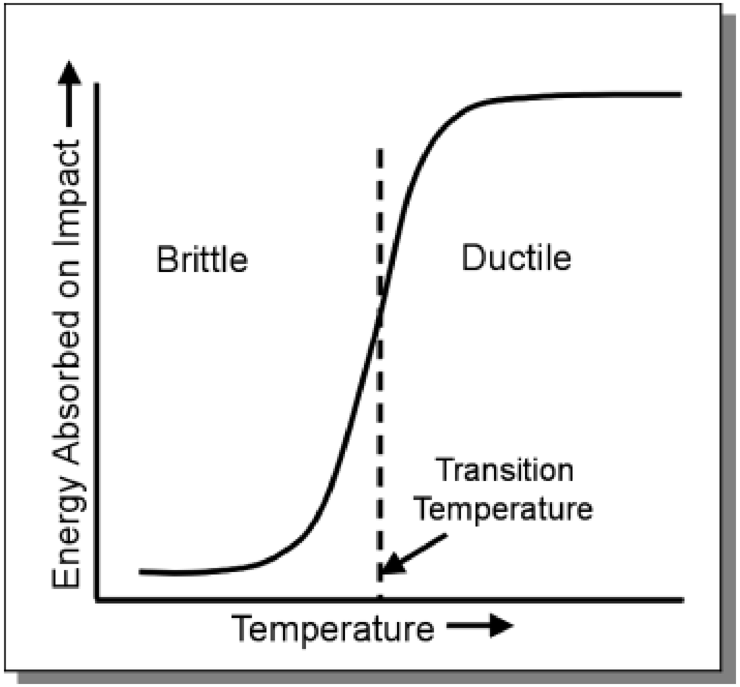
$$W^{max} = \frac{C^2}{2\pi a_c} \cdot \frac{{K_{1c}}^2}{E}$$

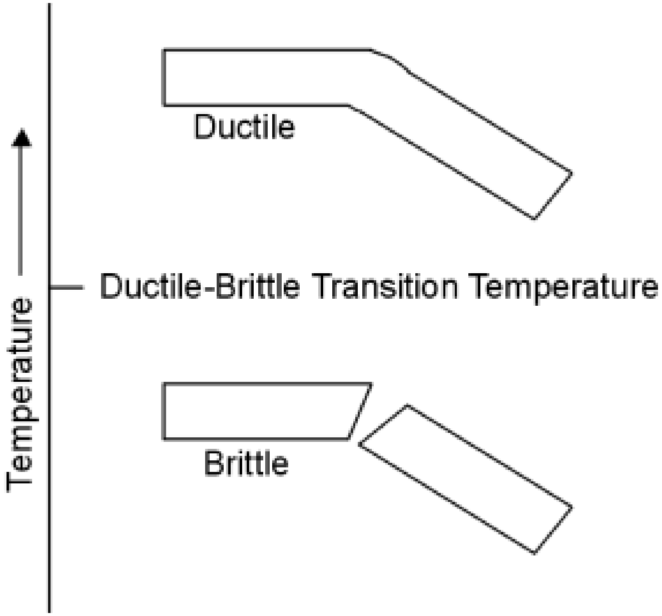
W^{max} ↑ $\dfrac{{K_{1c}}^2}{E}$ ↑

$$M_2 = \frac{{K_{1c}}^2}{E} \approx G_c$$

Toughness for a given flaw size

Ductile-Brittle Temperature



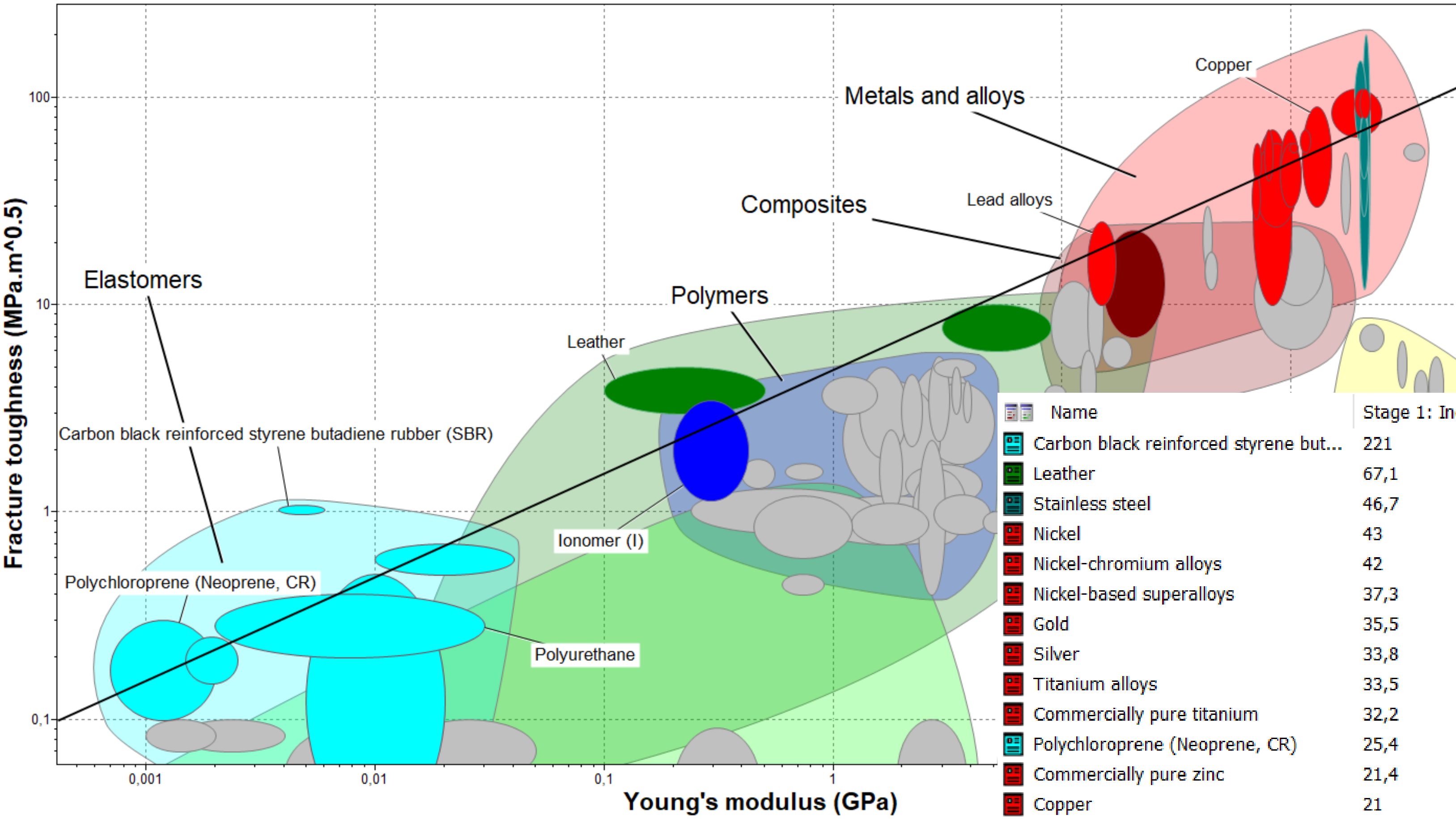


Metals, composites and some polymers

$J_c > 1$ kJ/m²

$W^{max} \uparrow \quad \frac{K_{1c}^{2}}{E} \uparrow$

Case Study 13: Energy-limited design



Name	Stage 1: Index, slope = 0,5
Carbon black reinforced styrene but...	221
Leather	67,1
Stainless steel	46,7
Nickel	43
Nickel-chromium alloys	42
Nickel-based superalloys	37,3
Gold	35,5
Silver	33,8
Titanium alloys	33,5
Commercially pure titanium	32,2
Polychloroprene (Neoprene, CR)	25,4
Commercially pure zinc	21,4
Copper	21
Natural rubber (NR)	19,4

Objective	• Minimize the volume (mass, cost)
Constraints	• Design deflection specified
Free Variables	• Choice of material

Case Study 13: Deflection-limited design

$$\begin{cases} \sigma_f = \dfrac{K_{1c} \cdot C}{\sqrt{\pi \cdot a_c}} \\ W_{el} = \dfrac{{\sigma_y}^2}{2E} \\ \varepsilon = \dfrac{\sigma}{E} \end{cases}$$

Snap on bottle tops

Snap-together fasteners

We want a large failure strain

$$\varepsilon_f = \frac{C}{\sqrt{\pi a_c}} \cdot \frac{K_{1c}}{E}$$

$$M_2 = \frac{K_{1c}}{E}$$

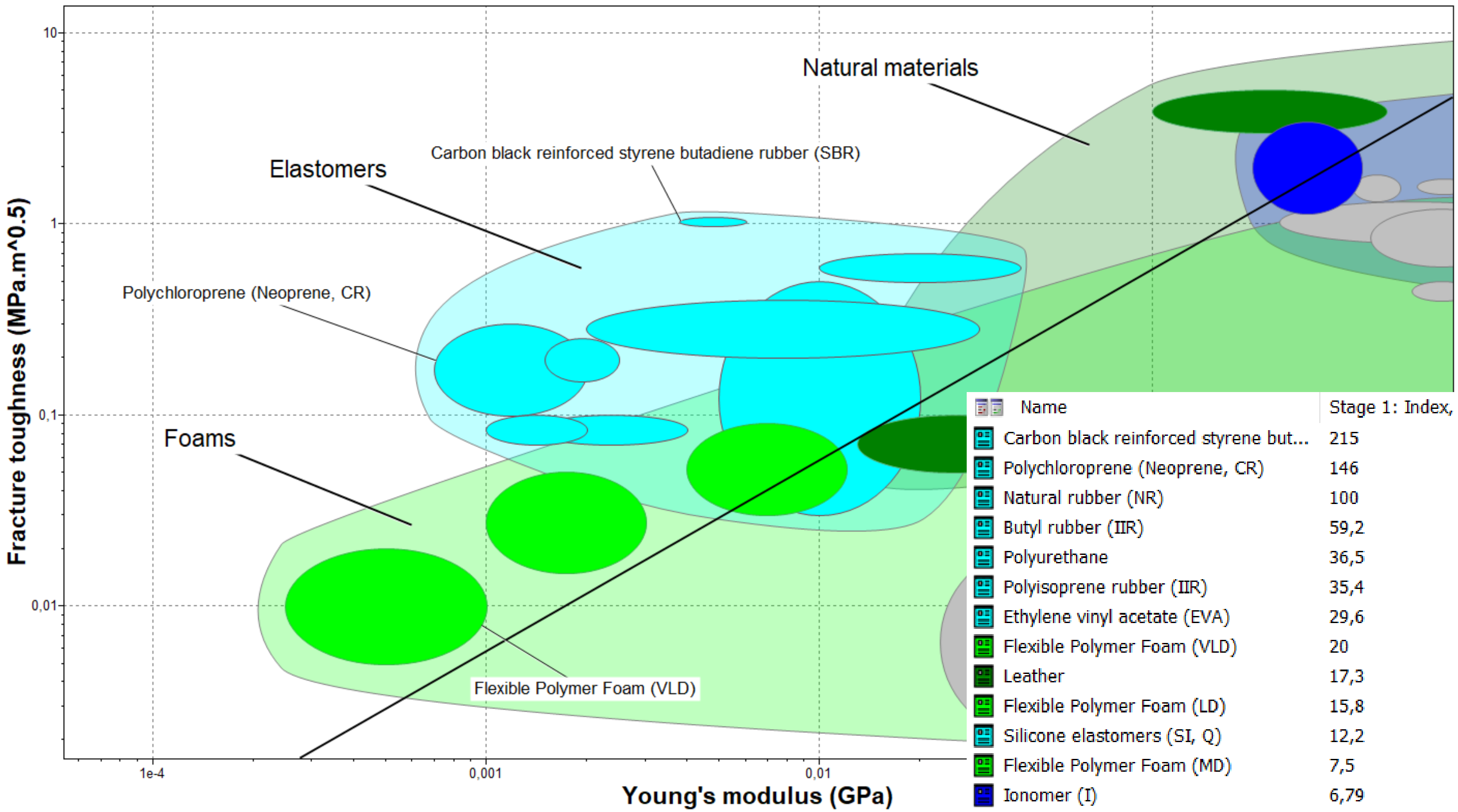
ε_f ↑ $\frac{K_{1c}}{E}$ ↑

Case Study 13: Deflection-limited design

Polymers, elastomers and toughest metals

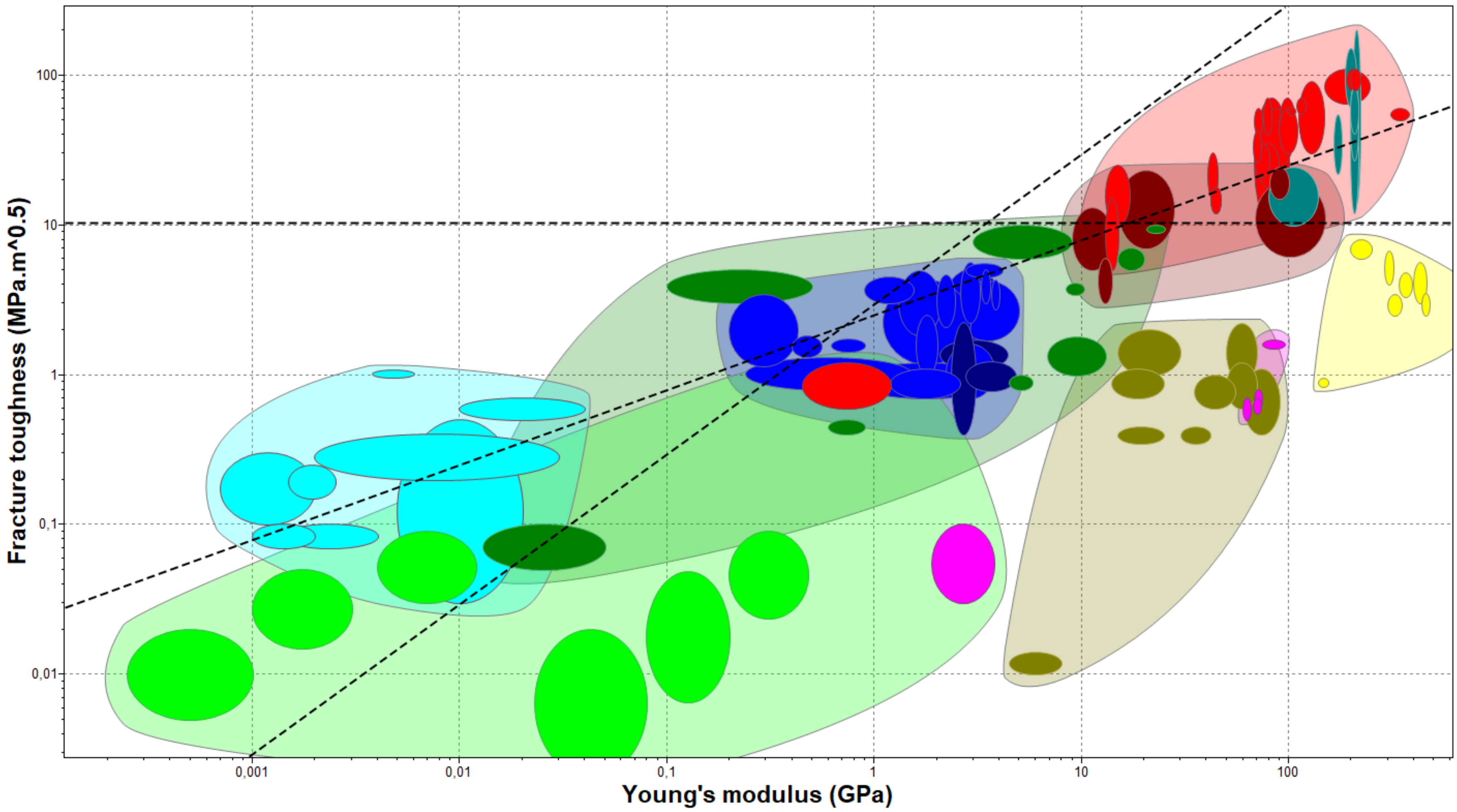
$$\frac{K_{1c}}{E} > 10^{-3}\ m^{1/2}$$

ε_f ↑ $\frac{K_{1c}}{E}$ ↑



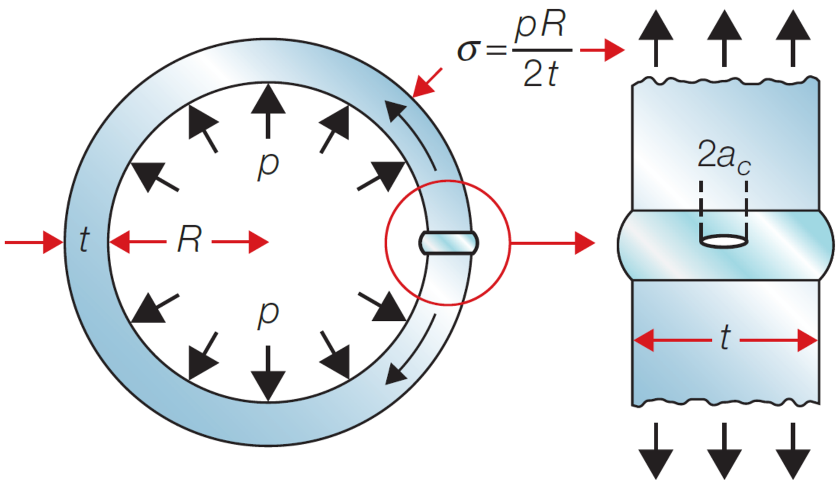
Name	Stage 1: Index, slope = 1
Carbon black reinforced styrene but...	215
Polychloroprene (Neoprene, CR)	146
Natural rubber (NR)	100
Butyl rubber (IIR)	59,2
Polyurethane	36,5
Polyisoprene rubber (IIR)	35,4
Ethylene vinyl acetate (EVA)	29,6
Flexible Polymer Foam (VLD)	20
Leather	17,3
Flexible Polymer Foam (LD)	15,8
Silicone elastomers (SI, Q)	12,2
Flexible Polymer Foam (MD)	7,5
Ionomer (I)	6,79

