Lightweight Materials
Their Properties, Technologies and Advanced Applicability

1.2 Material oriented approaches

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Lightweight Materials - Their Properties, Technologies and Advanced Applicability

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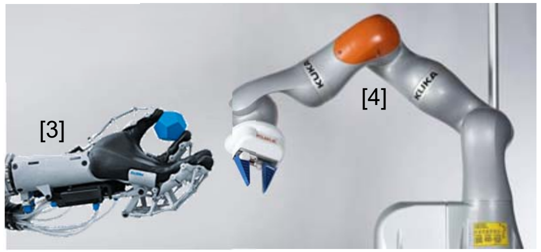

Lightweight design

How can we find a component‘s right material?

Leibniz-Institut für Werkstofforientierte Technologien

?


[1]


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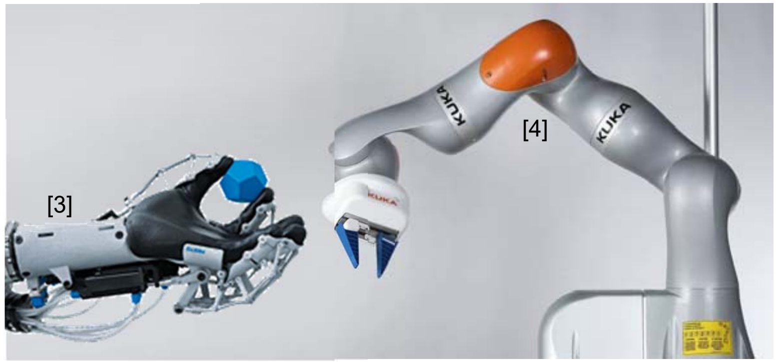
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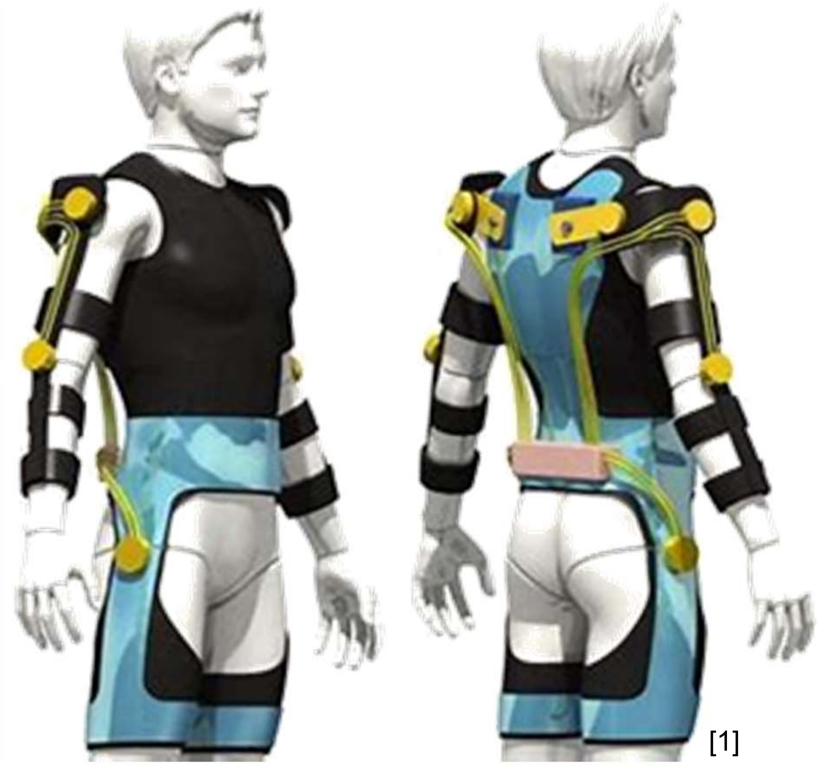
1.2 Material oriented approaches

Lightweight design

How can we find a component‘s right material?



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Lightweight design

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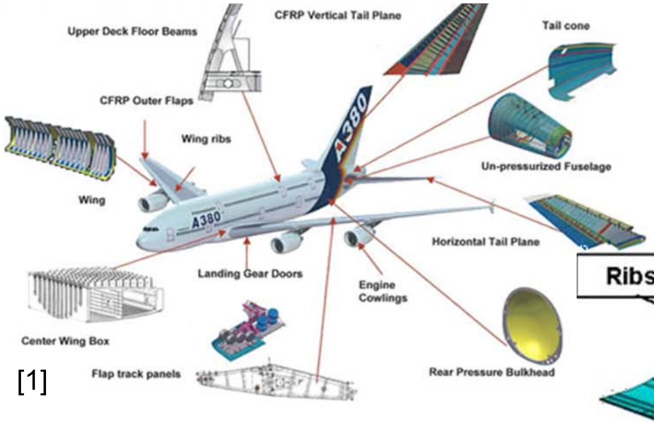

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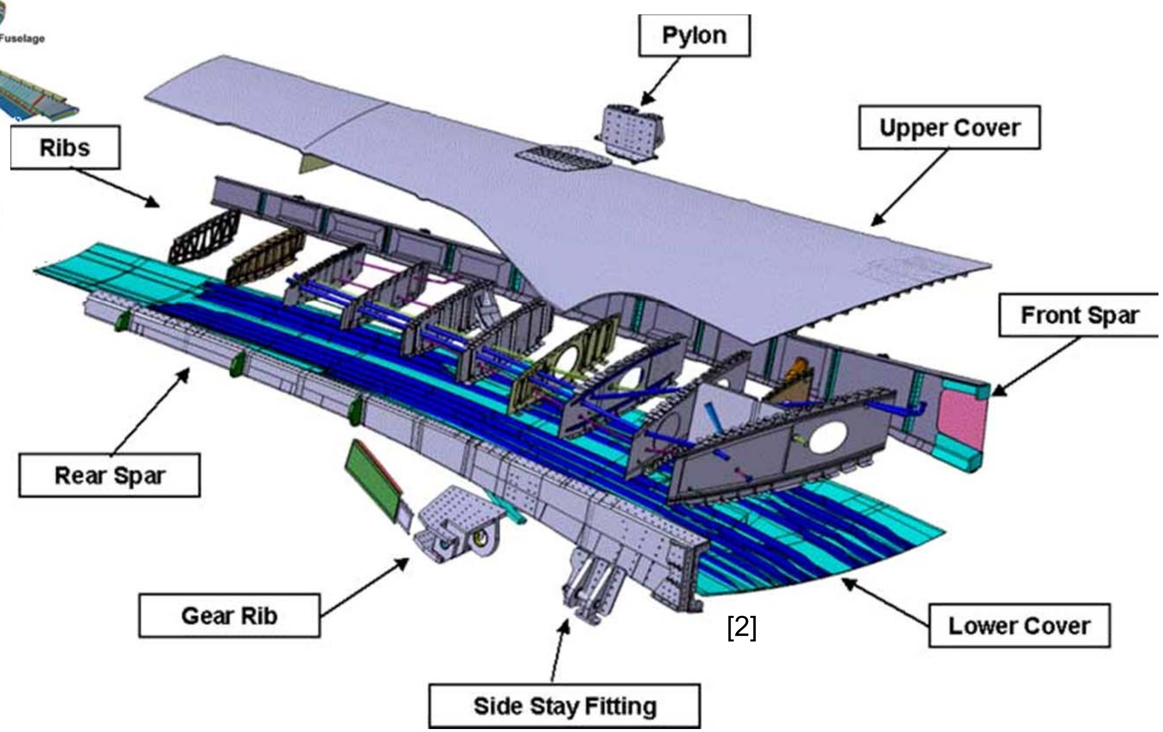
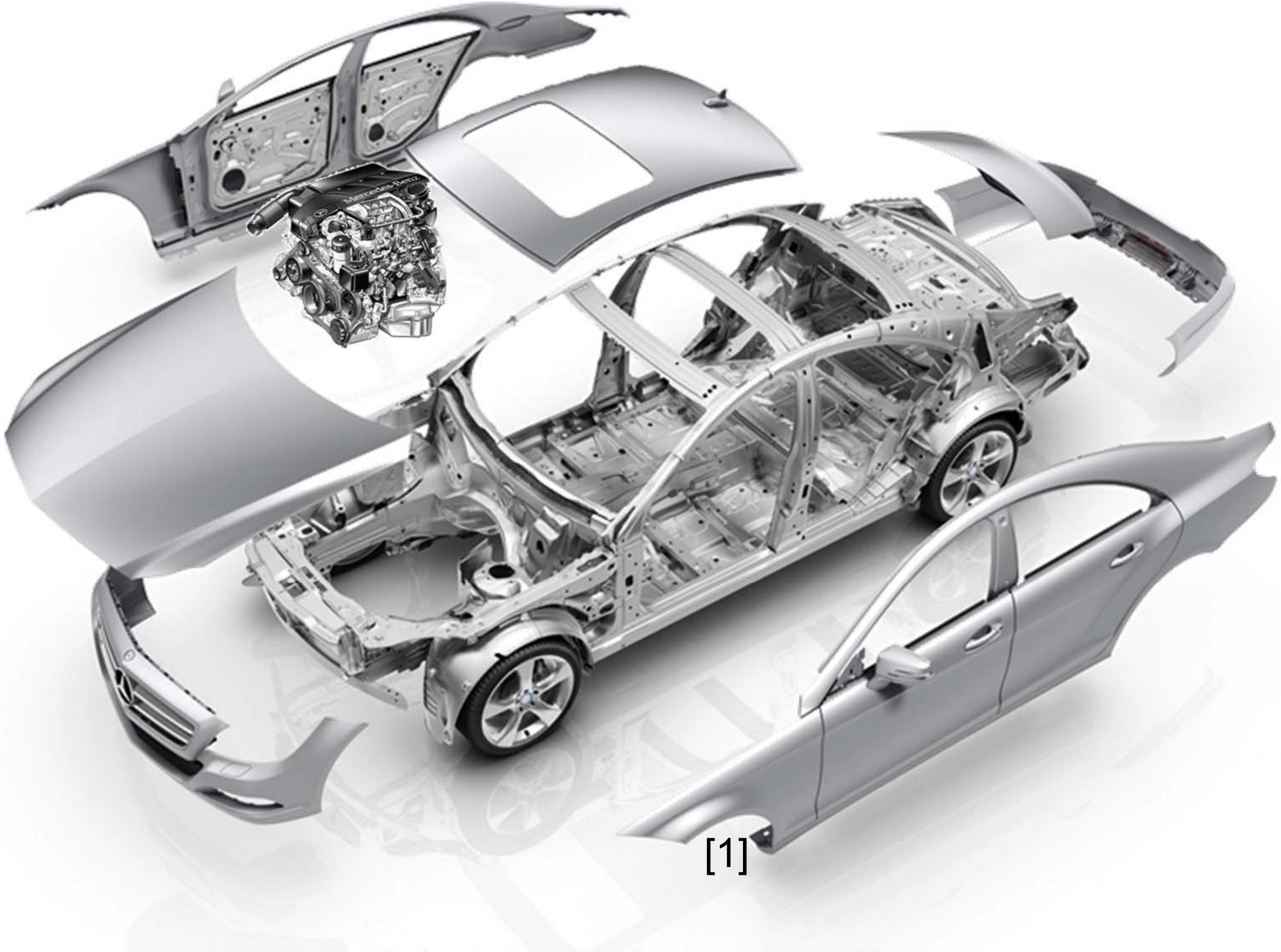


[2]

(Source: Airbus,)

Lightweight design

How can we find a component‘s right material?



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1.2 Material oriented approaches

Lightweight design

How can we find a component's right material?

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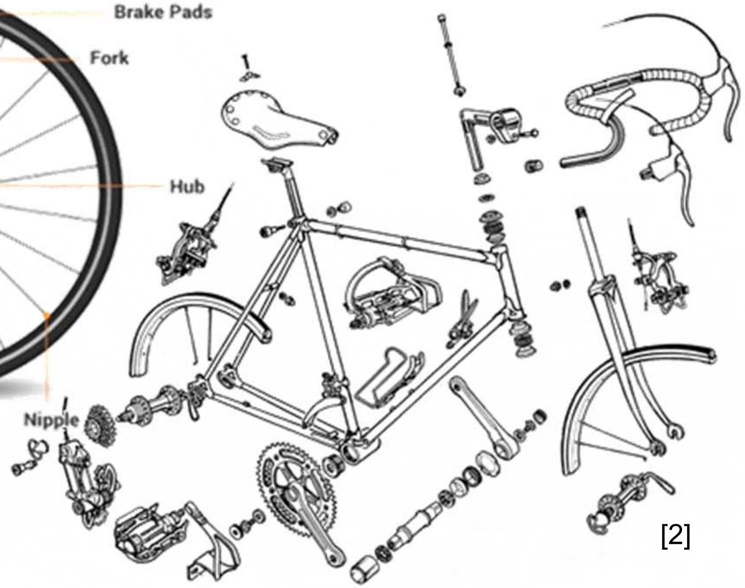


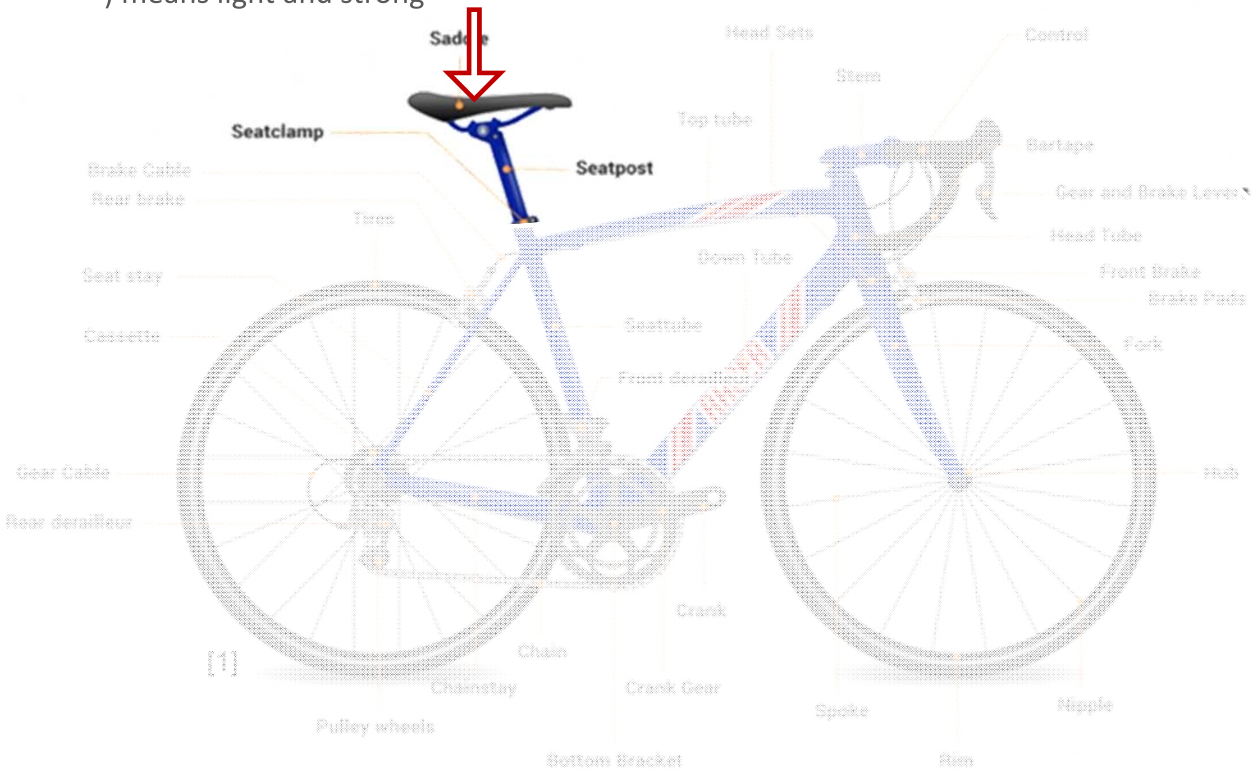
[2]

*) means light and strong

Design and dimensioning

How can we find the seat post‘s right* material?

*) means light and strong



Given:

- Cyclist‘s weight m=100 kg
- Horizontal distance between sattle and seat clamp x=100 mm
- Vertical distance between sattle and seat clamp y=200 mm
- Diameter of the seat post D=10 mm

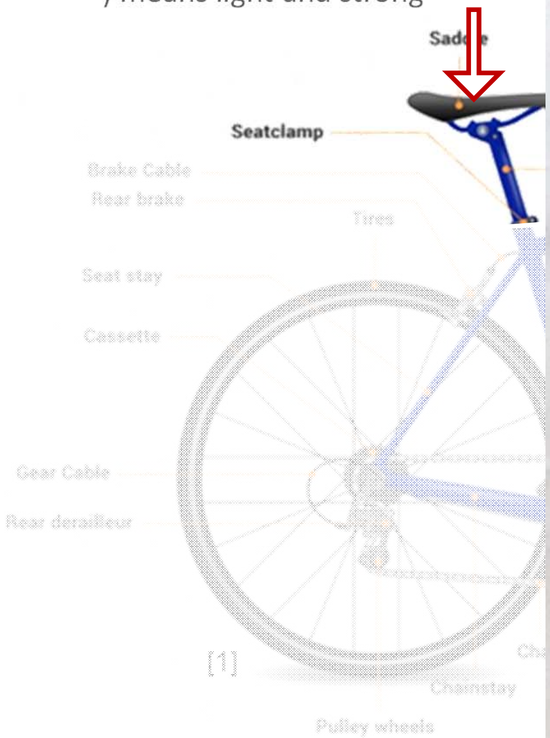
Wanted:

- Location of the highest load
- Type of local load
- Level of local load
- The seat post‘s right material choice (i.e. the lightest considered metal)

Design and dimensioning

How can we find the seat post‘s right* material?