The Fracture-limited design

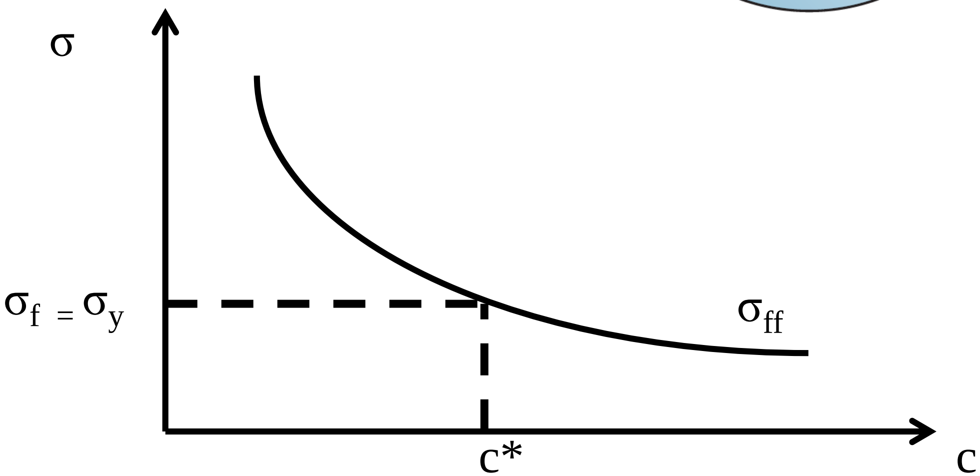


Case Study 14: Safe Pressure Vessels

Case Study 14: Safe Pressure Vessels



Two different approaches



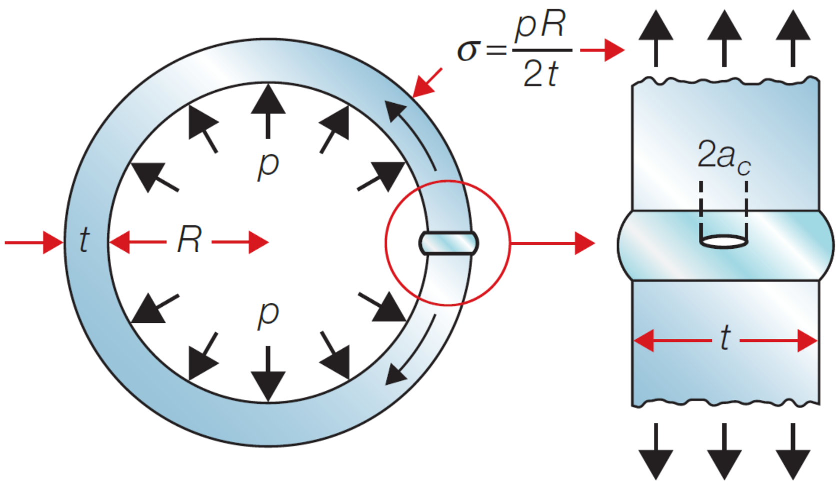
Yield-Before-Break (YBB)

No failure, but distortion
Small vessels are designed
to allow general yield

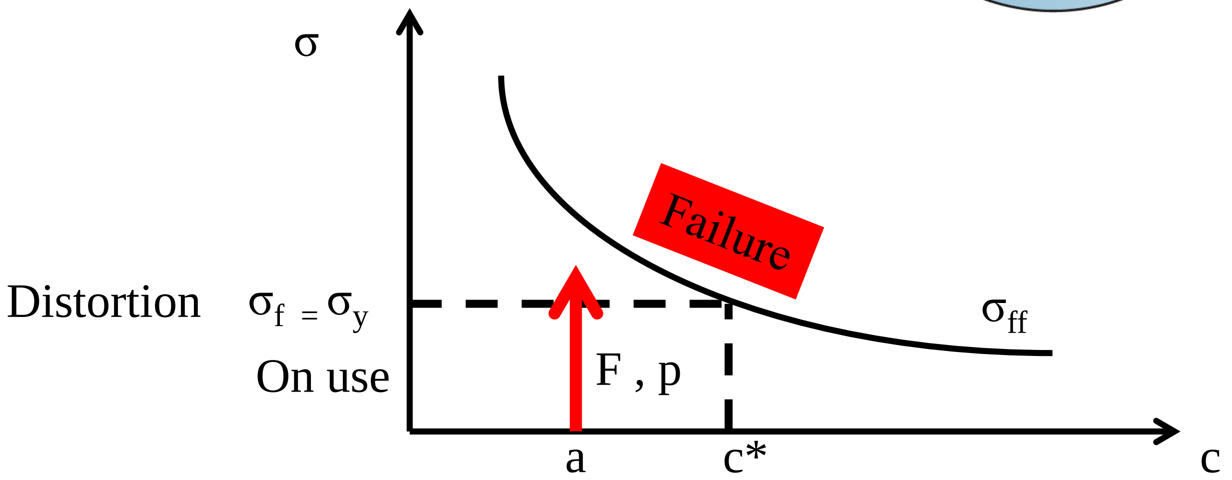
Leak-Before-Break (LBB)

Safe design
Smallest crack has a thickness greater
than the thickness of the vessel wall

Case Study 14:
Safe Pressure Vessels
YBB



Two different approaches



Yield-Before-Break (YBB)

No failure, but distortion
Small vessels are designed
to allow general yield

Objective	• Maximize safety (YBB)
Constraints	• R radius specified
Free Variables	• Choice of material

Case Study 14:
Safe Pressure Vessels
YBB

$$\begin{cases} \sigma \leq \dfrac{C \cdot K_{1c}}{\sqrt{\pi \cdot a^*{}_c}} \\ \sigma = \dfrac{p \cdot R}{2t} \end{cases}$$

$$p \leq \frac{2t \cdot K_{1c}}{R \cdot \sqrt{\pi \cdot a^*{}_c}}$$

$p \uparrow$ $K_{1c} \uparrow$

But not Fail-safe

If the inspection is faulty for some reasons the crack length is greater

$$\pi \cdot 2 \cdot c^* \leq C^2 \cdot \left(\frac{K_{1c}}{\sigma_y}\right)^2$$

a_c **Tolerable crack size**

$c^* \uparrow$ $\dfrac{K_{1c}}{\sigma_y} \uparrow$

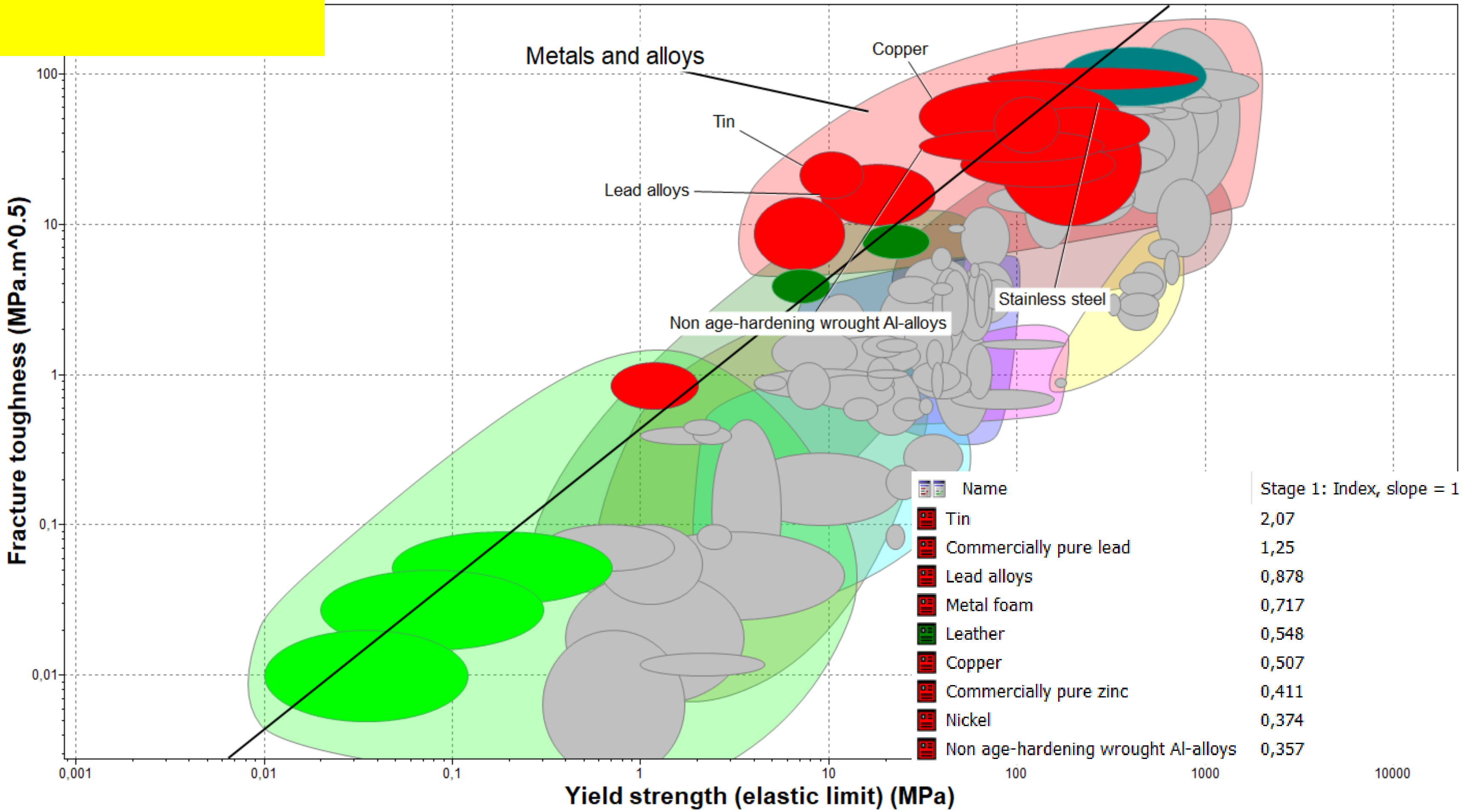
$$M_1 = \frac{K_{1c}}{\sigma_y}$$

Since $t = \frac{p \cdot R}{2\sigma}$

For Thinner t

$t \downarrow \quad \sigma_y \uparrow$

Case Study 14:
Safe Pressure Vessels
YBB

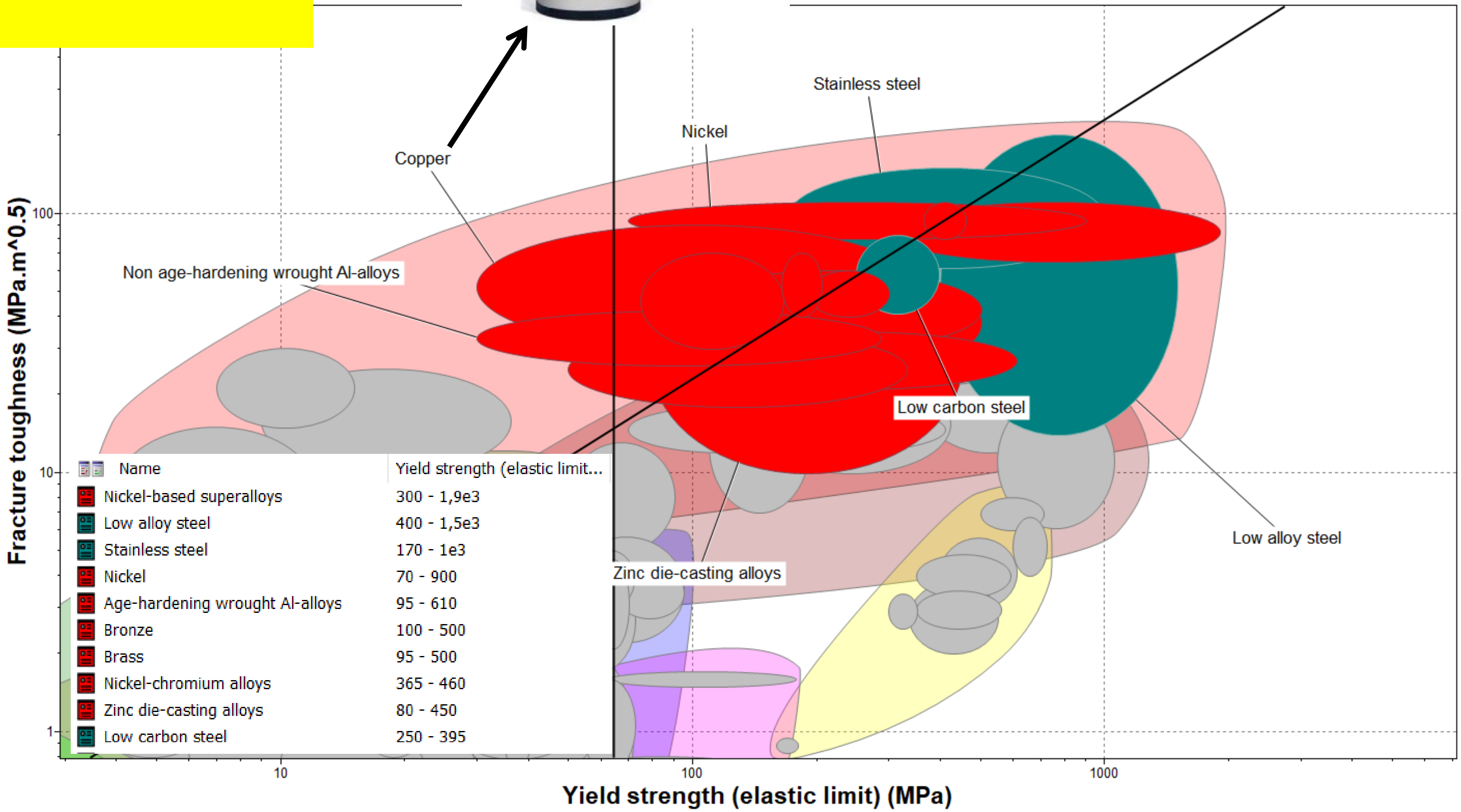


Name	Stage 1: Index, slope = 1
Tin	2,07
Commercially pure lead	1,25
Lead alloys	0,878
Metal foam	0,717
Leather	0,548
Copper	0,507
Commercially pure zinc	0,411
Nickel	0,374
Non age-hardening wrought Al-alloys	0,357

Small boilers
(Hard drawn copper)

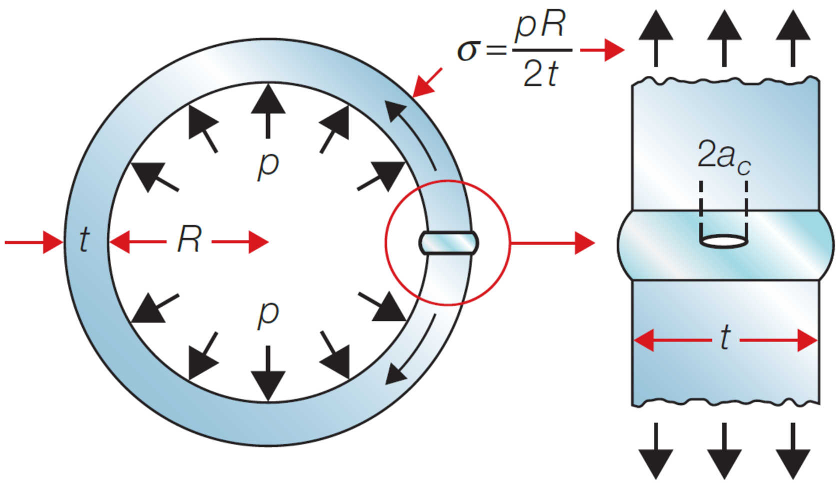
Low alloys steel = Classical choice

Case Study 14:
Safe Pressure Vessels
YBB

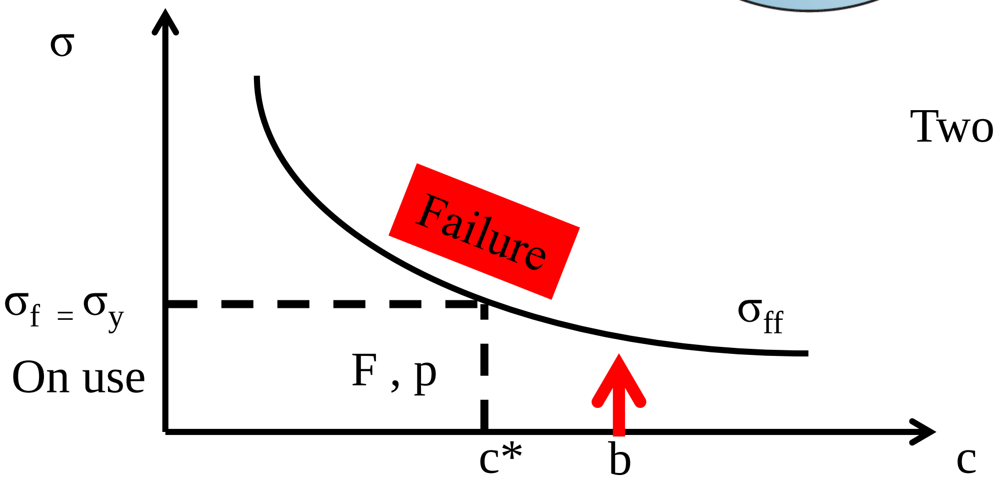


Case Study 14:
Safe Pressure Vessels
LBB

Two different approaches



Two different approaches



Leak-Before-Break(LBB)

Safe design
Smallest crack has a thickness greater than the thickness of the vessel wall

Objective	• Maximize safety (LBB)
Constraints	• R radius specified
Free Variables	• Choice of material

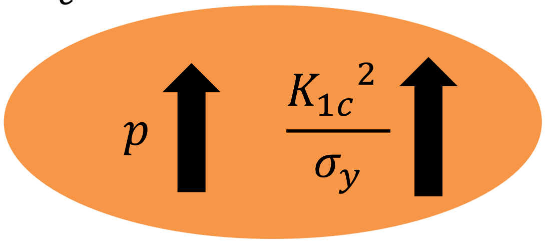
Case Study 14:
Safe Pressure Vessels
LBB