*) means light and strong



[1]

$m = 100\,kg$

$x = 100\,mm$

$y = 200\,mm$

$D = 10\,mm$

1) $F = m \cdot g = 100\,kg \cdot 9{,}81\,\frac{m}{s^2} \approx 1000\,N = 1\,kN$

2) $\Sigma F_{xA} = 0$

$\Sigma F_{yA} = 0: \quad F_{yA} - F = 0$

$\Leftrightarrow F_{yA} = F = 1\,kN$

$\Sigma M_A = 0: \quad M_A = F x = 1\,kN\ 100\,mm$

$\Leftrightarrow \quad M_b = 100\,kN\,mm$

3) $\sigma_{b,max} = \frac{M_b}{J_{ax}} \cdot \frac{D}{2} = \frac{M_b}{W_{ax}}$

with: $J_{ax} = \frac{\pi}{64} \cdot D^4$

$\Leftrightarrow \sigma_{b,max} = \frac{32 \cdot M_b}{\pi D^3} = \frac{M_b}{W_{ax}}$ where it is: $W_{ax} = \frac{\pi \cdot D^3}{32} \approx 100\,mm^3$

$\Leftrightarrow \underline{\sigma_{b,max}} = \frac{100\,kN\,mm}{100\,mm^3} = \frac{1\,kN}{mm^2} = \underline{1000\,MPa}$

$\Rightarrow$ $\boxed{\text{Search for materials with strenght} \geq 1{,}000\,MPa}$

Given:

- Cyclist‘s weight m=100 kg
- Horizontal distance between sattle and seat clamp x=100 mm
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- Diameter of the seat post D=10 mm

Wanted:

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Design and dimensioning

How can we find the seat post‘s right* material?

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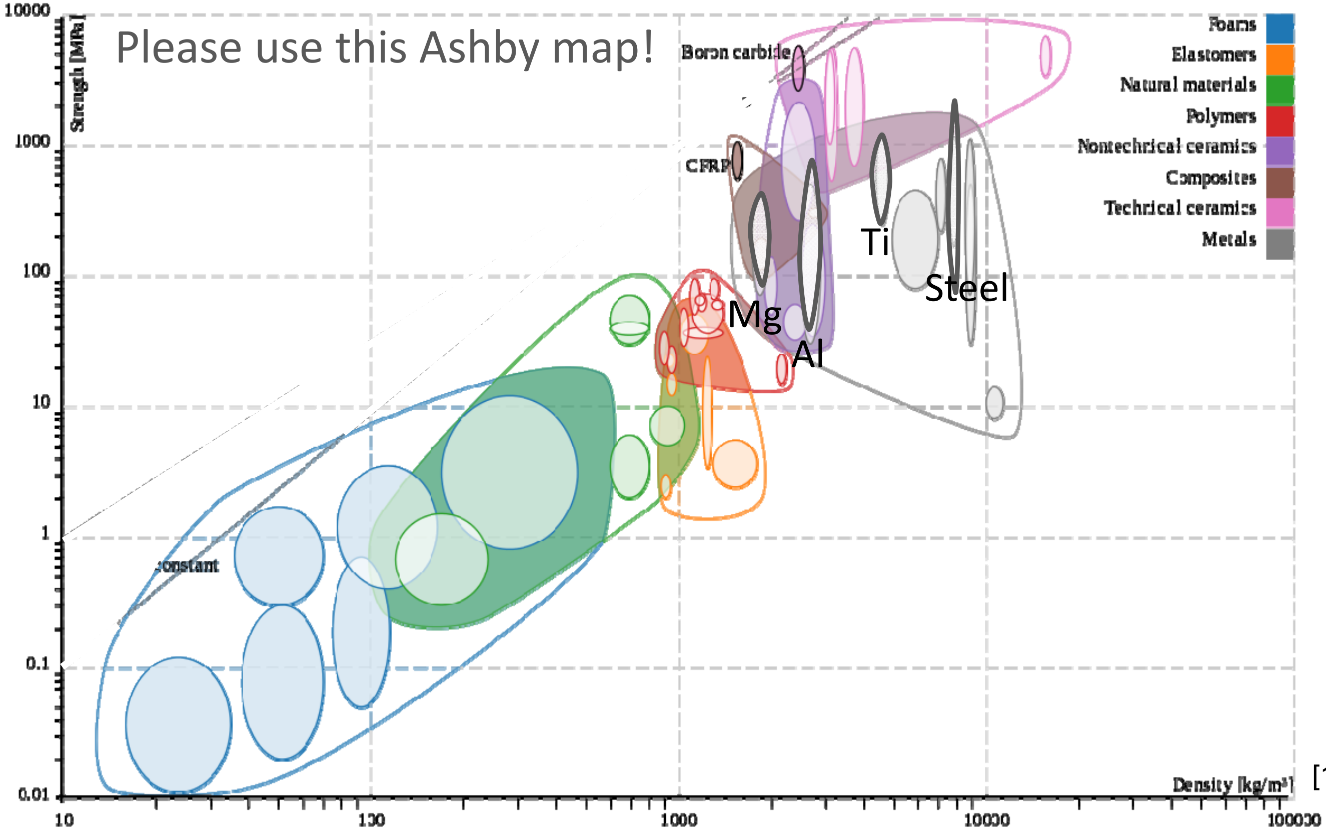

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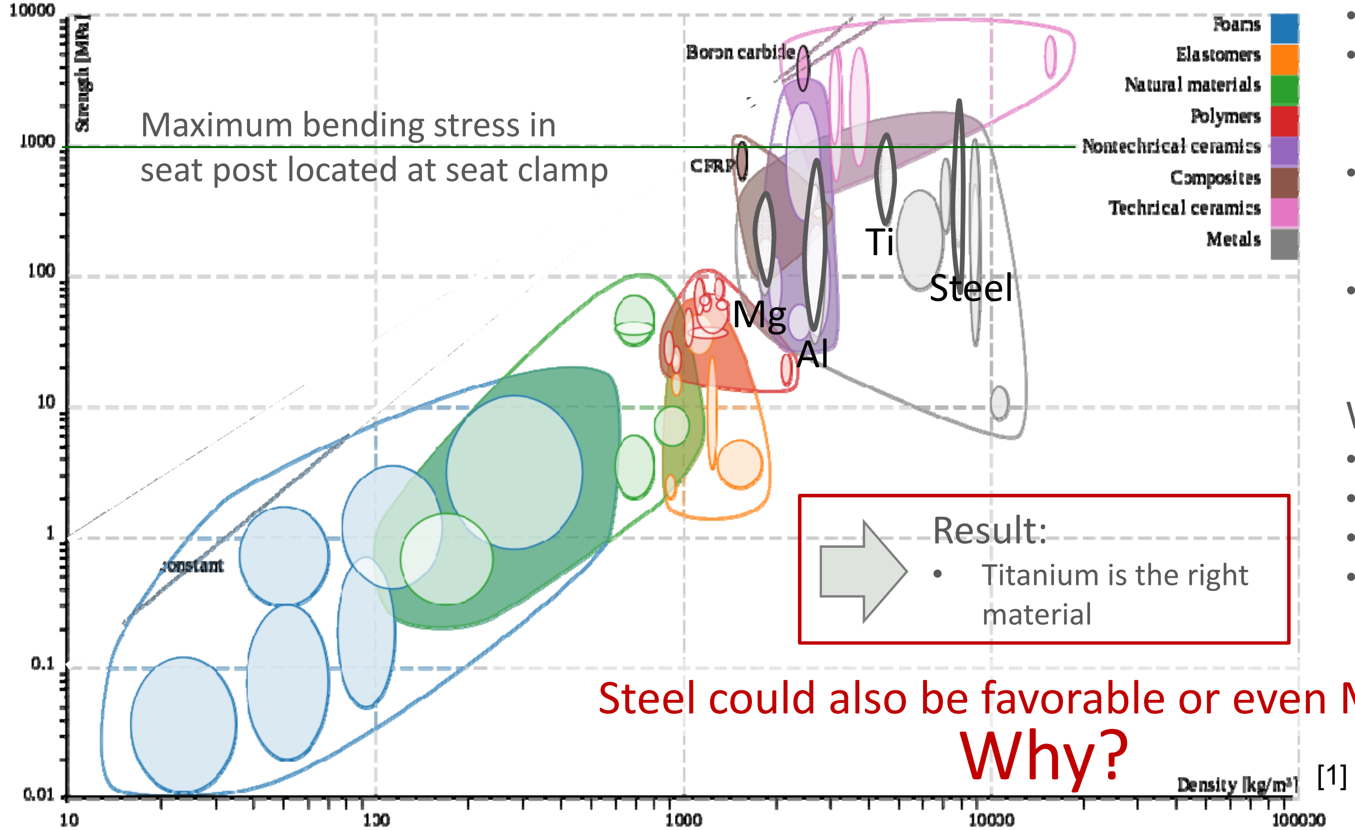

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Wanted:

- Location of the highest load
- Type of local load
- Level of local load
- The seat post‘s right material choice (i.e. the lightest considered metal)

Steel could also be favorable or even Magnesium!