Hp: $\boldsymbol{b = \frac{t}{2}}$

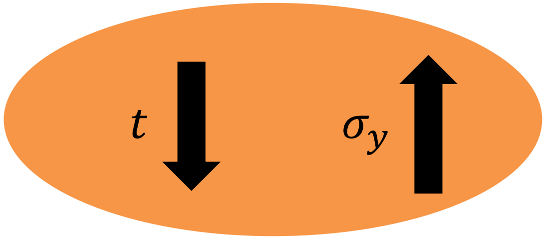
$$\begin{cases} \sigma \leq \dfrac{C \cdot K_{1c}}{\sqrt{\pi \cdot t/2}} \\ \sigma_y = \dfrac{p \cdot R}{2t} \end{cases} \rightarrow \quad t = \frac{p \cdot R}{2\sigma_y}$$

$$p \leq \frac{4C^2}{\pi R} \cdot \left(\frac{{K_{1c}}^2}{\sigma_y} \right) \qquad M_2 = \frac{{K_{1c}}^2}{\sigma_y}$$

a_c **Tolerable crack size**



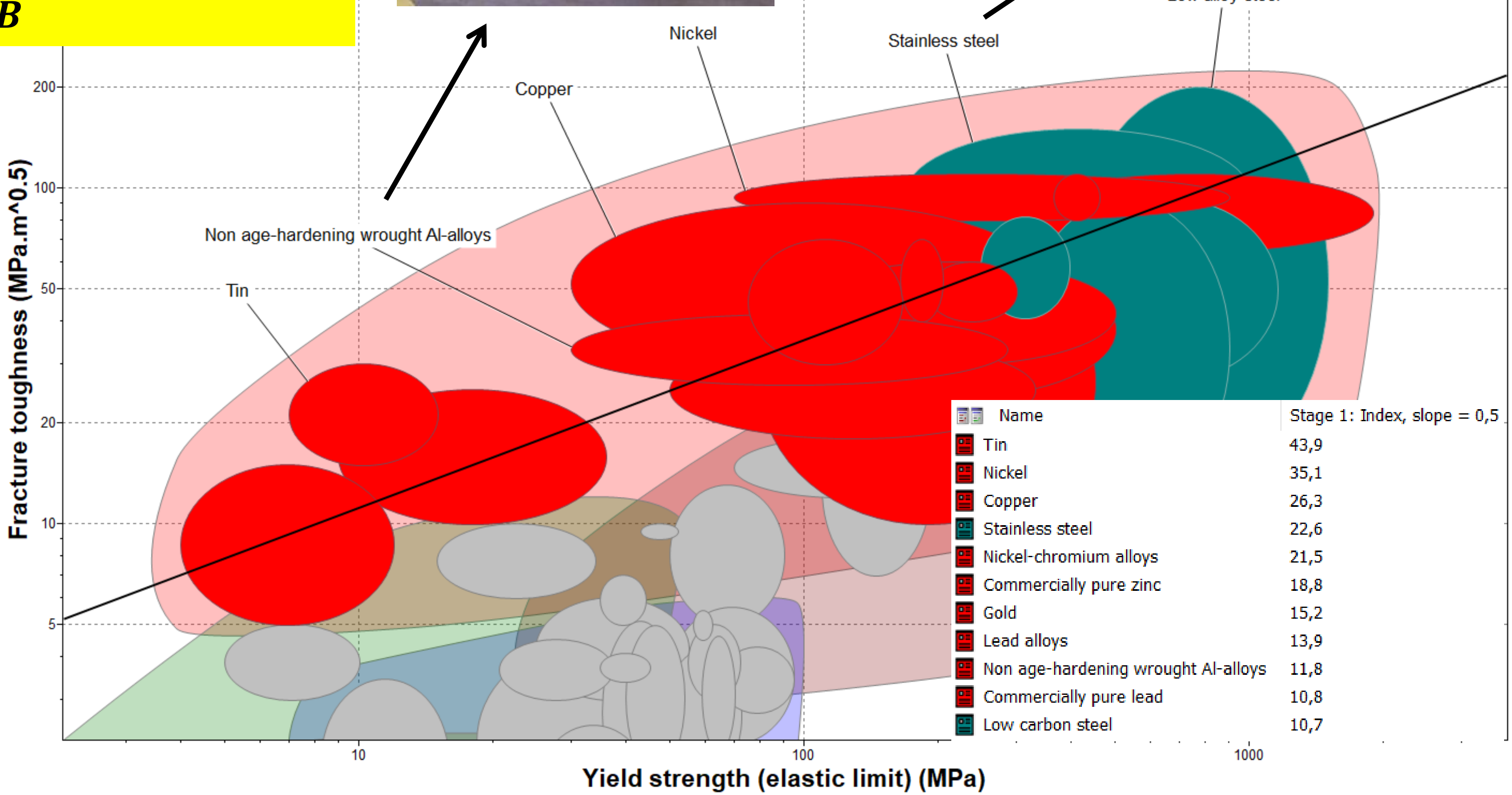
$$t = \frac{p \cdot R}{2\sigma_y} \quad \textit{Thinner } t$$



Pressure tanks of rockets

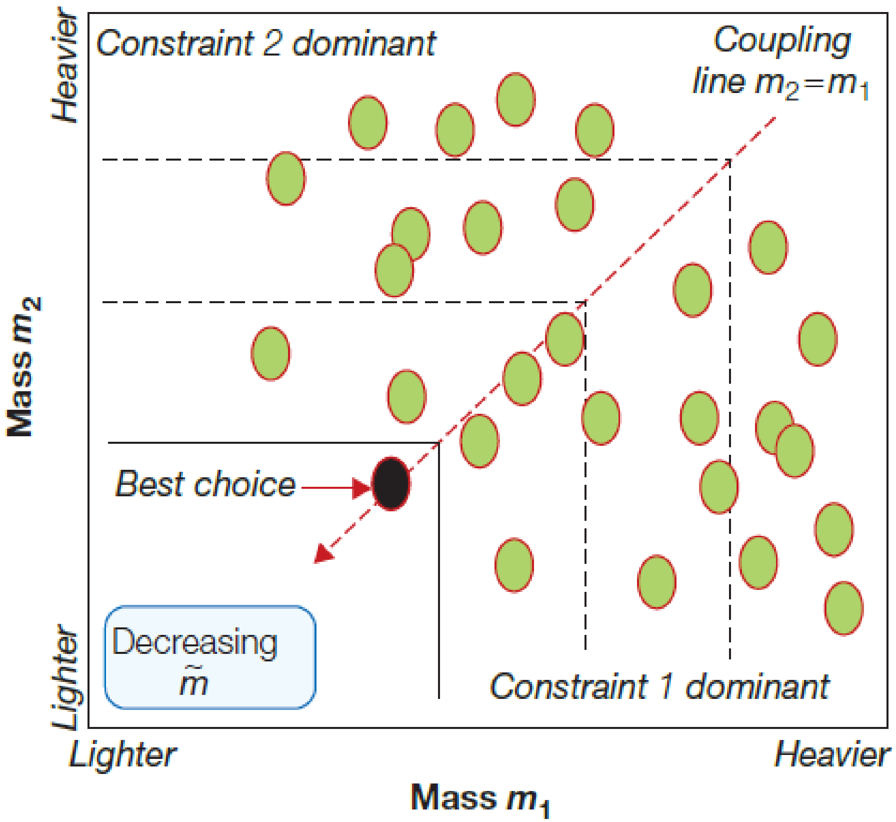
Nuclear pressure vessels (316 Stainless Steel)

Case Study 14: Safe Pressure Vessels LBB

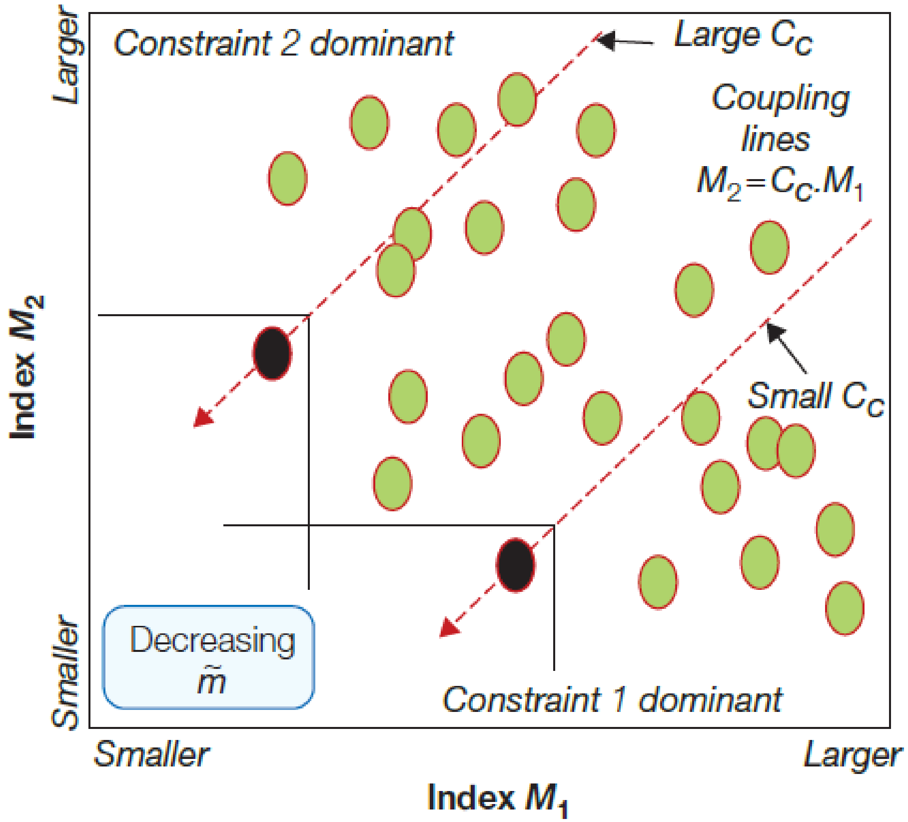


Name	Stage 1: Index, slope = 0,5
Tin	43,9
Nickel	35,1
Copper	26,3
Stainless steel	22,6
Nickel-chromium alloys	21,5
Commercially pure zinc	18,8
Gold	15,2
Lead alloys	13,9
Non age-hardening wrought Al-alloys	11,8
Commercially pure lead	10,8
Low carbon steel	10,7

Multiple constraints

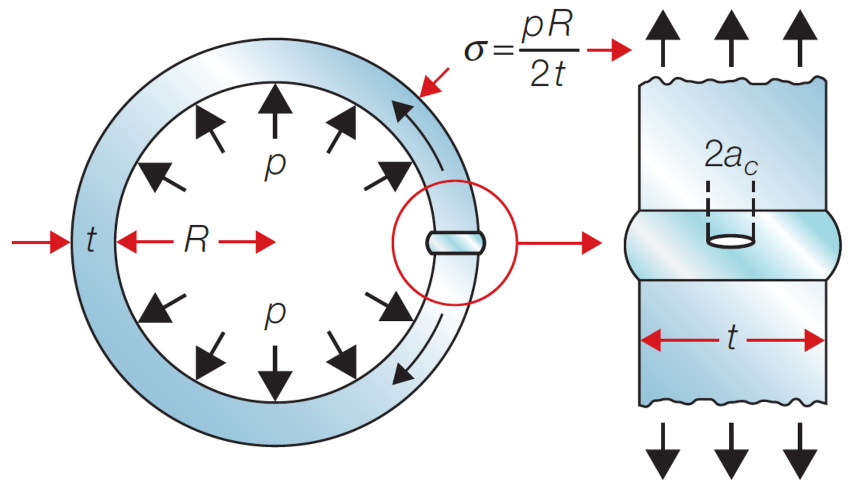


Minimize the mass



Minimize the volume

Case Study 14':
Materials for Light pressure Vessels With MULTIPLE CONSTRAINT APPROACH



Fracture constraint

$$\sigma = \frac{p \cdot R}{2t} \leq \frac{K_{1c}}{\sqrt{\pi \cdot c}}$$

$$m_1 = 2\pi R^3 \cdot p \cdot \sqrt{\pi \cdot c} \cdot \frac{\rho}{K_{1c}}$$

$$M_1 = \frac{\rho}{K_{1c}}$$

$$m = 4\pi R^2 \cdot t \cdot \rho$$

Yield constraint

$$\sigma = \frac{p \cdot R}{2t} \leq \sigma_y$$

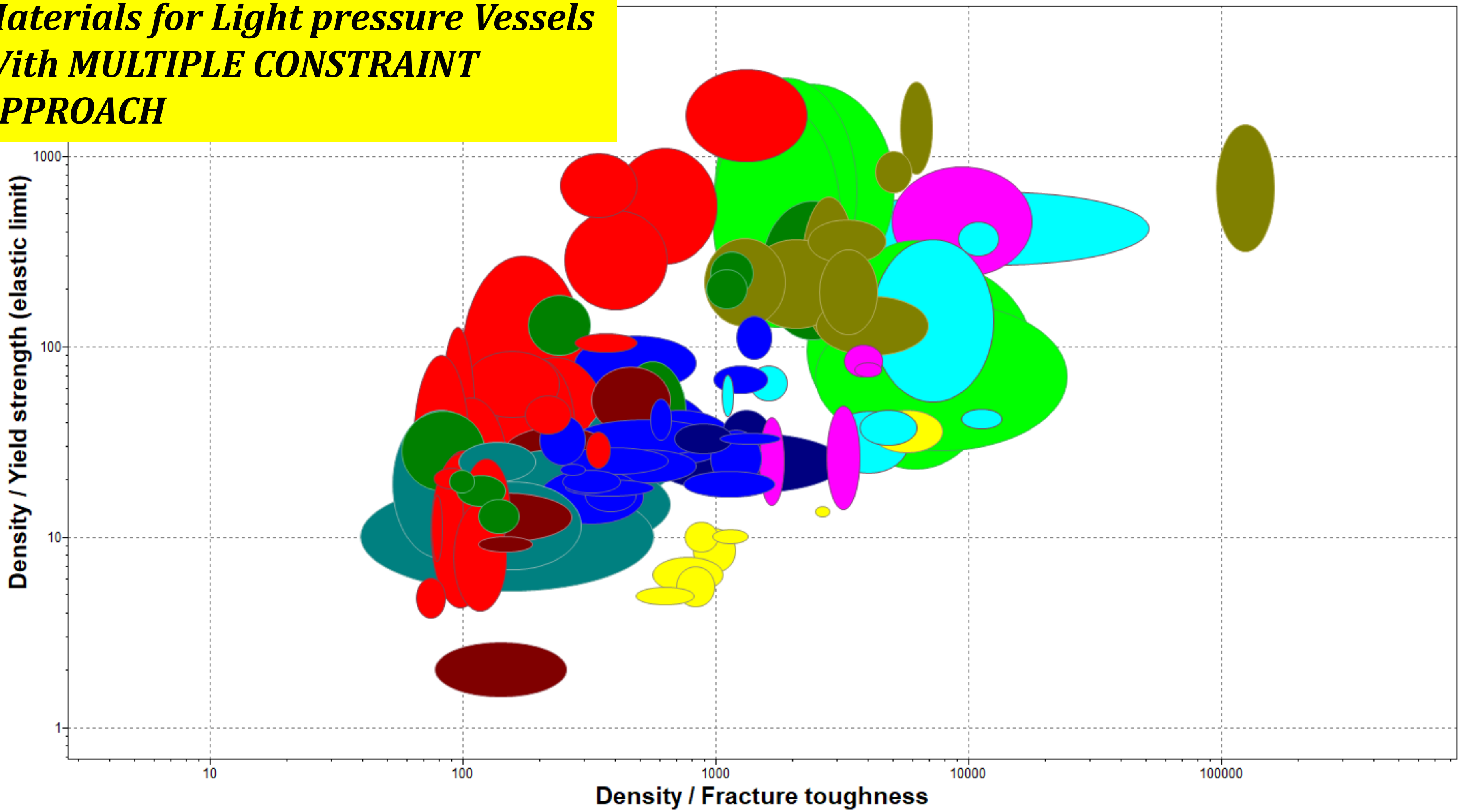
$$m_2 = 2\pi R^3 \cdot p \cdot \frac{\rho}{\sigma_y}$$

$$M_2 = \frac{\rho}{\sigma_y}$$

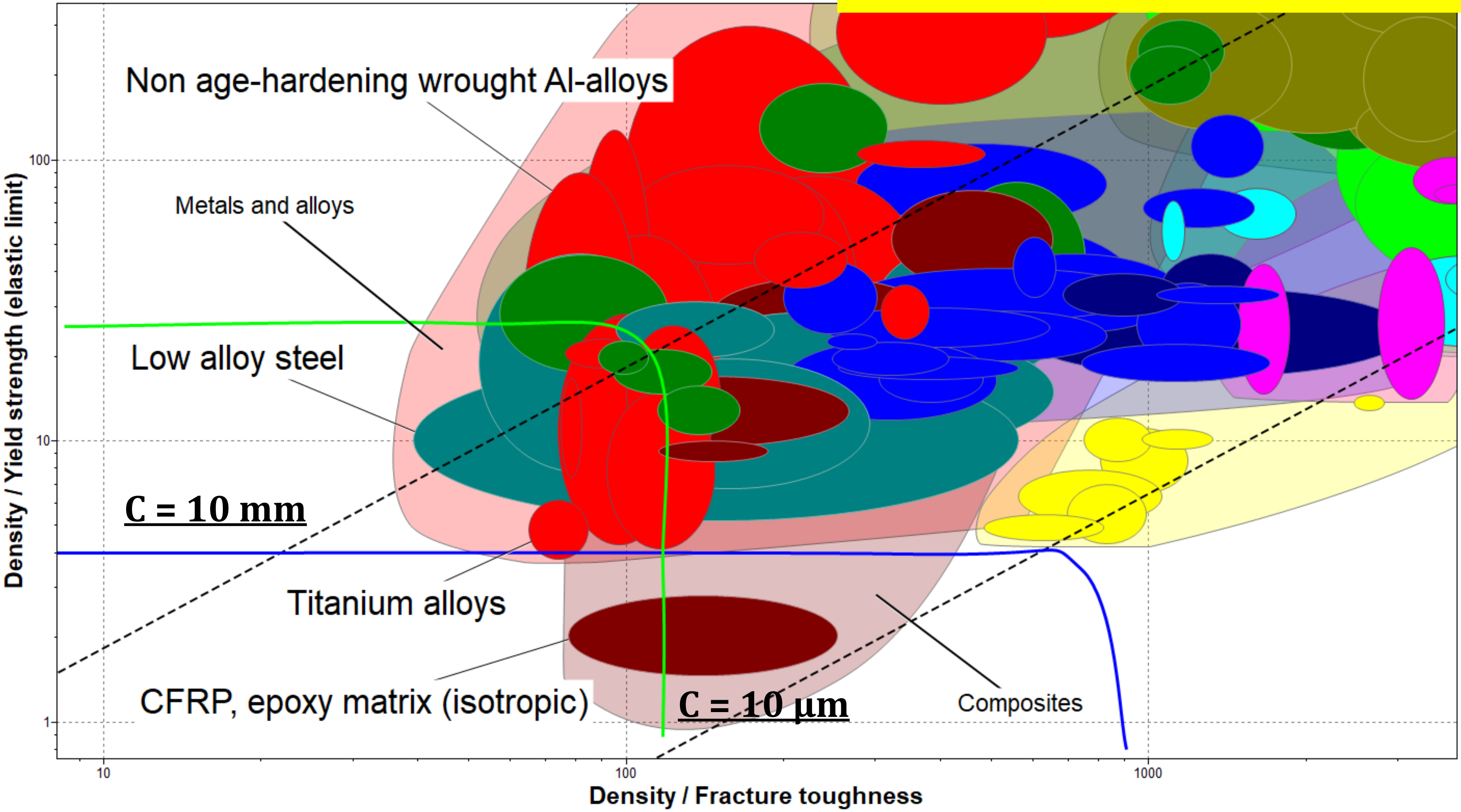
Objective | Constraints | Performance equation | Index

$$\frac{\rho}{\sigma_y} = \sqrt{\pi \cdot c} \cdot \frac{\rho}{K_{1c}} \qquad M_2 = \sqrt{\pi \cdot c} \cdot M_1$$

Case Study 14': Materials for Light pressure Vessels With MULTIPLE CONSTRAINT APPROACH



Case Study 14’:
Materials for Light pressure Vessels
With MULTIPLE CONSTRAINT
APPROACH



Theory: Method of the weight factor

$$Z_p = \alpha_H \cdot \frac{\text{H}}{\max(\text{H})} + \alpha_M \cdot \frac{\text{M}}{\max(\text{M})}$$

The most important point is to understand if you must maximize or minimize a property

Example:

	Young's Modulus	*Density*
Maximize	E	$1/\rho$
Minimize	$1/E$	ρ

With the normalization and the performance function you can consider all the properties that you want and with various order of magnitude.

But the importance coefficients? → **EDL**

Example of its application

7.6. EDL method and Performance function

The performance function is a selection method to analyze different materials and to discover which is the most proper for a particular utilization; the function can correlate many different material properties and based on the requirements it is possible assign an importance sequence with the EDL (Enhanced Digital Logic). In the study this methods were utilized to correlate the hardness values and the Magnegage values. The first is a complex value to understand because is due to the matrix and to the carbide present; instead the second is a value difficult to correlate due to the precise surveys and to the empiric bases of the analyses. In a HSS a property that is consider fundamental is the low percentage of retained austenite, thus the function is based on this assumption; as importance sign (α) the EDL method assigns 0.33 for the hardness and 0.67 for the retained austenite. The performance function is:

$$Z_p = \alpha_H \cdot \frac{\text{H}}{\max(\text{H})} + \alpha_M \cdot \frac{\text{M}}{\max(\text{H})} \quad (5)$$

Equation 5 : Performance function of the thermal treatments.

H and M are the sample values and they are divided for the maximum between them; with this important step the values are normalized, as consequence they can be correlated with other different properties and properties as Magnegage analysis can have a higher import. In the Table 33 all the performance function results (Z_p) are reported in the two relevant depths; to arrive at those values the data from Table 29 and Table 30 were used.

	R1	N0	N1	N2	N3	N4	N5	X1/X3	N6
20	0,25	0,44	0,75	0,97	0,93	0,91	0,97	0,89	0,80
50	0,54	0,47	0,68	0,80	0,78	0,80	0,91	0,92	0,77

Table 33 : Results of the performance function.

The samples are reported in order from the R1 (different thermal treatment) and N0 (as-cast conditions) to N6 that has the higher temperature of thermal treatment (double tempering). The results are putted in order from the higher value to the lower one in the two depths as shown in the Table 34.

A)

Sample	20
N2 (450)	0,97
N5(525)	0,97
N3 (475)	0,93
N4 (500)	0,91
X1/X3 (530)	0,89
N6 (550)	0,8
N1 (425)	0,75
N0	0,44
R1	0,25

B)

Sample	50
X1/X3 (530)	0,92
N5(525)	0,91
N2 (450)	0,8
N4 (500)	0,8
N3 (475)	0,78
N6 (550)	0,77
N1 (425)	0,68
R1	0,54
N0	0,47

C)

Sample	Mean value
N5(525)	0,94
X1/X3 (530)	0,905
N2 (450)	0,885
N3 (475)	0,855
N4 (500)	0,855
N6 (550)	0,785
N1 (425)	0,715
N0	0,455
R1	0,395

Table 34 : The results of Table 33 in order from the highest value to the lowest for the two depths (A and B). The different samples are written together with the thermal treatment temperature. The mean values of the two depths for every sample in (C).

The best material and in this case the best thermal treatment that can be applied on the material is the double tempering in the range of temperature 525-530°C as reported in the following table; to arrive at this conclusion it was done the mean value of the two depth values to try to consider the entire roll and not only a single part of it.

on a process

Theory: Enhanced Digital Logic

$$Z_p = \alpha_H \cdot \frac{\mathrm{H}}{\max(\mathrm{H})} + \alpha_M \cdot \frac{\mathrm{M}}{\max(\mathrm{M})}$$

σ Yield Strength
W Weldability

C Corrosion Resistance
F Fatigue Resistance

A really more important than B	3-1
A more important than B	2-1
A as imp. as B	1-1

Importance Sequence
σ > W = C > F

							Addition		
σ	2	2	3				7	0,389	0,39
W	1			1	2		4	0,222	0,22
C		1		1		2	4	0,222	0,22
F			1		1	1	3	0,167	0,17
							18		1

Theory: Enhanced Digital Logic

And if I want to have a property value similar to another material?

→ *Normalisation MANCINI-MAURIZI*

Example : Coefficient of thermal expansion α (CTE)

$$If\ the\ property\ is\ bigger\ than\ the\ target\ value\ \ N_n = 1 - \frac{CTE_n - CTE_{targ.}}{CTE_{max} - CTE_{targ.}}$$

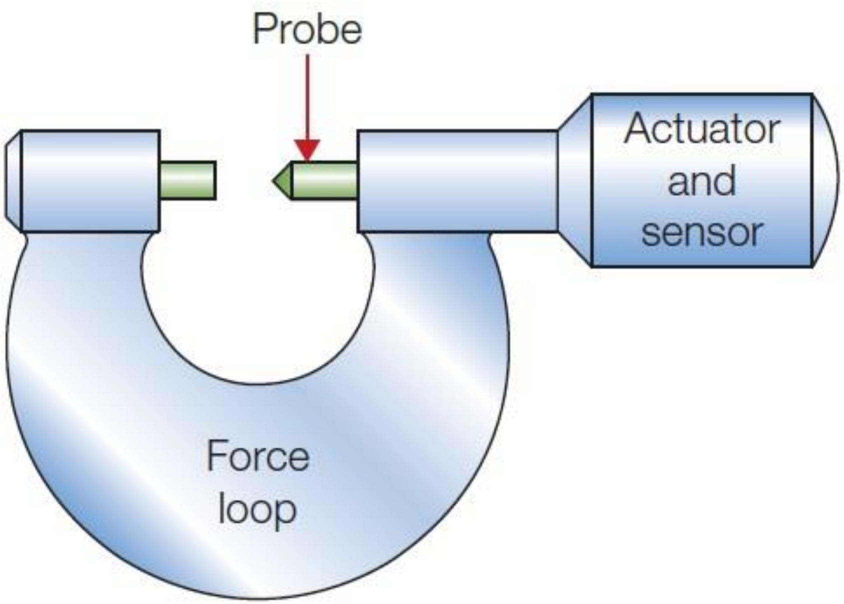
$$If\ the\ property\ is\ smaller\ than\ the\ target\ value\ \ N_n = 1 - \frac{CTE_{targ.} - CTE_n}{CTE_{targ.} - CTE_{min}}$$

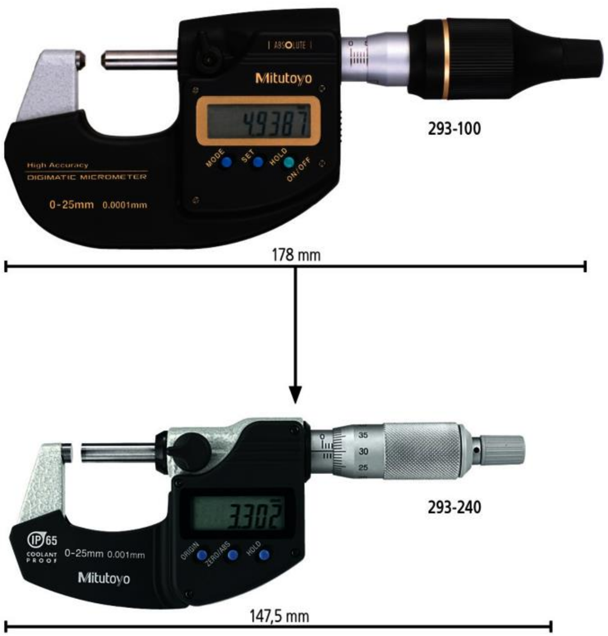
Again, a value close to 1 = the two CTEs are similar (the contrary to 0)

Using materials at high temperatures

Case Study 15: Materials for Precision devices →

Objective	• Minimize distortion to maximize positional accuracy
Constraints	• Tolerate heat flux • Tolerate vibration
Free Variables	• Choice of material





Es. Sub micrometer displacement gauge

Case Study 15:
Materials for Precision devices

Fourier's Law in steady state

$$\begin{cases} q = -\lambda \dfrac{dT}{dx} \\ \varepsilon = \alpha (T - T_0) \end{cases}$$

q *Heat flux*

λ *Thermal conductivity*

$\dfrac{dT}{dx}$ *resulting temperature gradient*

The distortion is proportional to the gradient of strain

$$\frac{d\varepsilon}{dx} = \alpha \cdot \frac{dT}{dx} == \frac{\alpha}{\lambda} \cdot q$$

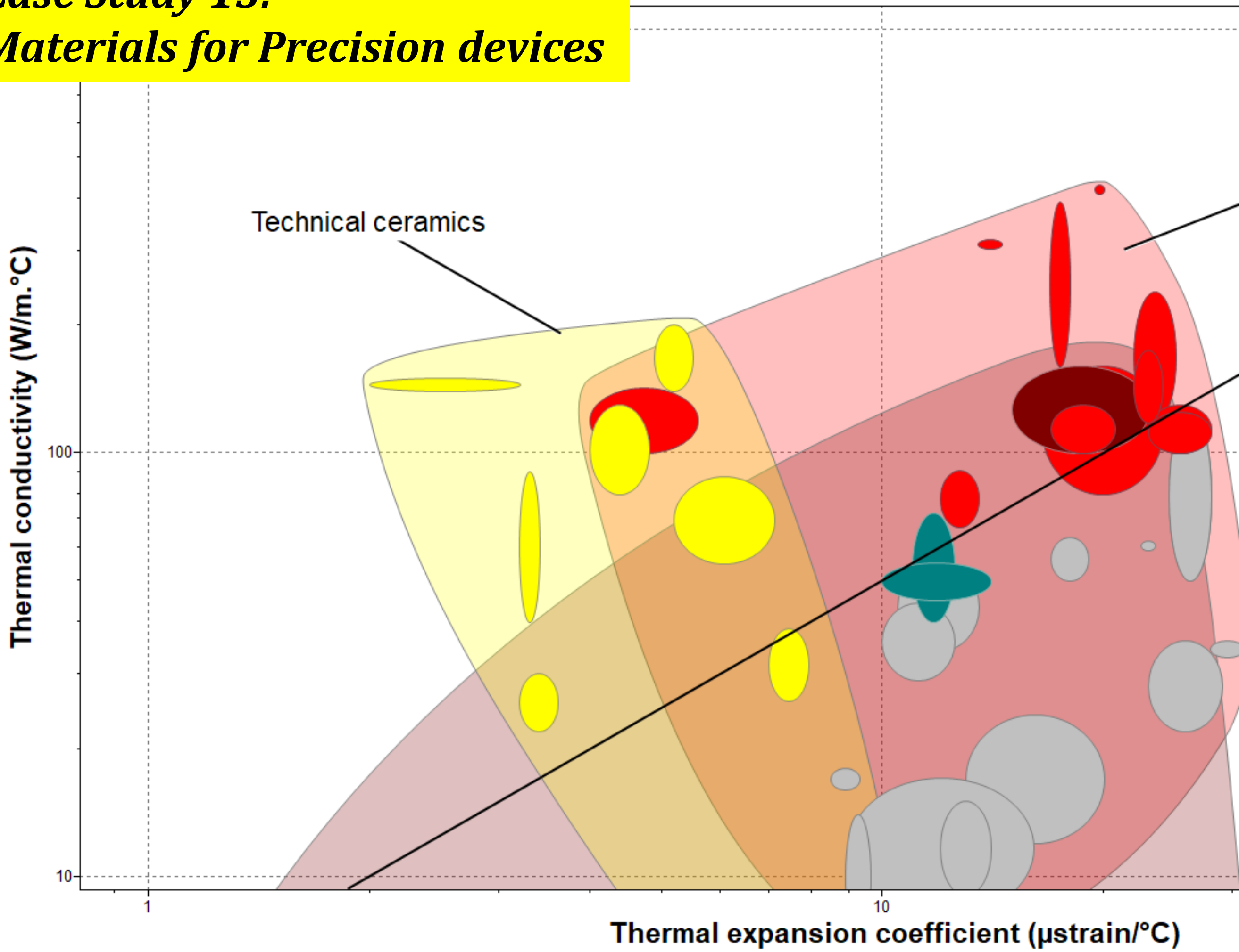
$\dfrac{d\varepsilon}{dx} \downarrow \quad \dfrac{\lambda}{\alpha} \uparrow$

Moreover, we want to avoid flexural vibrations at lowest frequencies; proportional to (finally must be stiff) →

$V \downarrow \quad \dfrac{E^{1/2}}{\rho} \uparrow$

$$\frac{d\varepsilon}{dx} \downarrow \qquad \frac{\lambda}{\alpha} \uparrow$$

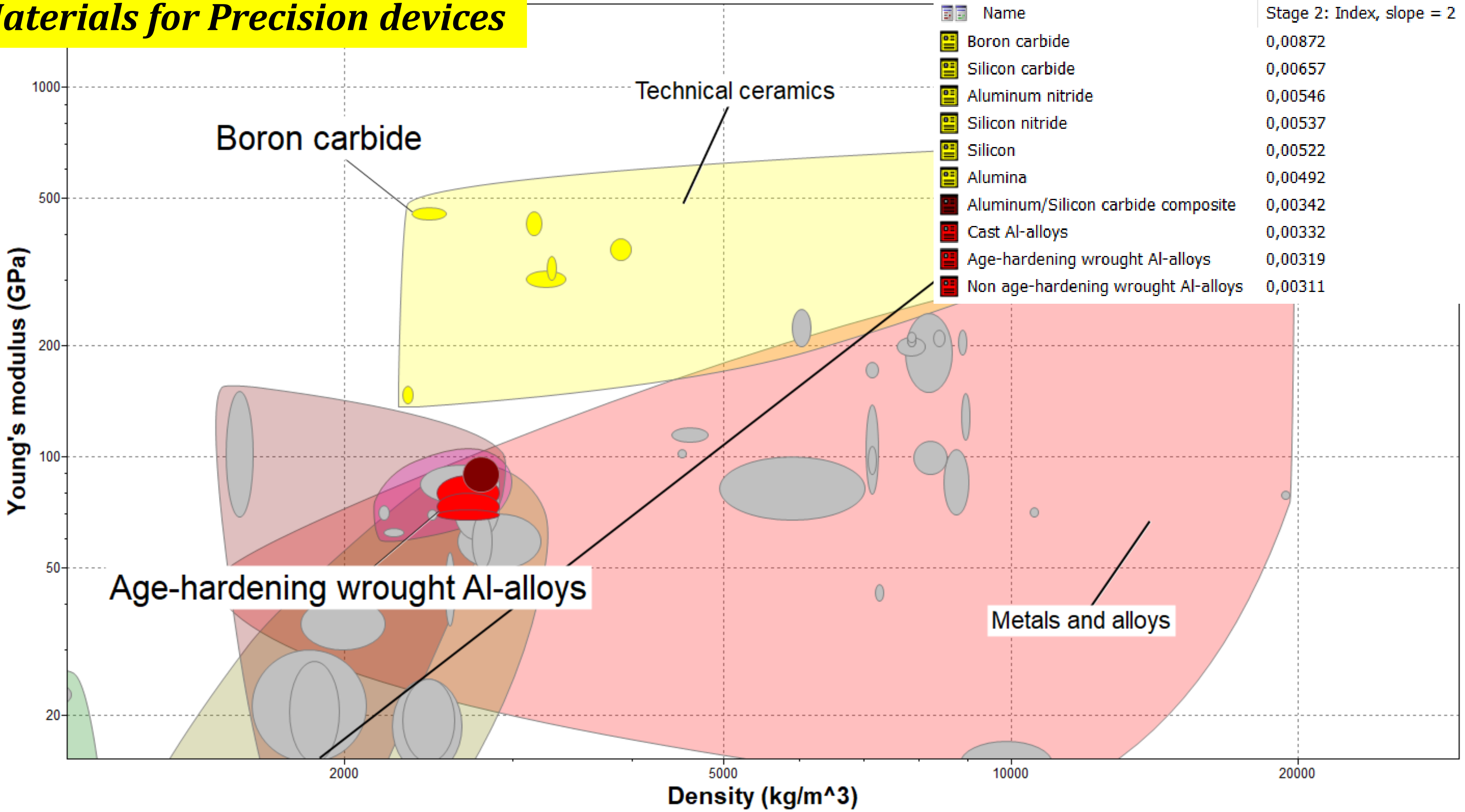
Case Study 15: Materials for Precision devices



Name	Stage 1: Index, slope = 1
Silicon	57,3
Aluminum nitride	32,2
Tungsten alloys	25,2
Silicon carbide	23,3
Gold	22,3
Silver	21,3
Boron carbide	18,2
Copper	14,3
Tungsten carbides	11,4
Silicon nitride	7,57
Non age-hardening wrought Al-alloys	7,21
Aluminum/Silicon carbide composite	6,81
Age-hardening wrought Al-alloys	6,24
Nickel	6,13
Brass	6,08
Cast Al-alloys	5,69
Cast iron, gray	4,58
Zinc die-casting alloys	4,49
Commercially pure zinc	4,41
Alumina	4,25
Medium carbon steel	4,2

Carbides? → Excellent performances, but difficult to shape
Copper → High density gives a low M2
Al alloys → the cheapest and most easily shaped choice
Silicon → the best choice