Why?

Design and dimensioning

How can we find the seat post‘s right* material?

*) means light and strong

	Magnesium	Aluminum	Titanium	Steel	
Cyclist mass m	100	100	100	100	kg
Lever arm length x	100	100	100	100	mm
Cyclist force F	1000	1000	1000	1000	N
Bending moment Mb	100000	100000	100000	100000	Nmm
Seatpost diamenter D	16,3	12,9	10	7,6	mm
Seatpost Length L	225	225	225	225	mm
Resistance moment W	422,8	211,2	98,2	42,6	mm^3
Bending stress σ,b max	**237**	**473**	**1019**	**2347**	**MPa**
Sestpost cross section A	207,9	130,9	78,5	45,0	mm^2
Density ρ	1700,0	2700,0	4500,0	7850,0	kg/m^3
Seatpost mass m =ρ*A*L	0,080	0,080	0,080	0,080	kg

Use as degree of freedom

Given:

- Cyclist‘s weight m=100 kg
- Horizontal distance between sattle and seat clamp x=100 mm
- Vertical distance between sattle and seat clamp y=200 mm
- Diameter of the seat post D=10 mm

Wanted:

- Location of the highest load
- Type of local load
- Level of local load
- The seat post‘s right material choice (i.e. the lightest considered metal)

Extend the range of materials by exploiting geometric degrees of freedom

Design and dimensioning

How can we find the seat post‘s right* material?

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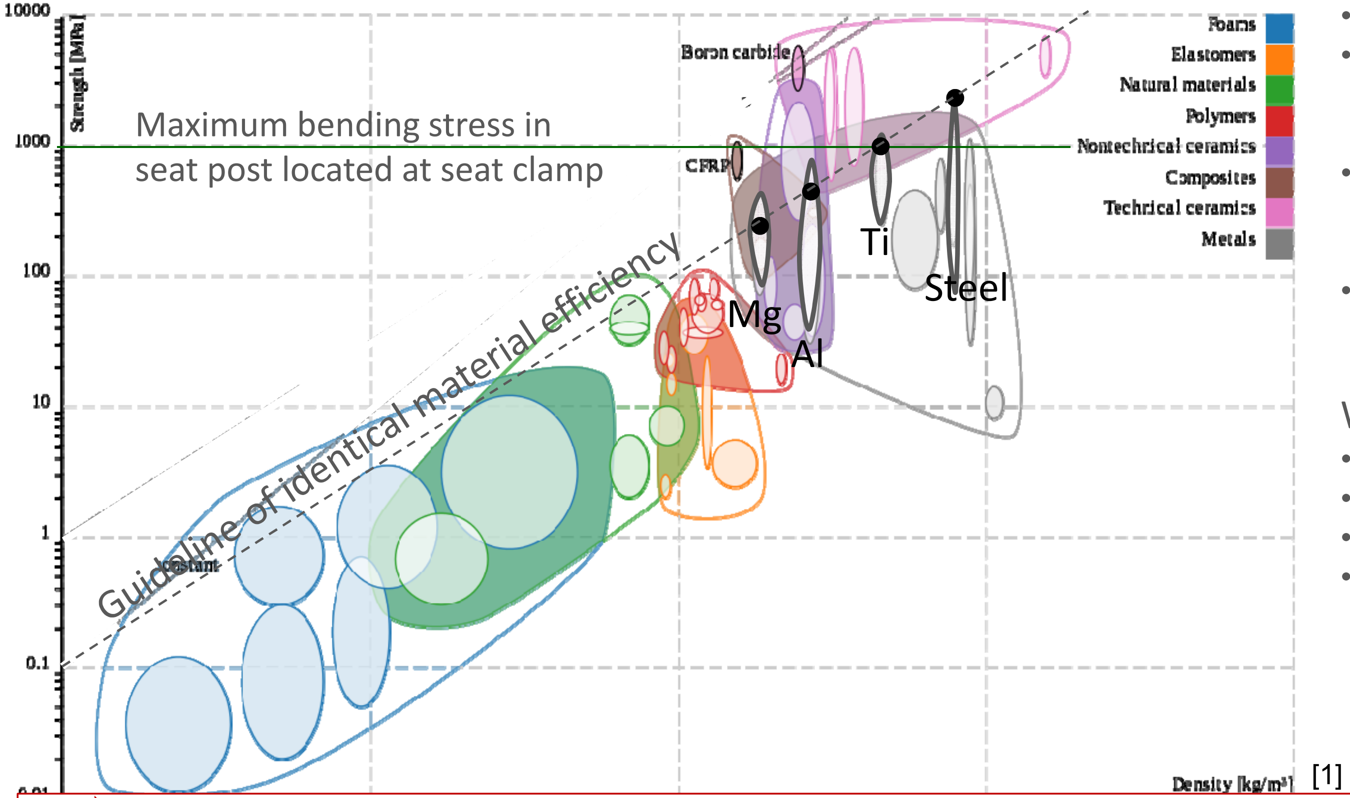


[1]

Given:

- Cyclist‘s weight m=100 kg
- Horizontal distance between sattle and seat clamp x=100 mm
- Vertical distance between sattle and seat clamp y=200 mm
- Degree of freedom: Diameter of the seat post

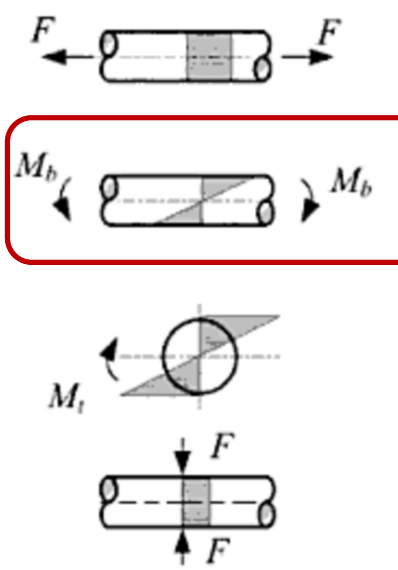
Wanted:

- Location of the highest load
- Type of local load
- Level of local load
- The seat post‘s right material choice (i.e. the lightest considered metal)

This brings us to the approach of **density specific material characteristics**

Design of a statically loaded, strong and light bending beam

Load type



Boundry conditions

- Permitted elongation
- Permitted strength
- Permitted toughness
- Given geometry incl. degrees of freedom
- …

Objective

- Maximum recycla-bility
- Minimum weight
- Minimum environ-mental impact
- Minimum costs
- …

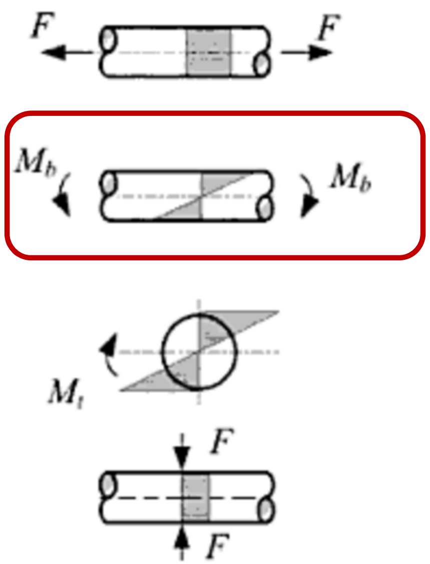
~~Highest strength + Lowest density~~

Wrong approach! Why?

Design and dimensioning with density specific material characteristics

Design of a statically loaded, strong and light bending beam

Load type



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- Maximum recycla-bility
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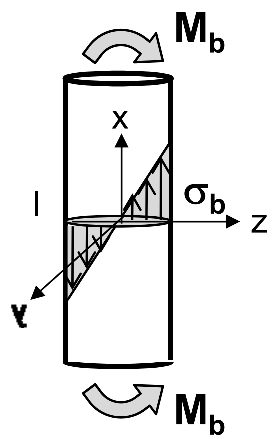
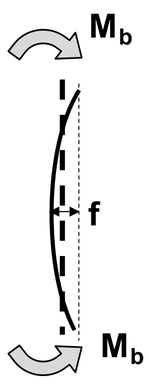
Densitiy specific strength

For an integrative approach density specific material characteristics are needed

1.2 Material oriented approaches





Deflection

$$f \approx \frac{1}{C} \cdot \frac{M_b \cdot l^2}{E \cdot J_{ax}}$$

Boundary conditions:

- Bending moment M_b
- Length l

Degrees of freedom

- Cross section A

Derivation of the density specific material characteristics (MC):

$$\rightarrow \sigma_{b,max} = \sigma = \frac{M_b}{J_{ax}} \cdot \frac{D}{2}$$ (Bending strength)

with: $$J_{ax} = \frac{A^2}{4 \cdot \pi} = \frac{\pi}{64} \cdot D^4$$

and: $$: m = \rho \cdot V = \rho \cdot \frac{\pi}{4} D^2 \cdot l \rightarrow MIN \quad \Rightarrow D = \sqrt{\frac{4 \cdot m}{\pi \cdot \rho \cdot l}}$$

$$\Leftrightarrow \sigma^2 = \frac{16 \cdot \pi \cdot M_b^2 \cdot \rho^3 \cdot l^3}{m^3}$$

$$\Leftrightarrow \frac{\sigma^2}{\rho^3} = \frac{16 \cdot \pi \cdot M_b^2 \quad l^3}{m^3} \quad \Leftrightarrow \frac{\sqrt[3]{\sigma^2}}{\rho} = \frac{2 \cdot l}{m} \cdot \sqrt[3]{2 \cdot \pi \cdot M_b^2}$$

$$\boxed{\Leftrightarrow MC = \frac{\sqrt[3]{\sigma^2}}{\rho} \rightarrow MAX}$$

Design and dimensioning with density specific material characteristics

How can we find the seat post‘s right* material?