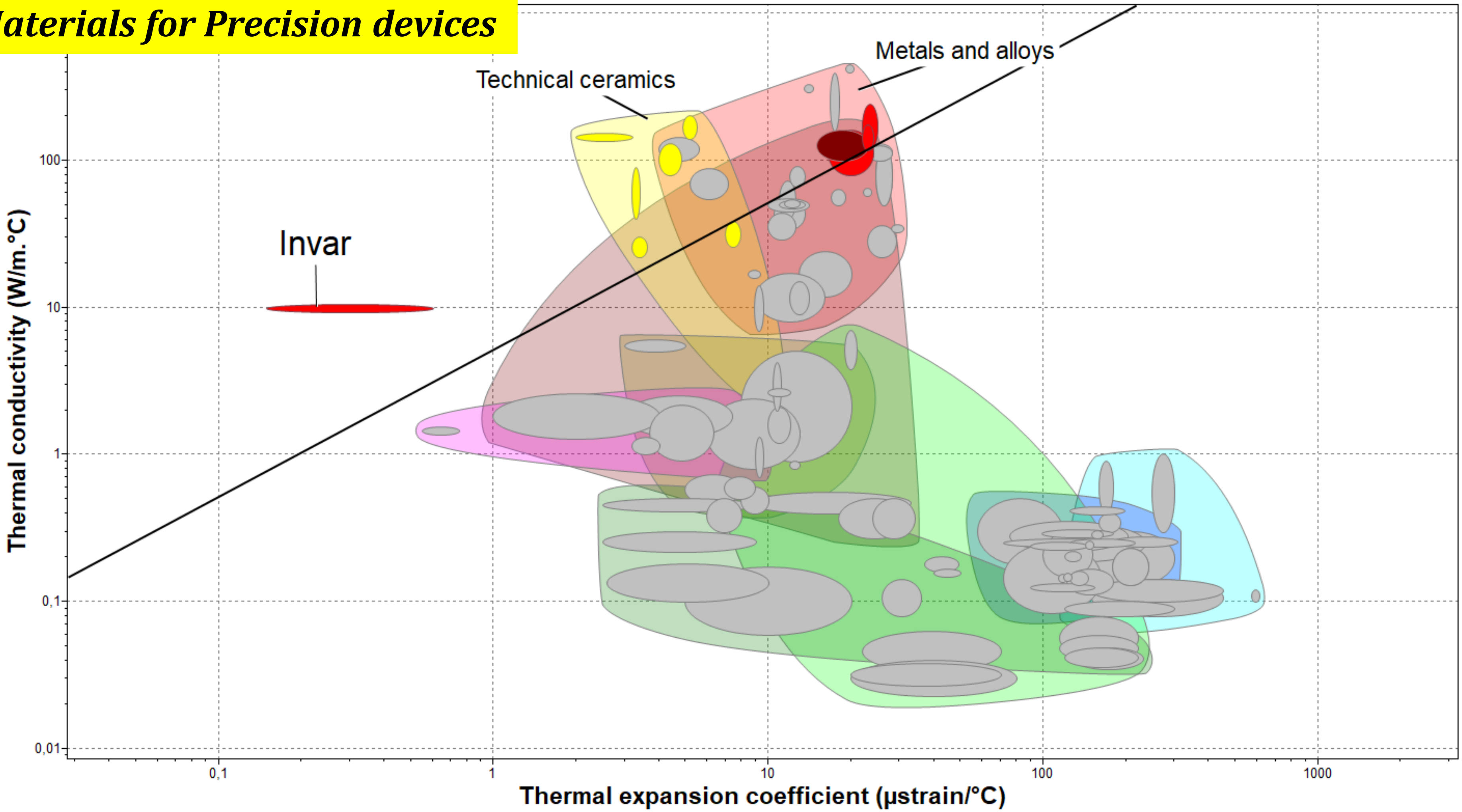
Case Study 15:
Materials for Precision devices



Name	Stage 2: Index, slope = 2
Boron carbide	0,00872
Silicon carbide	0,00657
Aluminum nitride	0,00546
Silicon nitride	0,00537
Silicon	0,00522
Alumina	0,00492
Aluminum/Silicon carbide composite	0,00342
Cast Al-alloys	0,00332
Age-hardening wrought Al-alloys	0,00319
Non age-hardening wrought Al-alloys	0,00311

With some researches you can find better materials!
Ex. Invar
Add Record IF IT HAS A SENSE

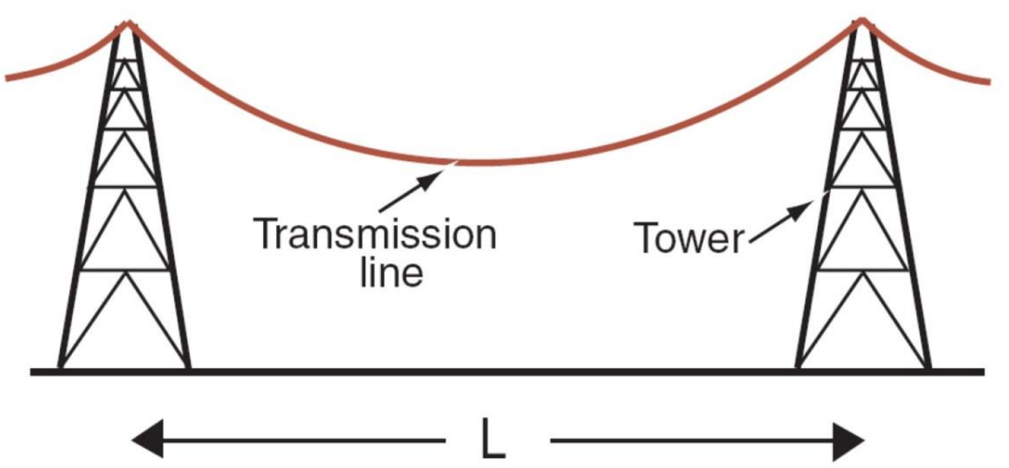
Case Study 15:
Materials for Precision devices



Conductors, insulators and dielectrics

Case Study 16: Materials for Long Span Transmission line

Objective	• Maximize current flux
Constraints	• Easy to manufacture • Must be strong? • Dimensions fixed
Free Variables	• Choice of material



Index from General Knowledge

Case Study 16:
Materials for
Long Span Transmission line

Wiedemann-Franz Law

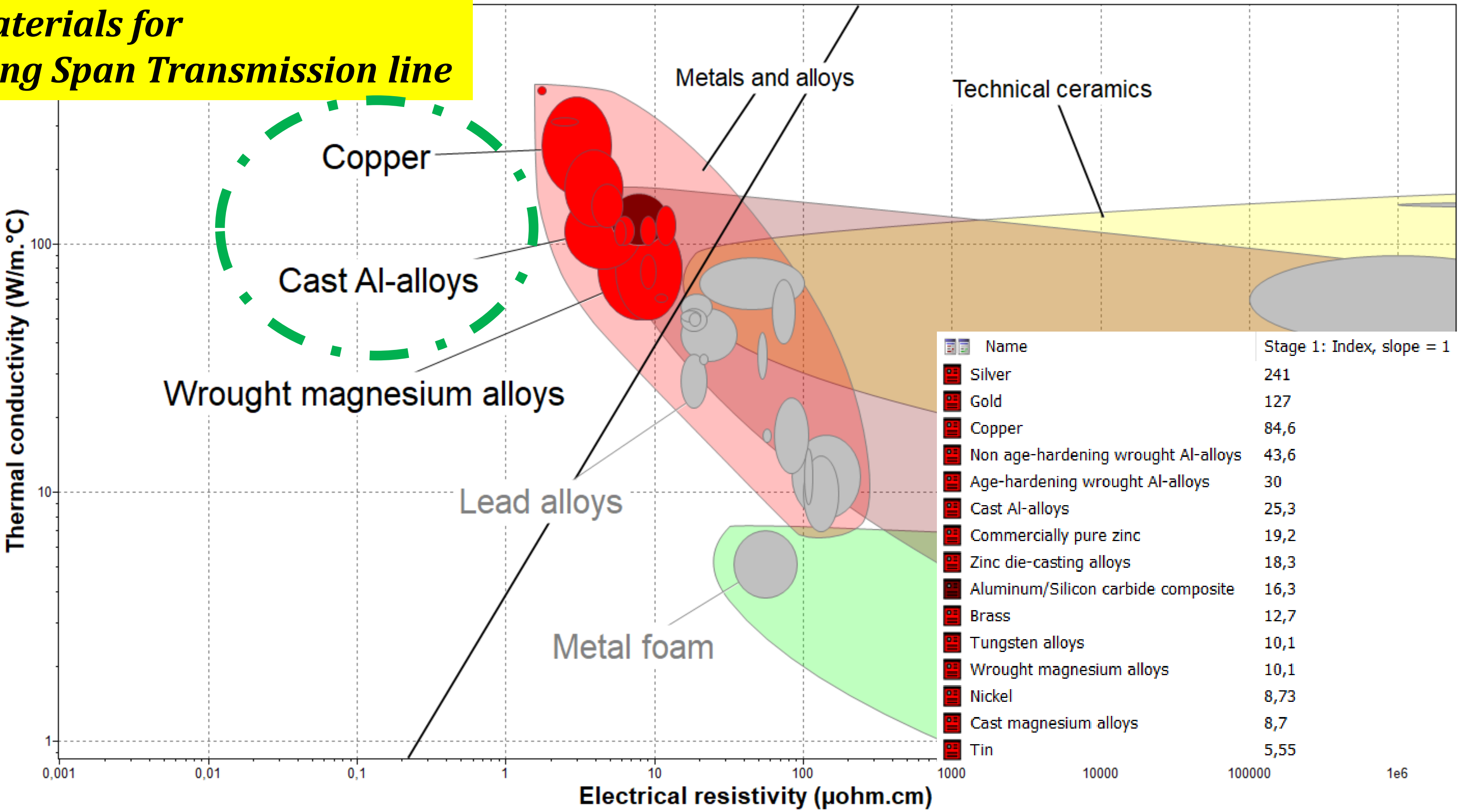
$$L \propto K = \frac{\lambda}{\rho_e}$$

L *Lorenz number*
K *Electrical conductivity*
λ *Thermal conductivity*
ρ_e *electrical resistivity*

$$K \uparrow \qquad \frac{\lambda}{\rho_e} \uparrow$$

[http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/thercond.html]

Case Study 16:
Materials for
Long Span Transmission line



How the shape can change the properties→ Decrease the I

Case Study 16:
Parenthesis about real life

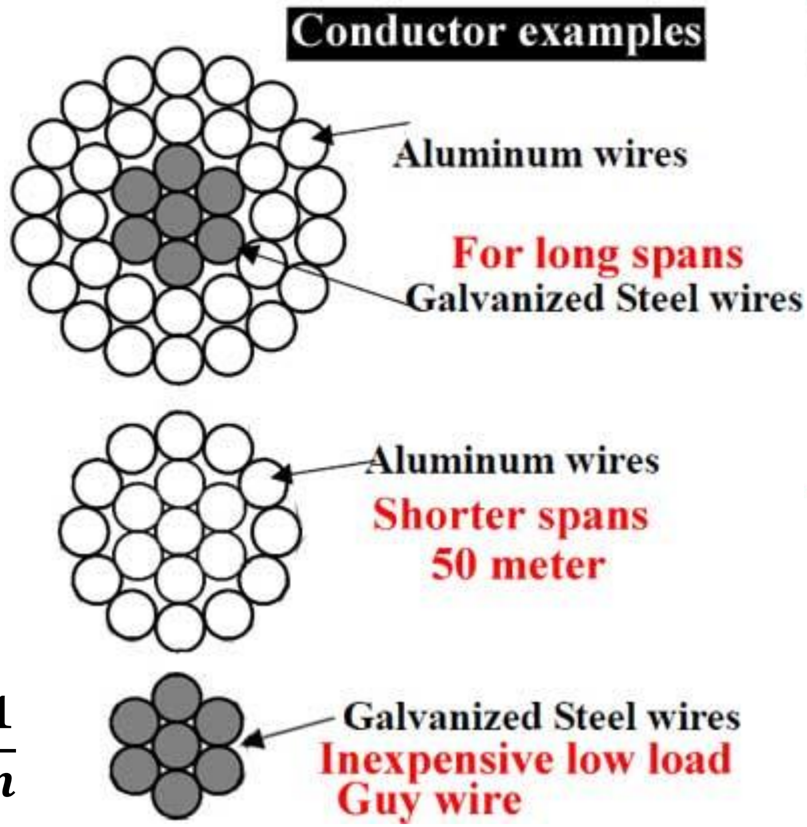
On a standard shape

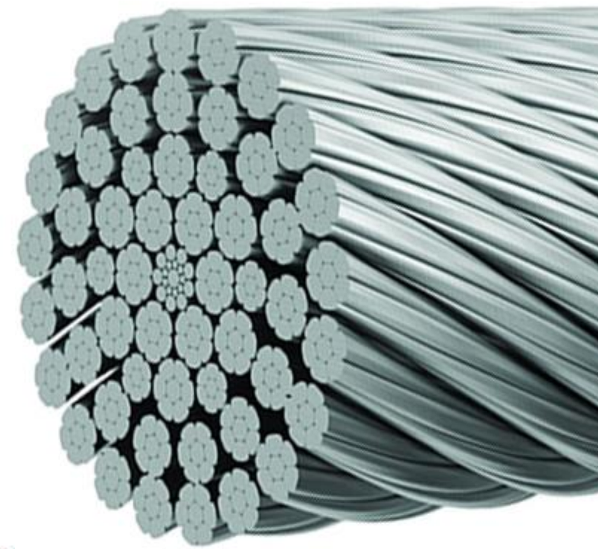
$$\begin{cases} n\pi r^2 = b^2 = A \\ I_0 = \dfrac{A^2}{12} = \dfrac{(n\pi r^2)^2}{12} \end{cases}$$

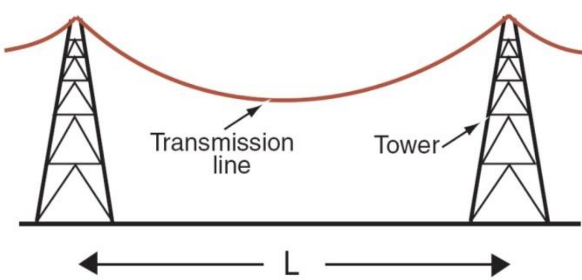
On the single wire

$$I = I_0 \cdot n = \frac{n\pi r^4}{4}$$

$$\boldsymbol{\frac{I}{I_0} = \frac{\frac{n\pi r^4}{4}}{\frac{(n\pi r^2)^2}{12}} = \frac{3}{n\pi} \propto \frac{1}{n}}$$

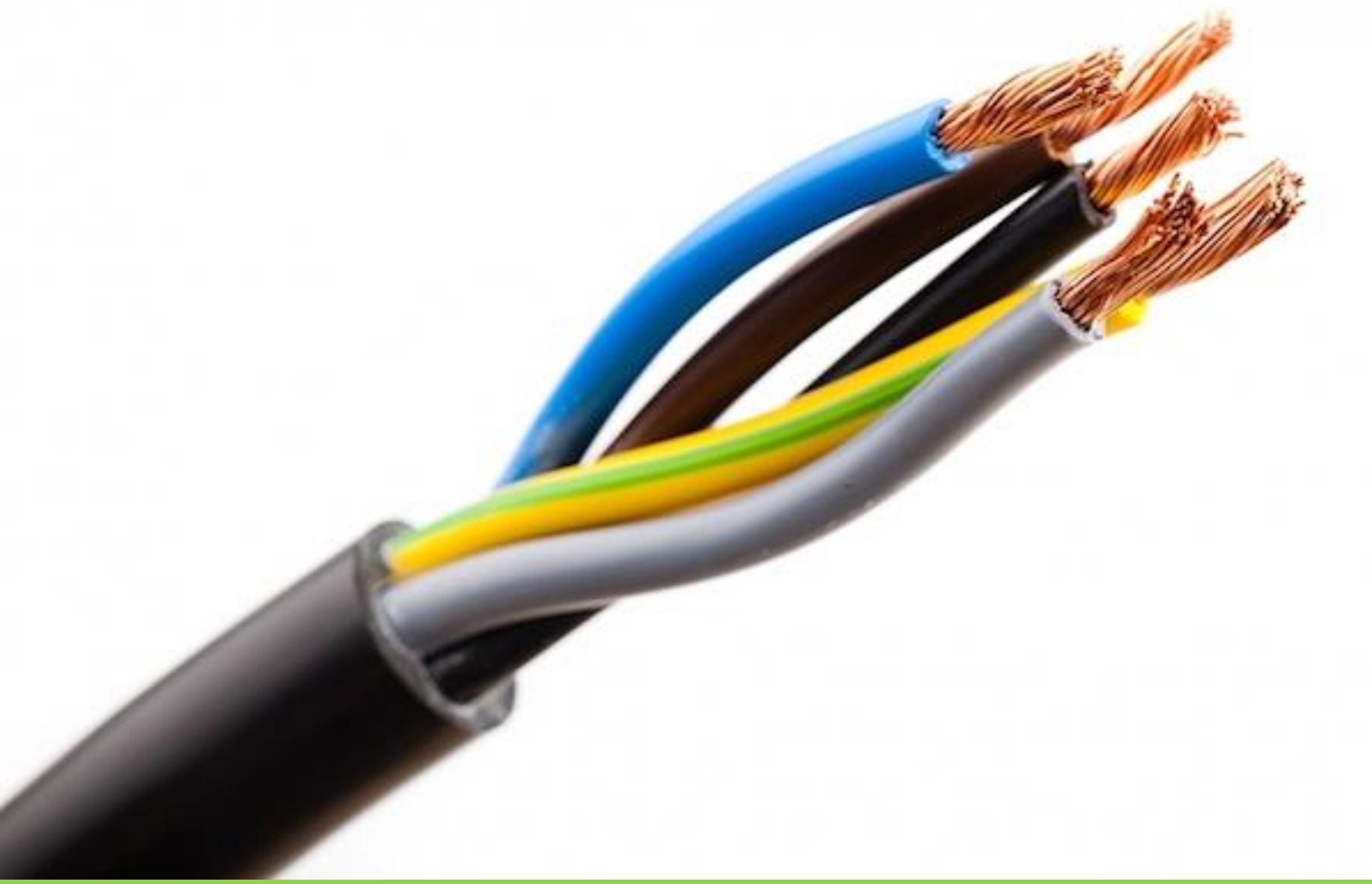






Case Study 17: Materials for Light Cable

Objective	• Minimize the mass
Constraints	• Good conductor • Easy to manufacture • Dimensions fixed
Free Variables	• Choice of material



Index from « Equations »

Case Study 17:
Materials for Light Cable

ρ_e *Electrical resistivity*

r *Electrical resistance of a uniform specimen of the material*

Pouillet's Law

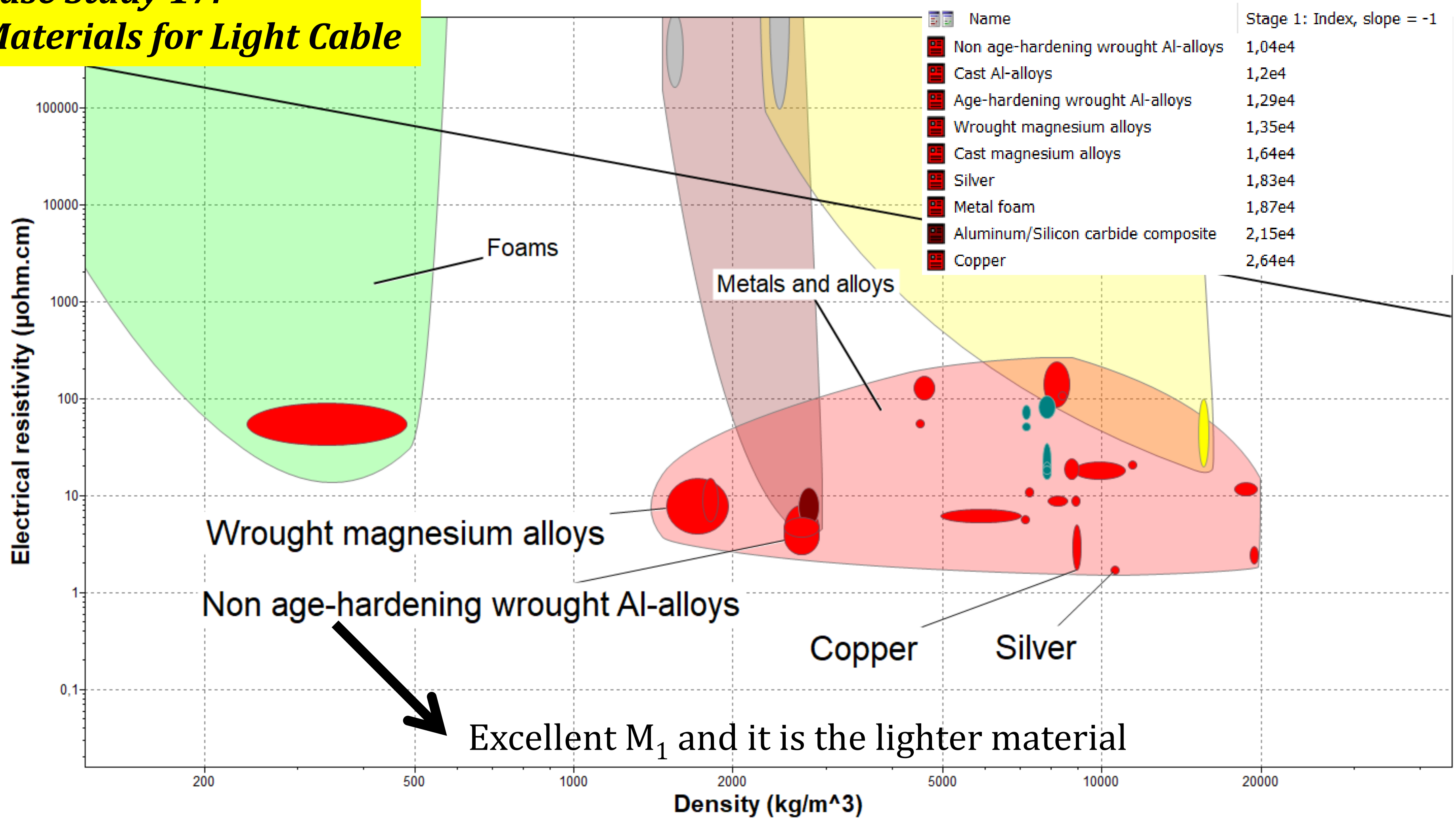
$$\begin{cases} r = \rho_e \dfrac{L}{A} \\ m = \rho \cdot L \cdot A \end{cases} \longrightarrow \quad A = \rho_e \frac{L}{r}$$

$$m = (\rho \cdot \rho_e) \cdot \frac{L^2}{r}$$

$$m \downarrow \qquad \frac{1}{\rho \cdot \rho_e} \uparrow$$

http://toelatingsexamen.org/en/app/course/71/pouillets-law-electrodynamics?chapterID=84&sectionID=3

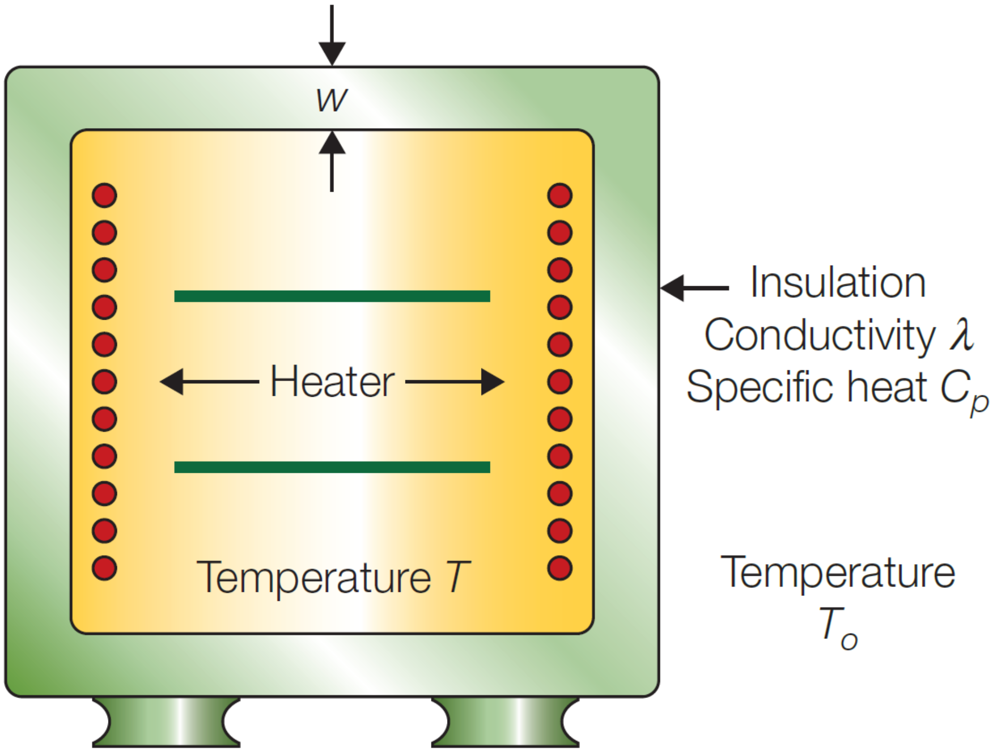
Case Study 17: Materials for Light Cable

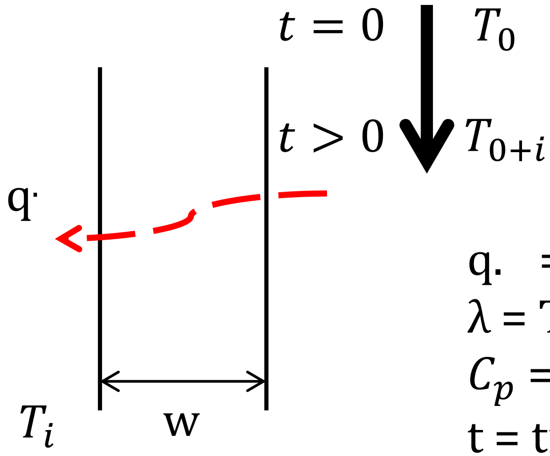


Excellent M_1 and it is the lighter material

Case Study 18: Materials for Kiln Walls

Objective	• Minimize energy consumed in firing cycle
Constraints	• Maximum and minimum operating temperature • Possible limit on W for space reasons
Free Variables	• Choice of material





q. = Heat flux
λ = Thermal conductivity
C_p = Specific heat capacity
t = time

Case Study 18: Materials for Kiln Walls

Heat loss by conduction

$$Q_1 = -\lambda \frac{(T_i - T_0)}{w} \cdot t$$

Heat (loss) absorbed by walls

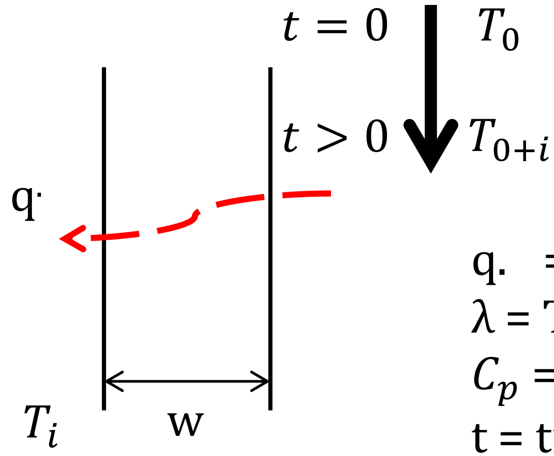
$$Q_2 = \frac{\Delta T \cdot w \cdot \rho \cdot C_p}{2}$$

Energy-efficient kiln walls? Reduce λ and w

$$Total\ energy\ consumed\ during\ the\ use\ Q = Q_1 + Q_2$$

$$Thus, we\ want\ a\ Minimum\ Q(w) \dashrightarrow \text{a w that correspond to } \frac{dQ}{dw} = 0$$

Case Study 18:
Materials for Kiln Walls



q. = Heat flux
λ = Thermal conductivity
C_p = Specific heat capacity
t = time

a = Thermal diffusivity

$$Q = Q_1 + Q_2 = -\lambda \frac{(T_i - T_0)}{w} \cdot t + \frac{\Delta T \cdot w \cdot \rho \cdot C_p}{2}$$

$$\frac{dQ}{dw} = 0 = -\lambda \frac{(T_i - T_0)}{w^2} \cdot t + \frac{\Delta T \cdot w \cdot \rho \cdot C_p}{2}$$

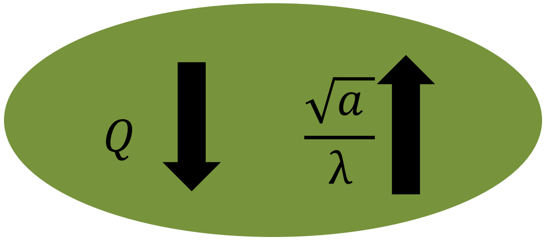
For an optimum thickness

$$w^* = \sqrt{\frac{2\lambda t}{\rho \cdot C_p}} = \sqrt{2at}$$

So, if we consider

$$Q = Q_1 + Q_2 \rightarrow Q = \frac{\Delta T \cdot \sqrt{2t} \cdot \lambda}{\sqrt{a}}$$

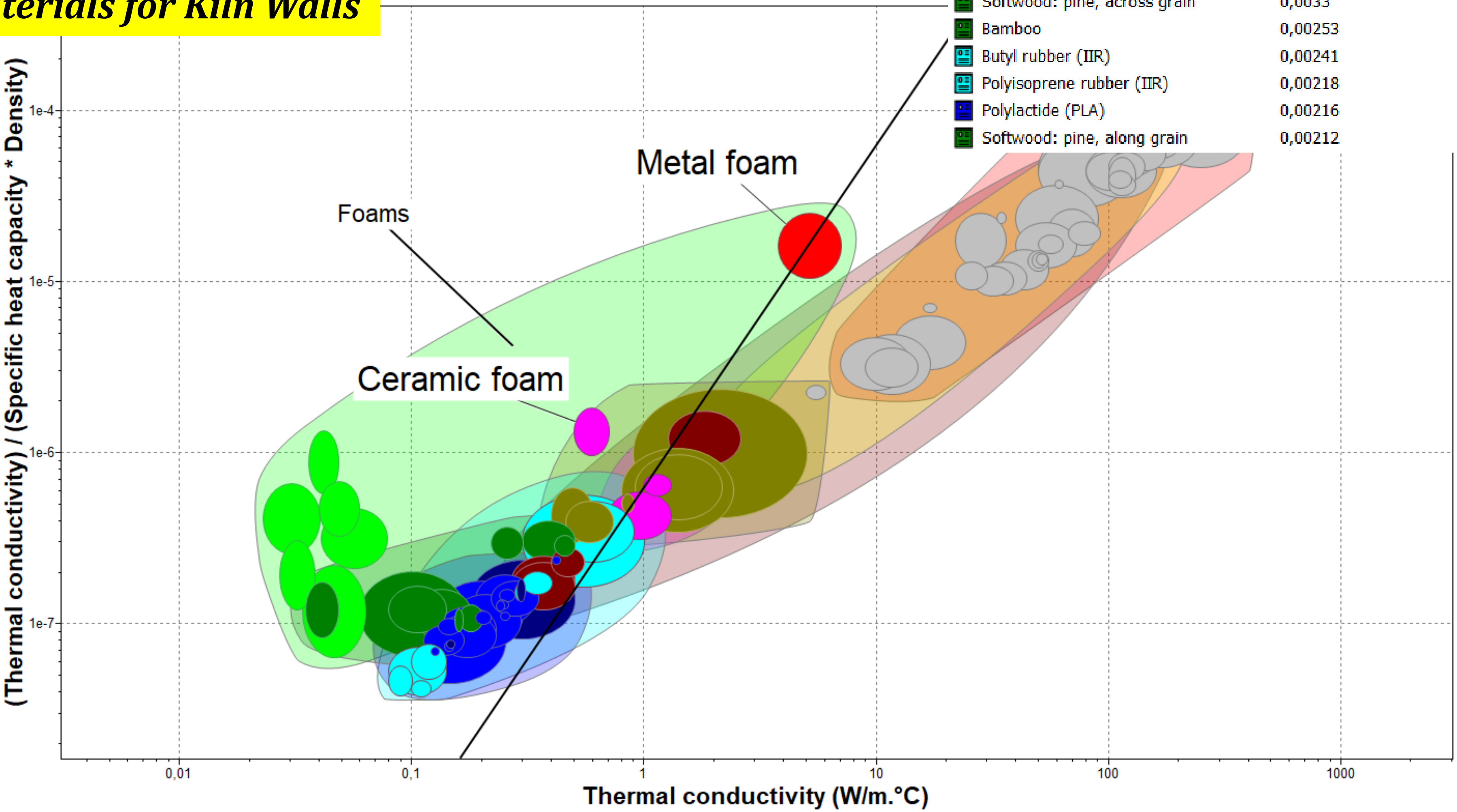
$$w^* = \sqrt{2at}$$



$Q \downarrow \quad \frac{\sqrt{a}}{\lambda} \uparrow$

Case Study 18: Materials for Kiln Walls

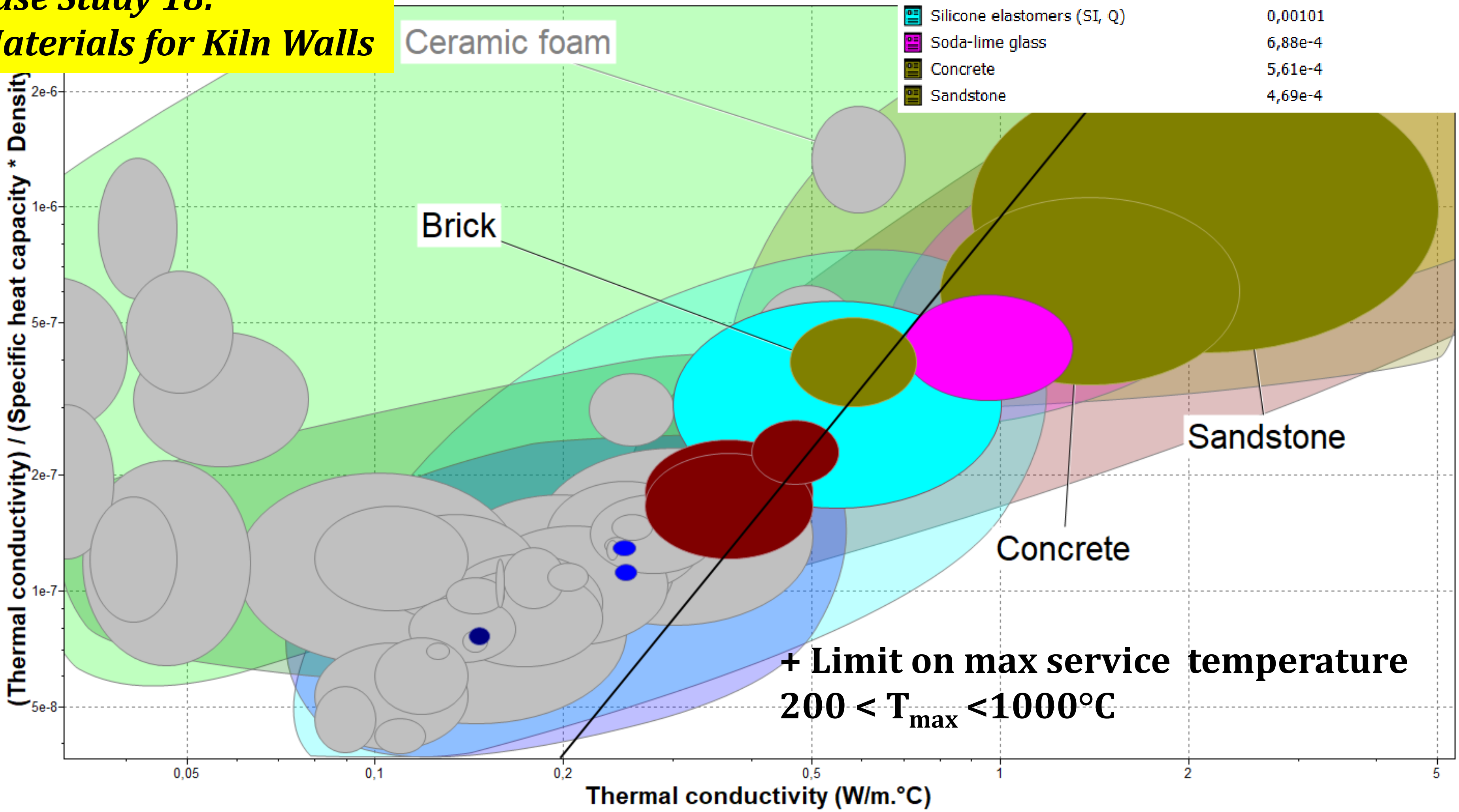
Name	Stage 1: Index, slope = 2
Flexible Polymer Foam (VLD)	0,0226
Rigid Polymer Foam (LD)	0,0212
Flexible Polymer Foam (LD)	0,0142
Rigid Polymer Foam (MD)	0,0137
Flexible Polymer Foam (MD)	0,00996
Cork	0,00848
Rigid Polymer Foam (HD)	0,00744
Paper and cardboard	0,00335
Softwood: pine, across grain	0,0033
Bamboo	0,00253
Butyl rubber (IIR)	0,00241
Polyisoprene rubber (IIR)	0,00218
Polylactide (PLA)	0,00216
Softwood: pine, along grain	0,00212