*) means light and strong

	Magnesium	Aluminum	Titanium	Steel	
Cyclist mass m	100	100	100	100	kg
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- Diameter of the seat post D=10 mm

Wanted:

- Location of the highest load
- Type of local load
- Level of local load
- The seat post‘s right material choice (i.e. the lightest considered metal)

The same density specific MC means the same material efficiency

Design and dimensioning with density specific material characteristics

How can we find the seat post‘s right* material?

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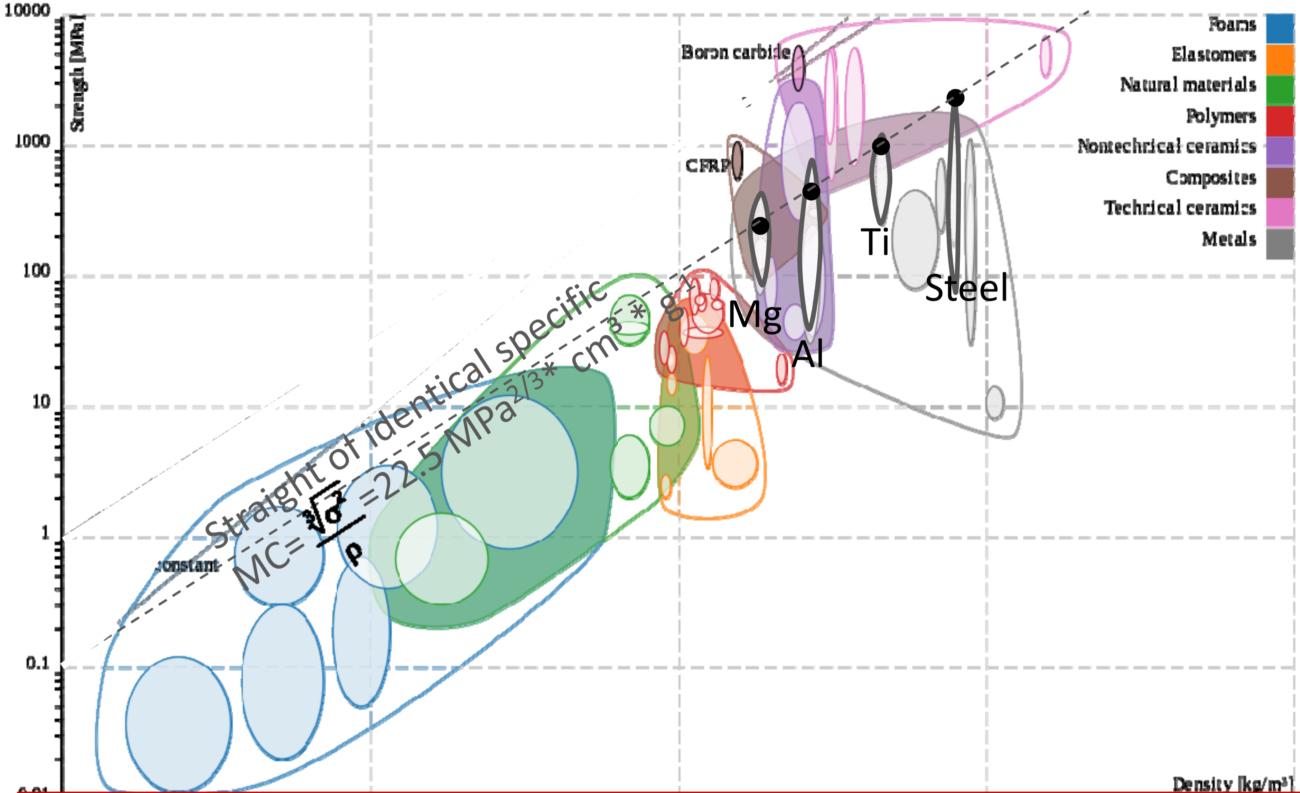

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Given:

- Cyclist‘s weight m=100 kg
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- Vertical distance between sattle and seat clamp y=200 mm
- Degree of freedom: Diameter of the seat post

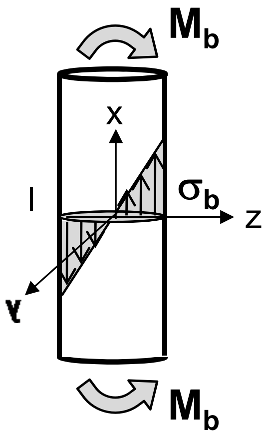
Wanted:

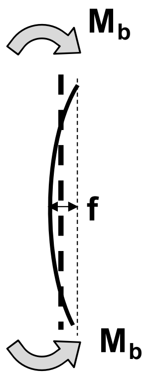
- Location of the highest load
- Type of local load
- Level of local load
- The seat post‘s right material choice (i.e. the lightest considered metal)

All Materials on the line provide the same specific MC of 22.5 MPa$^{2/3}$* cm³ * g^{-1}

Design and dimensioning with density specific material characteristics

Example: Design of a statically loaded, stiff and light bending beam





Deflection

$$f \approx \frac{1}{C} \cdot \frac{M_b \cdot l^2}{E \cdot J_{ax}}$$

Boundary conditions:

- Bending moment M_b
- Length l
- Deflection f

Degrees of freedom

- Cross section A

Derivation of the density specific material characteristics (MC):

$$\rightarrow E \cdot J_{ax} \approx \frac{M_b \cdot l^2}{C \cdot f} \quad \text{(Bending stiffness)}$$

$$\text{mit: } J_{ax} = \frac{A^2}{4 \cdot \pi} = \frac{\pi}{64} \cdot D^4$$

$$\text{und: } \underline{m = \rho \cdot V = \rho \cdot A \cdot l \rightarrow \text{MIN}} \Rightarrow A = \frac{m}{\rho \cdot l}$$

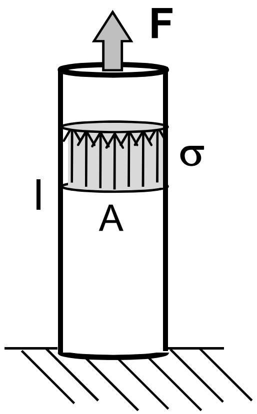
$$\Leftrightarrow \frac{E \cdot m^2}{4 \cdot \pi \cdot \rho^2 \cdot l^2} = \frac{M_b \cdot l^2}{C \cdot f}$$

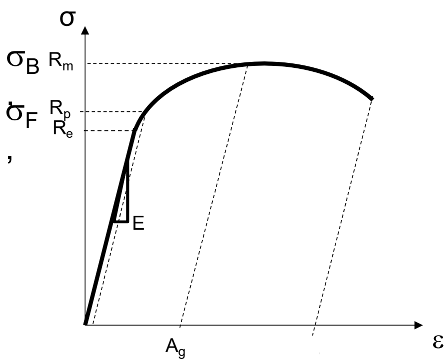
$$\Leftrightarrow \frac{E}{\rho^2} = \frac{M_b \cdot 4 \cdot \pi \cdot l^4}{m^2 \cdot C \cdot f} \Leftrightarrow \frac{\sqrt{E}}{\rho} = \frac{1}{m} \cdot \sqrt{\frac{M_b \cdot 4 \cdot \pi \cdot l^4}{C \cdot f}}$$

$$\boxed{\Leftrightarrow \text{MC} = \frac{\sqrt{E}}{\rho} \rightarrow \text{MAX}}$$

Design and dimensioning with density specific material characteristics

Example: Design of a statically loaded, strong and light tension bar





Boundary conditions:

- Permissible Force F
- Length l

Degrees of freedom

- Cross section A

Derivation of the density specific material characteristics (MC):

$$\rightarrow \sigma_{zul} = \frac{F}{A} \quad \text{(Tensile strength)}$$

$$\text{with: } m = \rho \cdot V = \rho \cdot A \cdot l \rightarrow MIN \;\Rightarrow A = \frac{m}{\rho \cdot l}$$

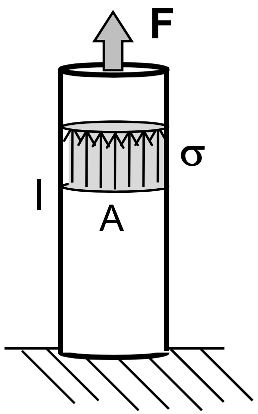
$$\Leftrightarrow \sigma_{zul} = \frac{F \cdot \rho \cdot l}{m}$$