Case Study 18: Materials for Kiln Walls

$Q \downarrow \quad \frac{\sqrt{a}}{\lambda} \uparrow$

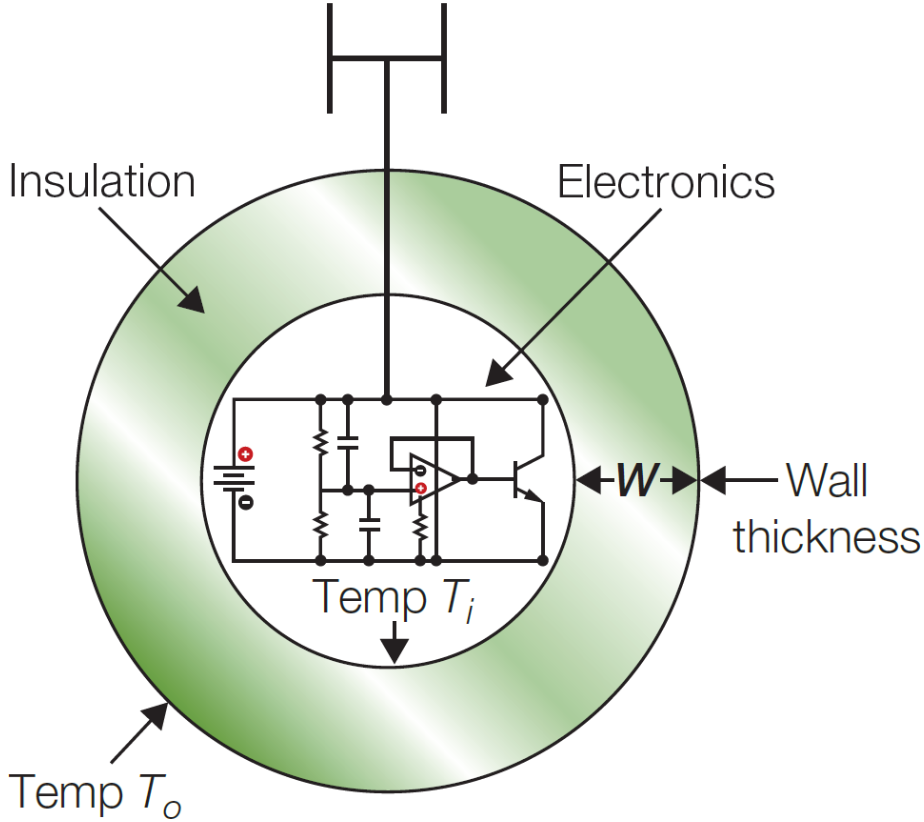
Name	Stage 1: Index, slope = 2
Phenolics	0,00189
Polyetheretherketone (PEEK)	0,00144
Polytetrafluoroethylene (Teflon, PTFE)	0,00133
Sheet molding compound, SMC, polyester ...	0,00116
Dough (Bulk) molding compound, DMC (BM...	0,00111
Brick	0,00109
GFRP, epoxy matrix (isotropic)	0,00102
Silicone elastomers (SI, Q)	0,00101
Soda-lime glass	6,88e-4
Concrete	5,61e-4
Sandstone	4,69e-4



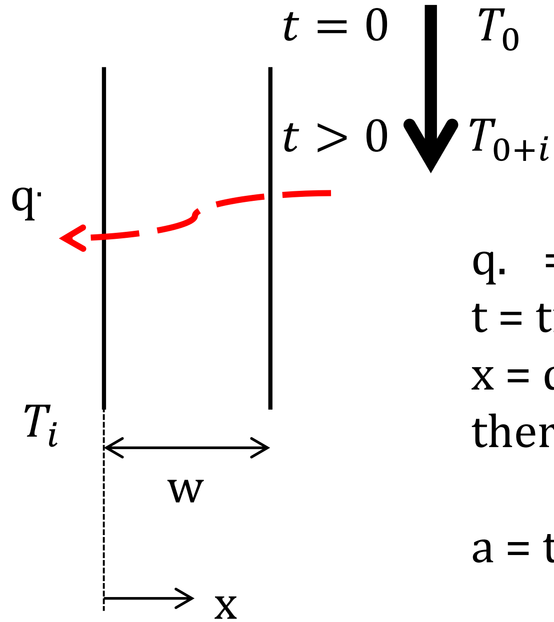
+ Limit on max service temperature
$200 < T_{max} < 1000°C$

Case Study 19:
Materials for Insulation for <u>Short-Term</u> isothermal containers

Objective	• Maximize the time t before internal temperature changes when external temperature suddenly drops
Constraints	• Wall thickness (W)
Free Variables	• Choice of the material



Case Study 19:
Materials for Insulation for
<u>Short-Term</u> isothermal containers



q. = Heat flux
t = time
x = distance of propagation of thermal equilibrium

a = thermal diffusivity

Fick's Law for the temperature at Steady state

$$q^{\cdot} = -\lambda \frac{(T_i - T_0)}{w}$$

WE ARE NOT MINIMIZING THE HEAT FLUX!!!
WE WANT TO MAXIMIZE THE TIME t BEFORE T_0 CHANGE CONSIDERABLY

Fick's Law for the temperature at not-steady state

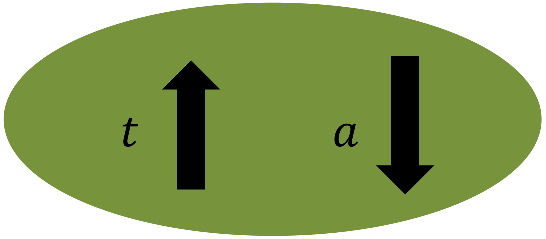
$$\frac{\partial T}{\partial t} = \mathrm{a} \frac{\partial^2 T}{\partial x^2}$$

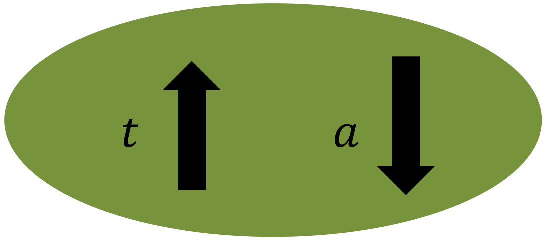
Too complex, so we use

$$x \cong \sqrt{2at} \leq w$$

$$a = \frac{\lambda}{\rho \cdot C_p}$$

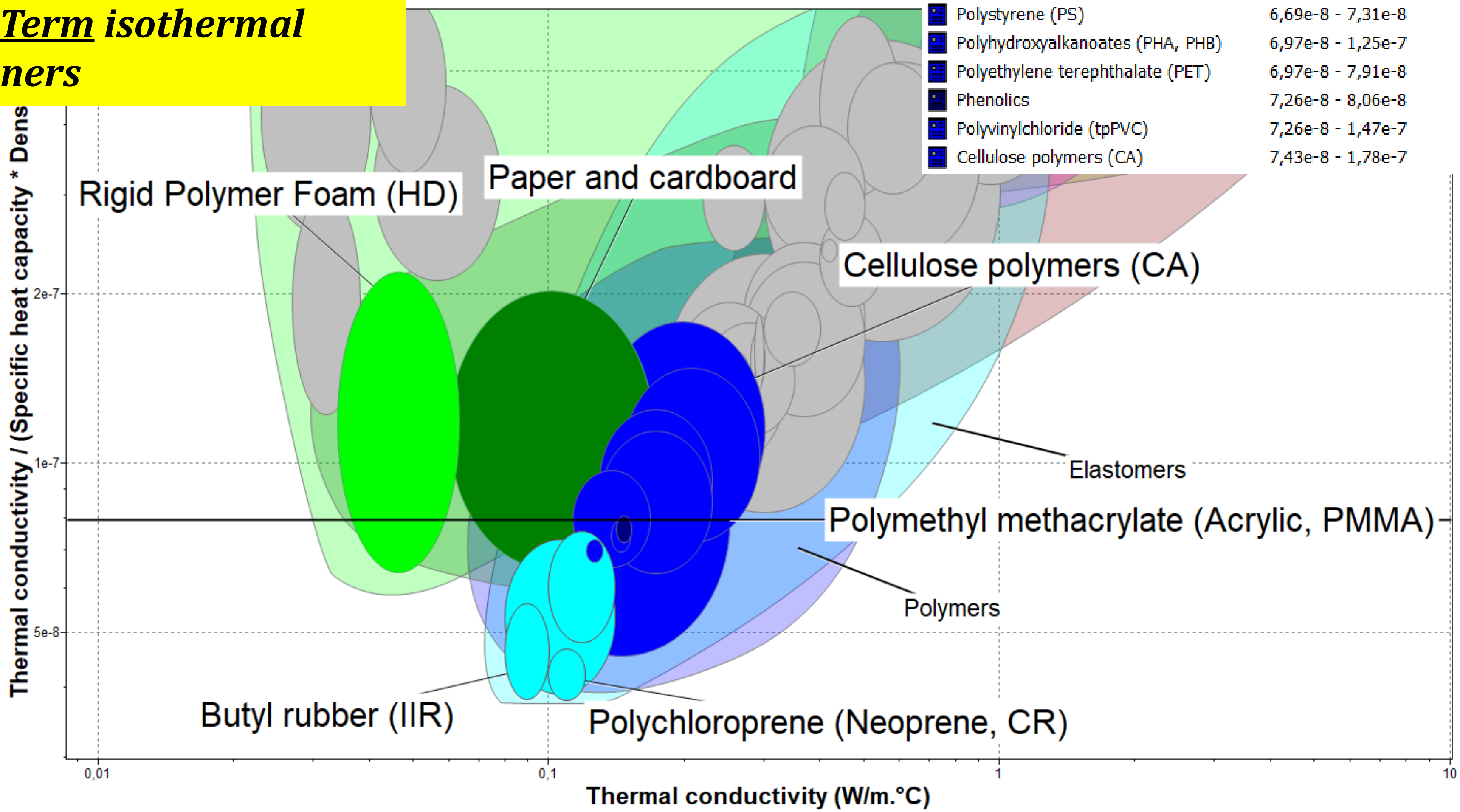
$$t = \frac{w^2}{2a}$$





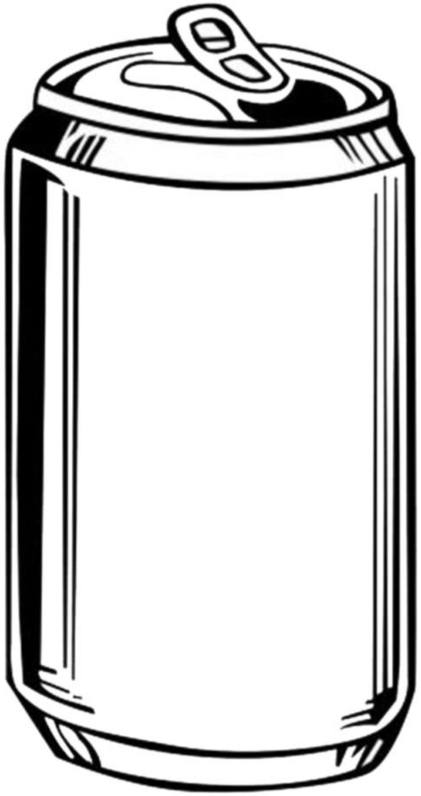
Name	Thermal conductivity / (Sp...
Polychloroprene (Neoprene, CR)	3,8e-8 - 4,66e-8
Butyl rubber (IIR)	3,82e-8 - 5,63e-8
Polyisoprene rubber (IIR)	3,9e-8 - 7,3e-8
Polymethyl methacrylate (Acrylic, PM...	4,55e-8 - 1,37e-7
Natural rubber (NR)	4,8e-8 - 7,57e-8
Starch-based thermoplastics (TPS)	6,38e-8 - 1,14e-7
Rigid Polymer Foam (HD)	6,42e-8 - 2,19e-7
Paper and cardboard	6,51e-8 - 2,02e-7
Polypropylene (PP)	6,56e-8 - 9,72e-8
Polystyrene (PS)	6,69e-8 - 7,31e-8
Polyhydroxyalkanoates (PHA, PHB)	6,97e-8 - 1,25e-7
Polyethylene terephthalate (PET)	6,97e-8 - 7,91e-8
Phenolics	7,26e-8 - 8,06e-8
Polyvinylchloride (tpPVC)	7,26e-8 - 1,47e-7
Cellulose polymers (CA)	7,43e-8 - 1,78e-7

Case Study 19: Materials for Insulation for <u>Short-Term</u> isothermal containers

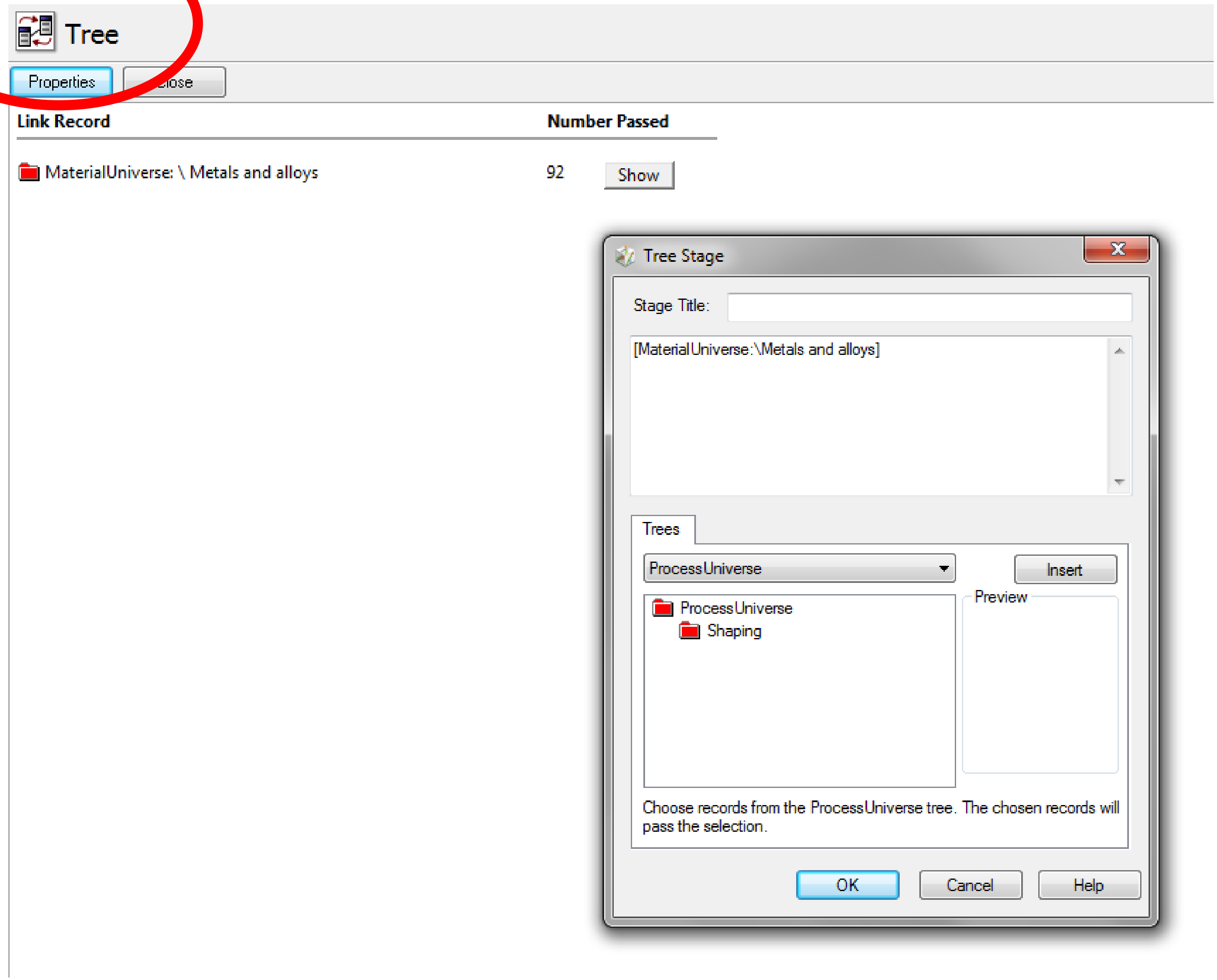


Case Study 20: Process for a Can

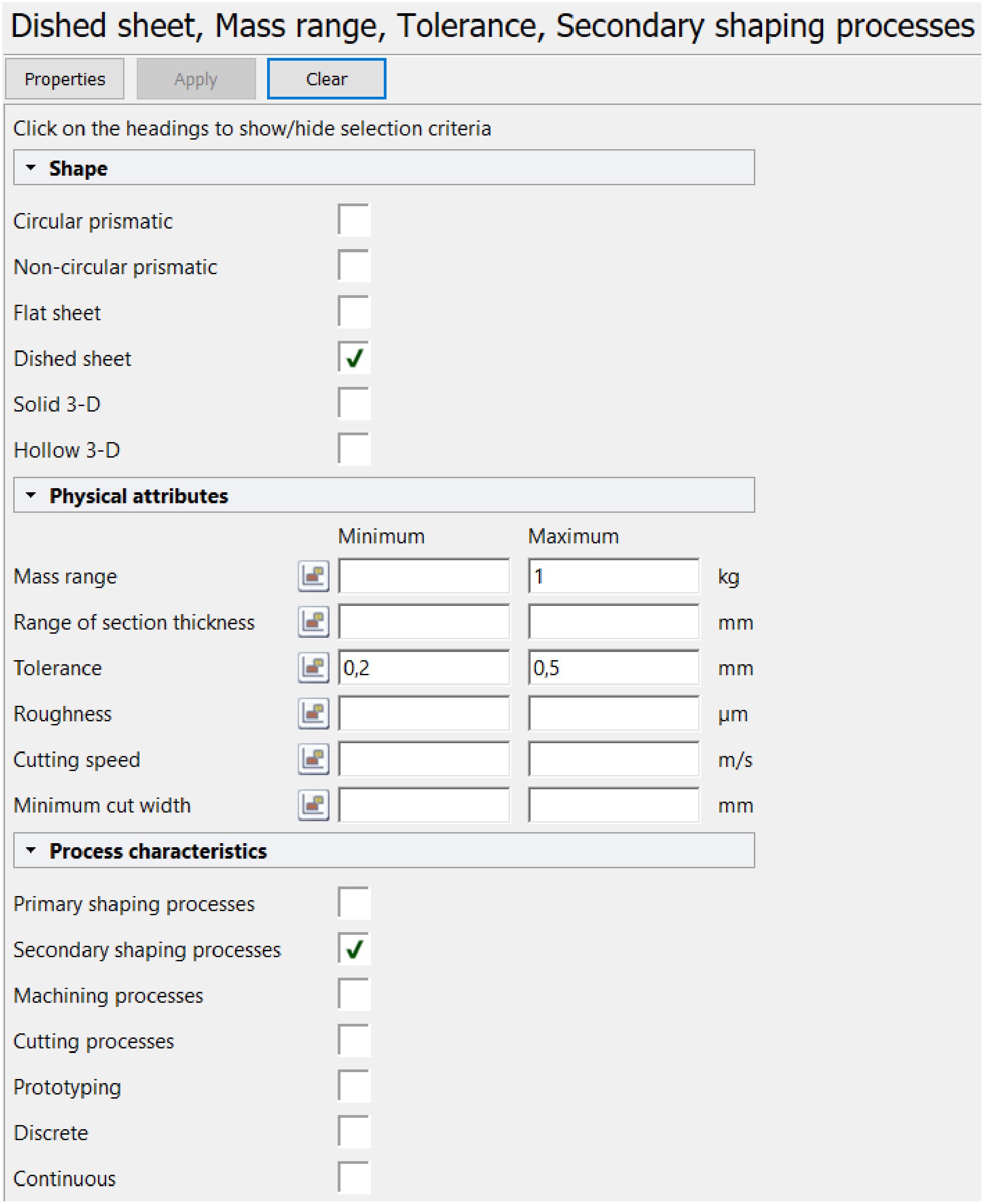
Objective	• Find an High production + Cheap process
Constraints	• Shape : Dished Sheet • Physical aspect : 1. Mass range max 1 kg 2. Tolerance 0,2-0,5 mm • Primary Process
Free Variables	• Choice of process



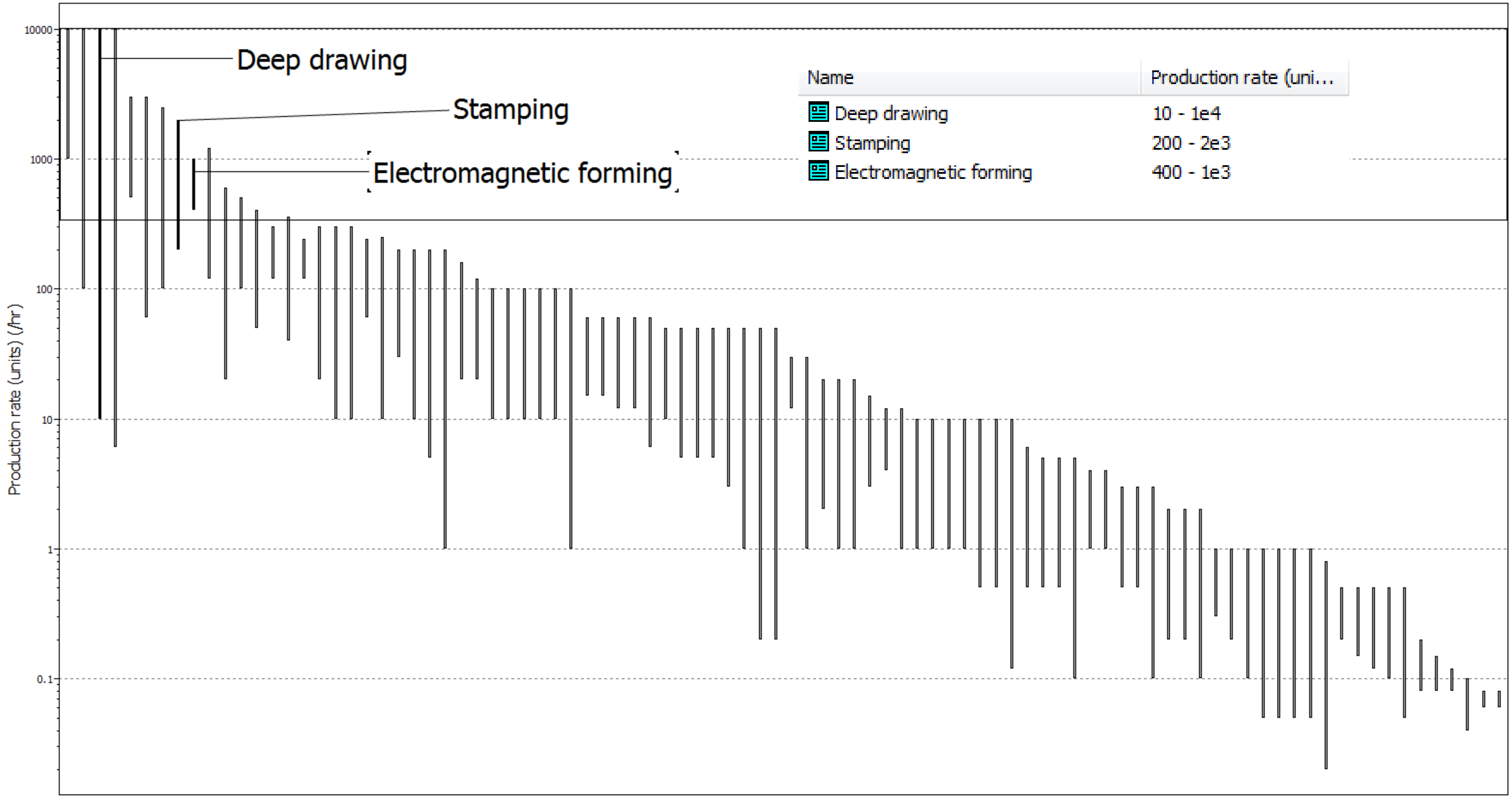
Case Study 20: Process for a Can



Case Study 20: Process for a Can



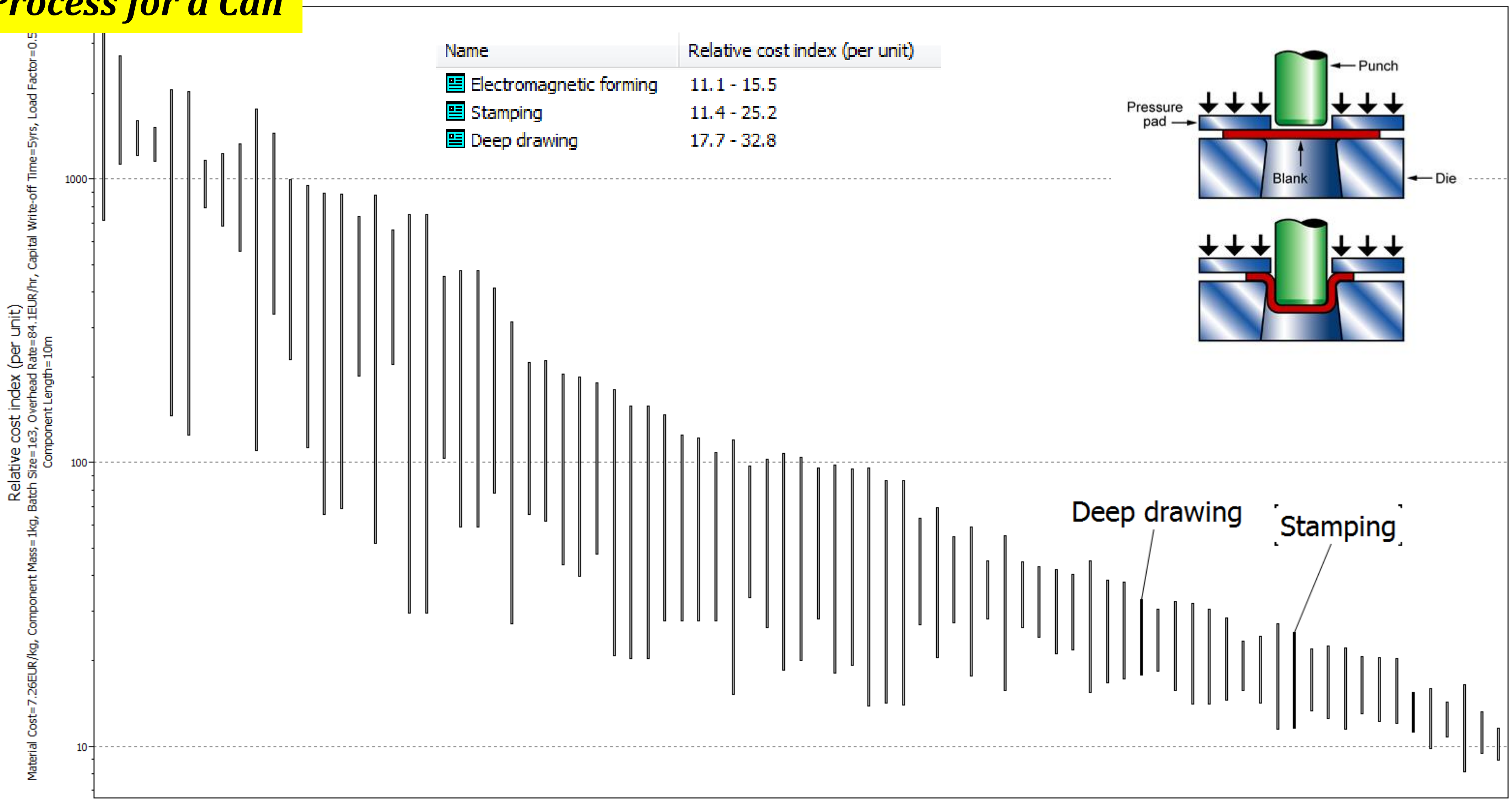
Case Study 20: Process for a Can



Results :

Deep drawing (deep drawing is a particular stamping)

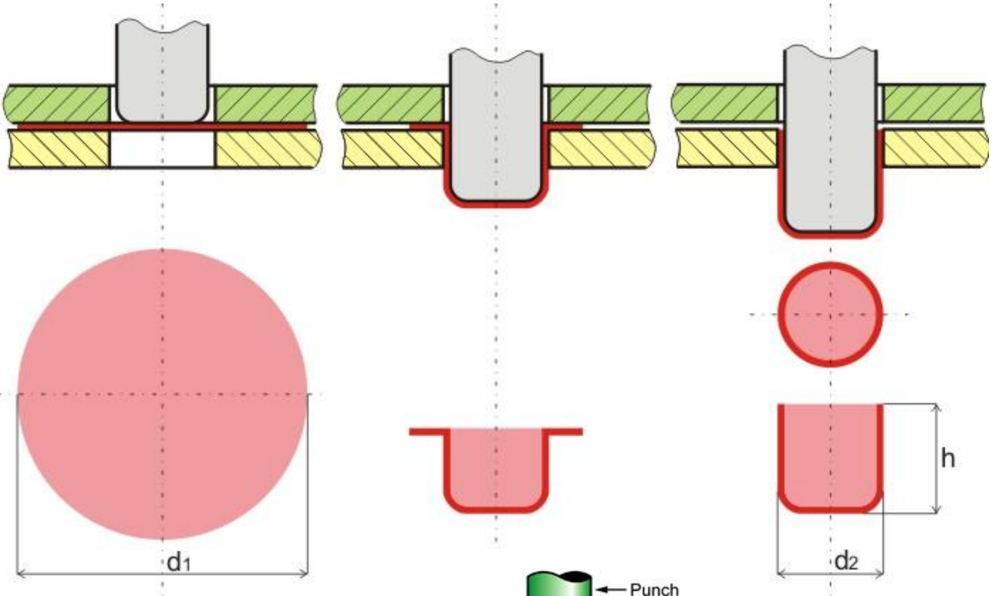
Case Study 20: Process for a Can

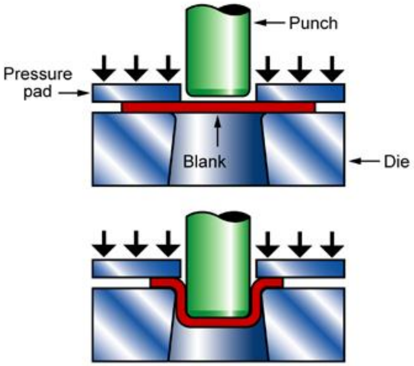


Name	Relative cost index (per unit)
Electromagnetic forming	11.1 - 15.5
Stamping	11.4 - 25.2
Deep drawing	17.7 - 32.8

Case Study 20: Process for a Can

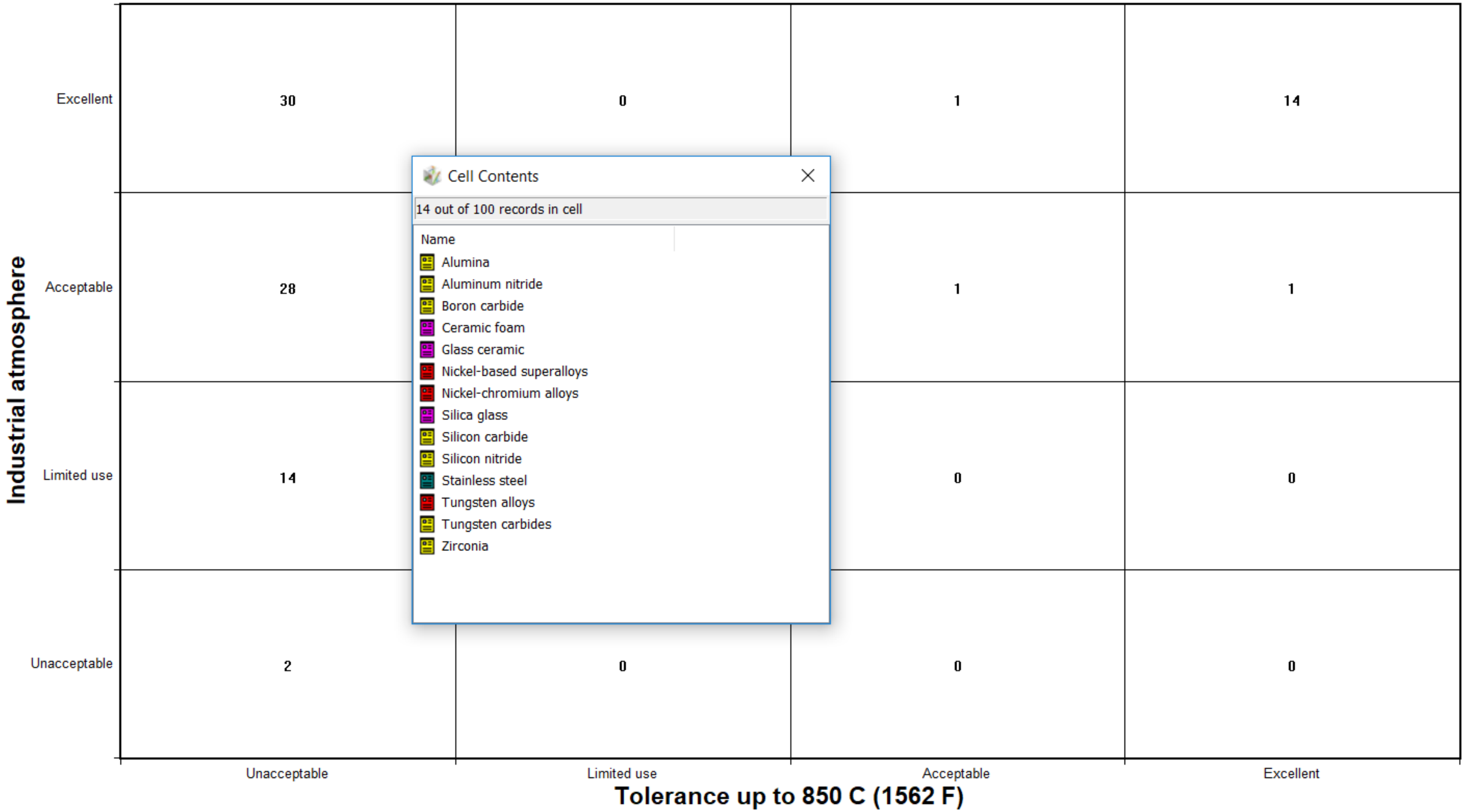
Deep drawing (deep drawing is a particular stamping)



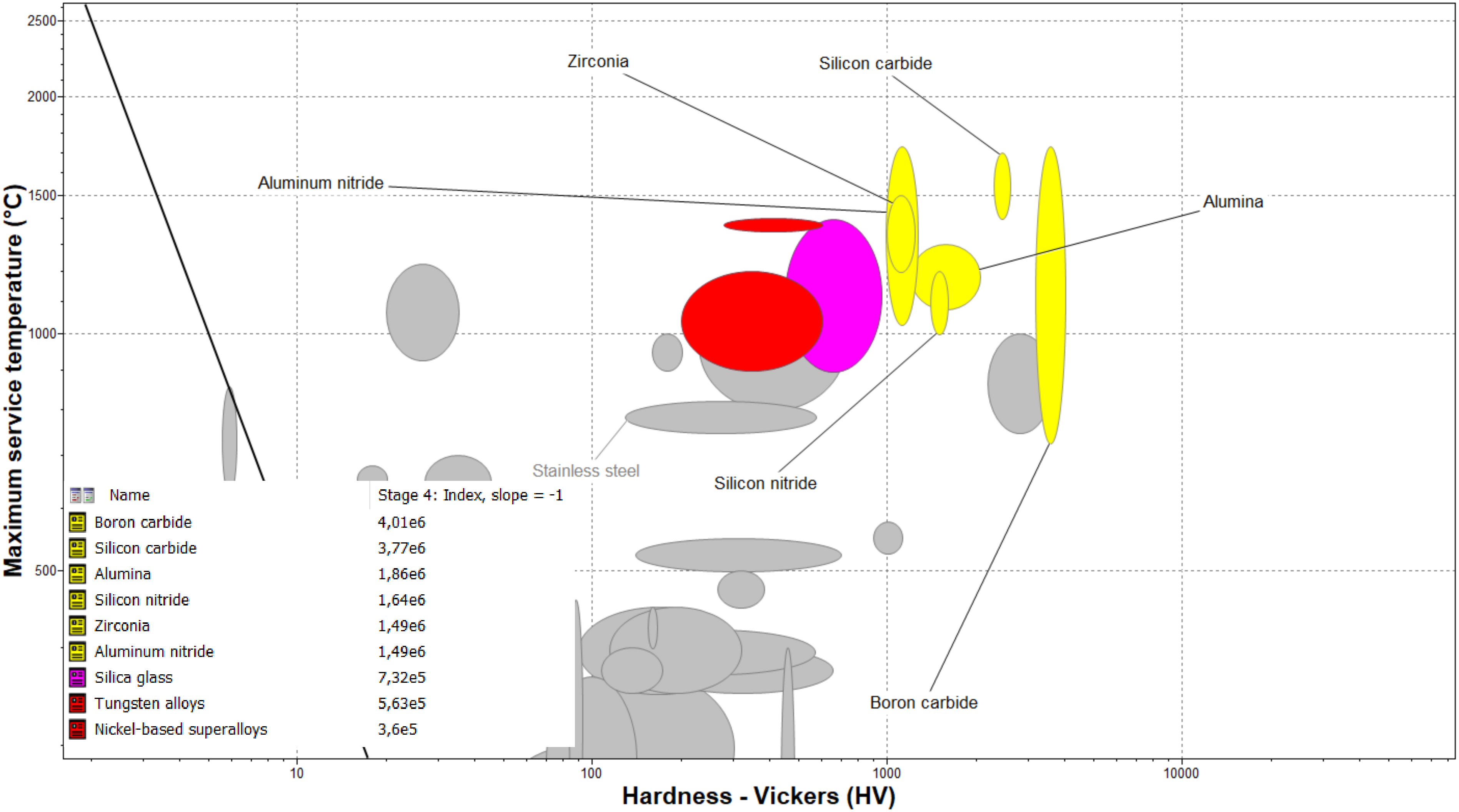


Secret slides : Kubota case

Secret slides : Kubota case



Secret slides : Kubota case



Name	Stage 4: Index, slope = -1
Boron carbide	4,01e6
Silicon carbide	3,77e6
Alumina	1,86e6
Silicon nitride	1,64e6
Zirconia	1,49e6
Aluminum nitride	1,49e6
Silica glass	7,32e5
Tungsten alloys	5,63e5
Nickel-based superalloys	3,6e5