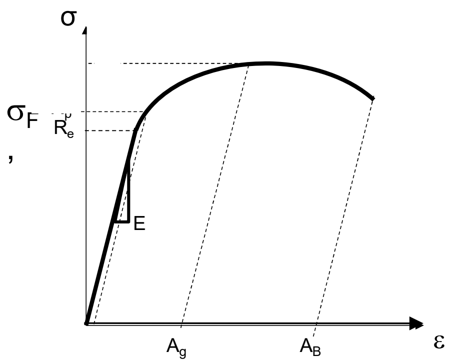
$$\Leftrightarrow \frac{\sigma_{zul}}{\rho} = \frac{F}{m} \cdot l$$

$$\boxed{\Leftrightarrow MC = \frac{\sigma}{\rho} \rightarrow MAX} \quad \text{(whereas: } \sigma = \sigma_F, \sigma_B, R_p, R_e, R_m \ldots\text{)}$$

Design and dimensioning with density specific material characteristics

Example: Design of a statically loaded, stiff and light tension bar





Boundary conditions:

- Permissible elon-gation ε
- Permissible Force F
- Length l

Degrees of freedom

- Cross section A

Derivation of the density specific material characteristics (MC):

$$\rightarrow E \cdot A = \frac{F}{\varepsilon_{zul}} \quad \text{(Tensile stiffness)}$$

$$\text{mit: } \underline{m = \rho \cdot V = \rho \cdot A \cdot l \rightarrow MIN} \;\Rightarrow A = \frac{m}{\rho \cdot l}$$

$$\Leftrightarrow \varepsilon_{zul} = \frac{F \cdot \rho \cdot l}{E \cdot m}$$

$$\Leftrightarrow \frac{E}{\rho} = \frac{F}{m \cdot \varepsilon_{zul}} \cdot l$$

$$\boxed{\Leftrightarrow MC = \frac{E}{\rho} \rightarrow MAX}$$

IWT

Load type/body	Boundary conditions	Degree of freedom	MCs for dimensioning acc. to		
			Stiffness	Strength	Toughness
Tension/ compression rod	Force, length	Cross-sectional area	$\frac{E}{\rho}$	$\frac{\sigma}{\rho}$	$\frac{K_{Ic}}{\rho}$
Shaft, torsionally stressed	Moment, length	Cross-sectional area	$\frac{\sqrt{G}}{\rho}$	$\frac{\sqrt[3]{\sigma^2}}{\rho}$	$\frac{\sqrt[3]{K_{Ic}^2}}{\rho}$
	Moment, length, outside diameter	Wall thickness	$\frac{G}{\rho}$	$\frac{\sigma}{\rho}$	$\frac{K_{Ic}}{\rho}$
	Moment, length, wall thickness	Outer diameter	$\frac{\sqrt[3]{G}}{\rho}$	$\frac{\sqrt{\sigma}}{\rho}$	$\frac{\sqrt{K_{Ic}}}{\rho}$
Bending beam	Force or moment, (deflection), length	Cross-sectional area	$\frac{\sqrt{E}}{\rho}$	$\frac{\sqrt[3]{\sigma^2}}{\rho}$	$\frac{\sqrt[3]{K_{Ic}^2}}{\rho}$
	Force or moment, (deflection), length, height	Width	$\frac{E}{\rho}$	$\frac{\sigma}{\rho}$	$\frac{K_{Ic}}{\rho}$
	Force or moment, (deflection), length, width	Hights	$\frac{\sqrt[3]{E}}{\rho}$	$\frac{\sqrt{\sigma}}{\rho}$	$\frac{\sqrt{K_{Ic}}}{\rho}$
Buckling bar	Force, length	Cross-sectional area	$\frac{\sqrt{E}}{\rho}$	$\frac{\sigma}{\rho}$	$\frac{K_{Ic}}{\rho}$

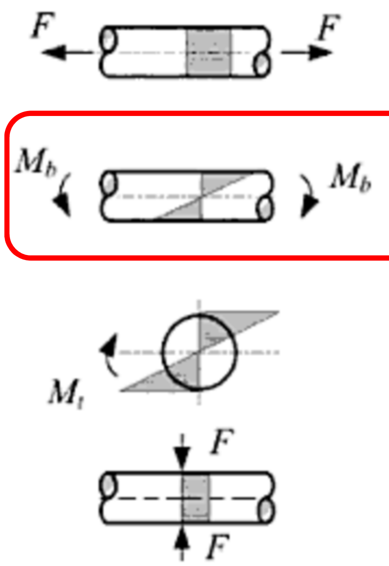
σ: Strength (umtimate and yield strength respectively)

(acc. to M.F. Ashby)

Material selection

Pre-select load type, boundary conditions and objective for your component

Load type



Boundry conditions

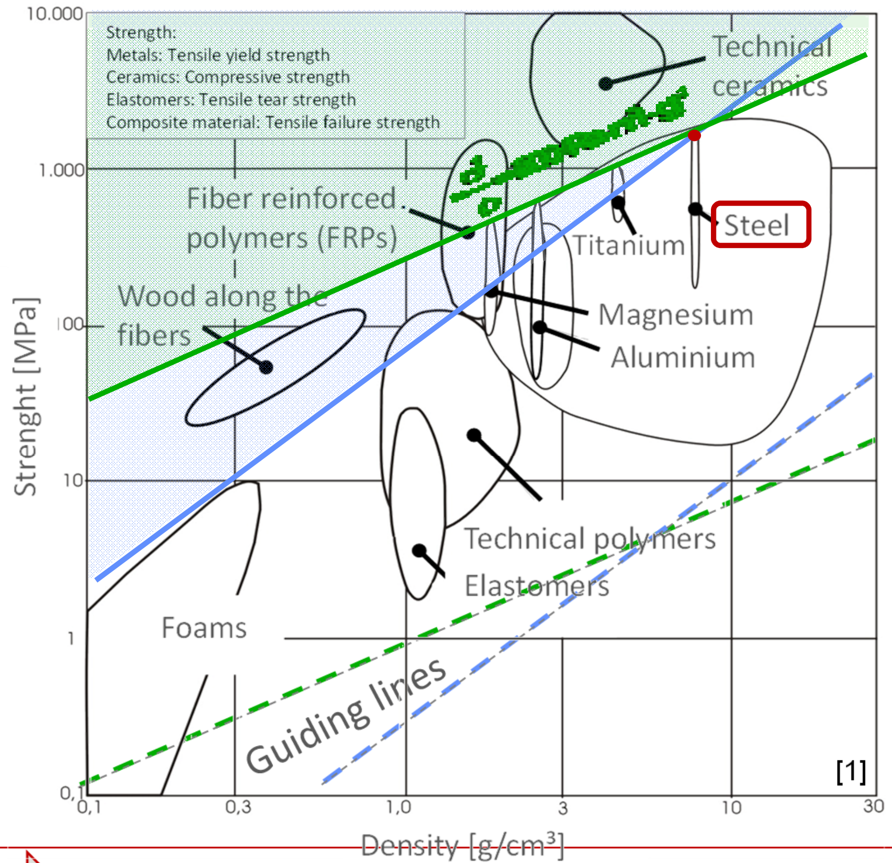
- Permitted elongation
- Permitted strength
- Permitted toughness
- Given geometry incl. degrees of freedom
- …

Objective

- Maximum recycla-bility
- Minimum weight
- Minimum environ-mental impact
- Minimum costs
- …

Select densitiy specific MC from the table

For an integrative approach density specific material characteristics are needed



- Transformation of density specific strength into a straight equation:

$$\rightarrow MC = \frac{\sigma^n}{\rho} \rightarrow MAX$$

$$\Leftrightarrow \log \sigma^n = \log \rho + \log MC$$

$$\Leftrightarrow \log \sigma = \frac{1}{n} \cdot \log \rho + \frac{1}{n} \cdot \log MC$$

(Base equation: $y = m \cdot x + b$)

- Tensile/ compression loading

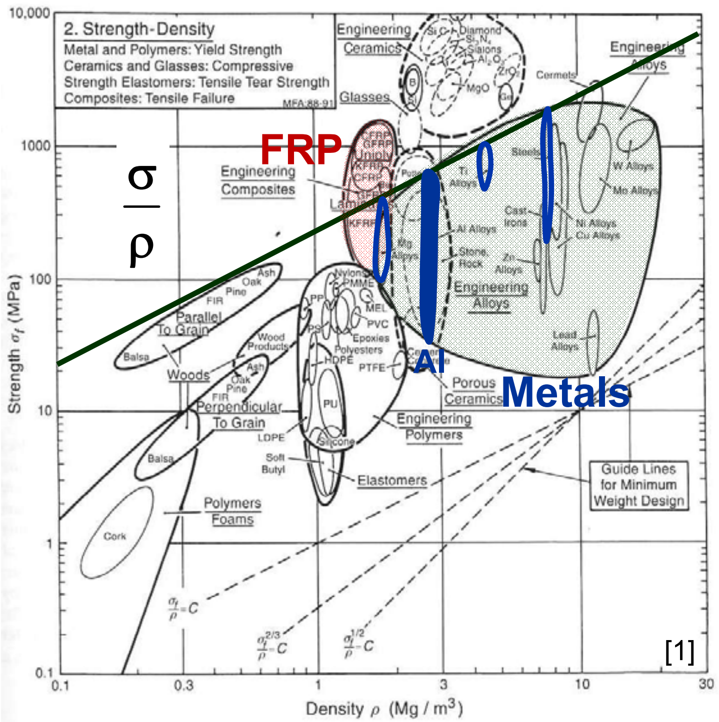
$$\rightarrow n = 1 \Leftrightarrow \frac{1}{n} = 1$$

- Bending loading (bending beams with circular cross sections)

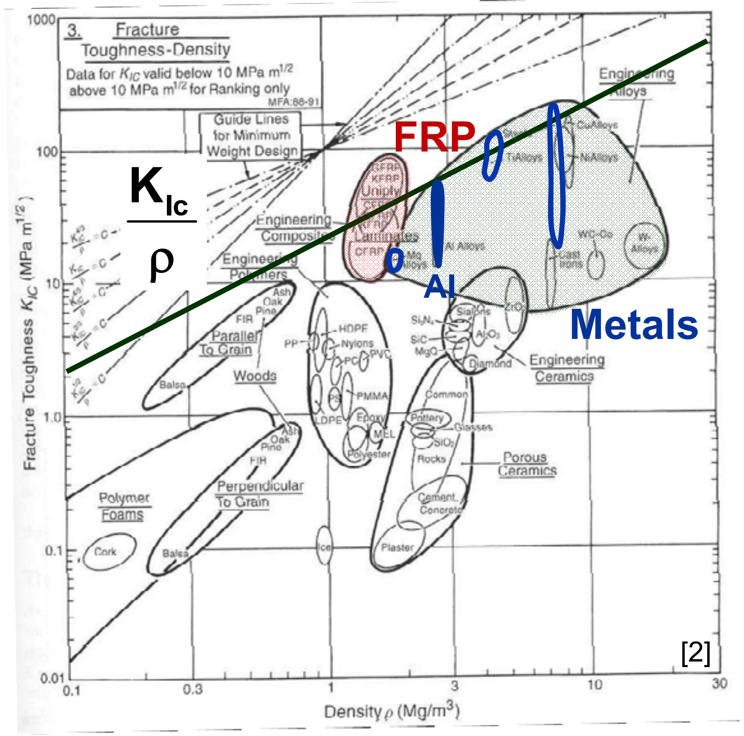
$$\rightarrow n = \frac{2}{3} \Leftrightarrow \frac{1}{n} = \frac{3}{2}$$

All Materials above the line provide a higher, below a lower lightweight potential

Strong and light tensile/compression bar*



Tough and light tensile/compression bar*

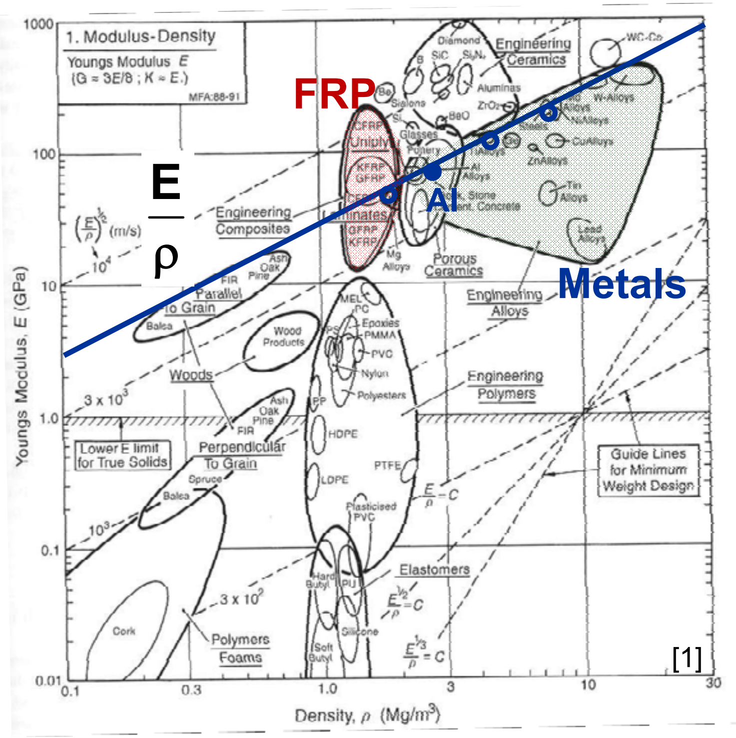


*) Reference: Aluminium

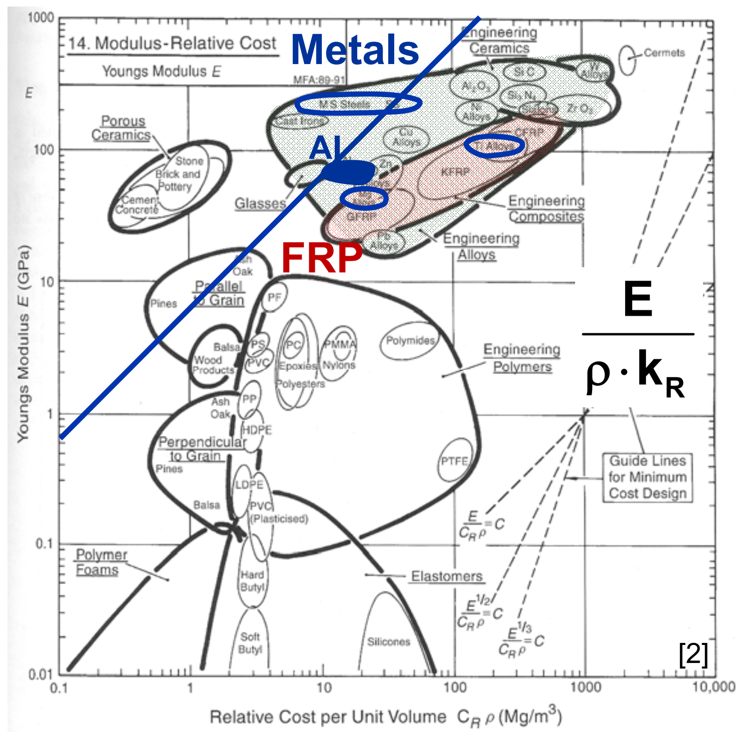
Material selection

How to find the right material with Ashby maps

Stiff and light tensile/compression bar*



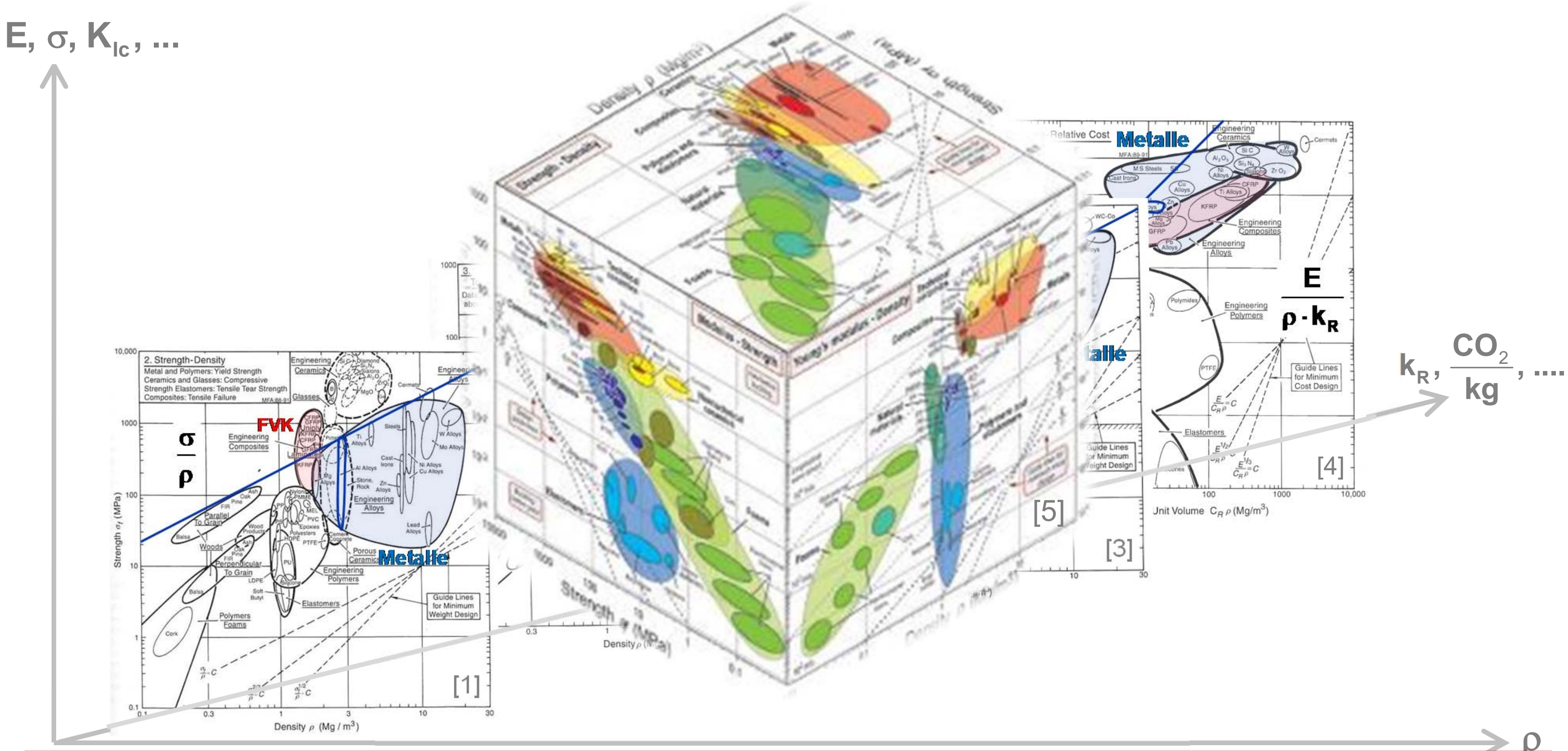
Stiff, light and cost-effective tensile/compression bar*



*) Reference: Aluminium

Material selection

How to find the right material with Ashby maps



This requires a multi-dimensional approach

Material oriented approaches
Summary

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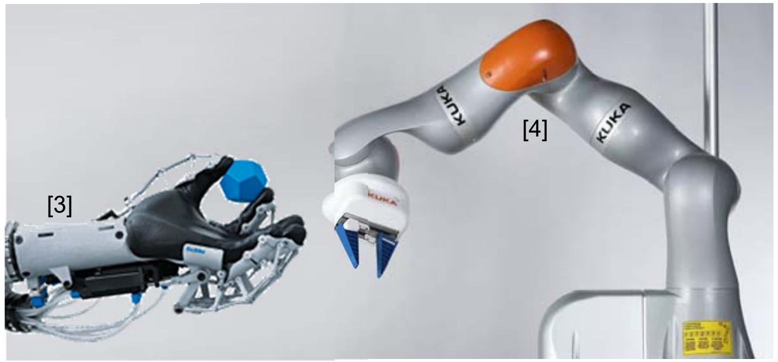
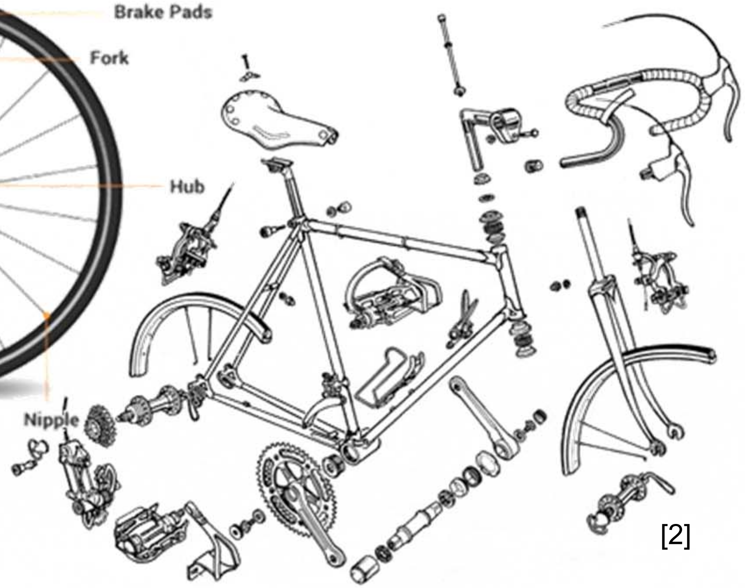


Case study

How can we find the right* material for the frame?

[1]



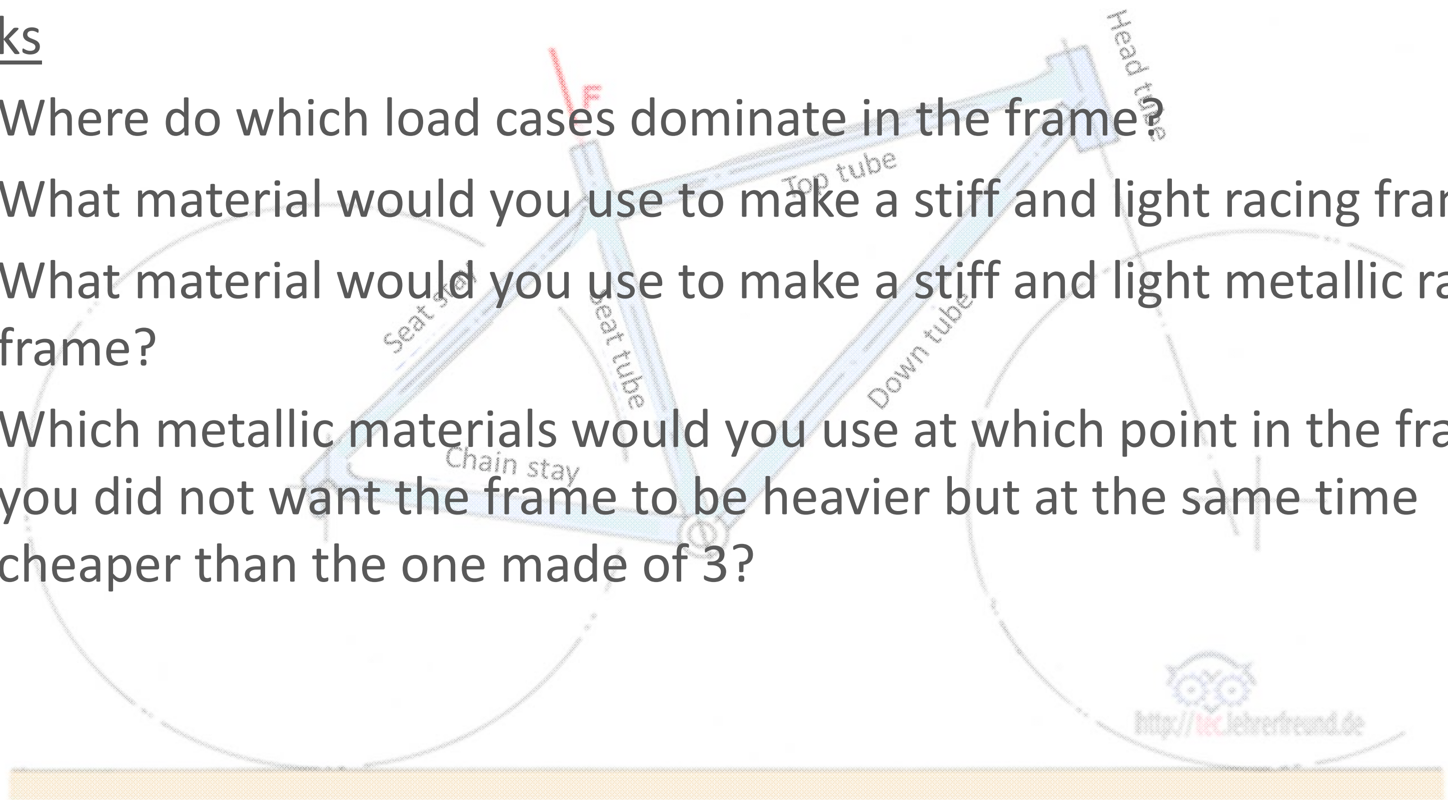
[2]

*) means light and stiff

1.2 Material oriented approaches

Tasks

1. Where do which load cases dominate in the frame?
2. What material would you use to make a stiff and light racing frame?
3. What material would you use to make a stiff and light metallic racing frame?
4. Which metallic materials would you use at which point in the frame if you did not want the frame to be heavier but at the same time cheaper than the one made of 3?



http://www.lehrerfreund.de/technik/1s/kraefte-am-fahrrad1/4000

Lightweight Materials - Their Properties, Technologies and Advanced Applicability

Content

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	1	1.2 Material oriented approaches From component load to Materials Selection
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2	3	2.1 Advanced Alloys (part 1): Steels Multi-Phase Steels and TRIP/TWIP for Automotive Applications
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5	3	3.1 Metal Additive Manufacturing (part 1) The Process Chain from Powder to finished Part
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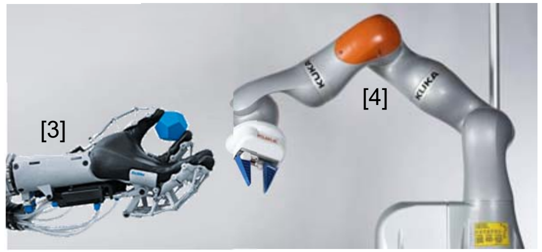
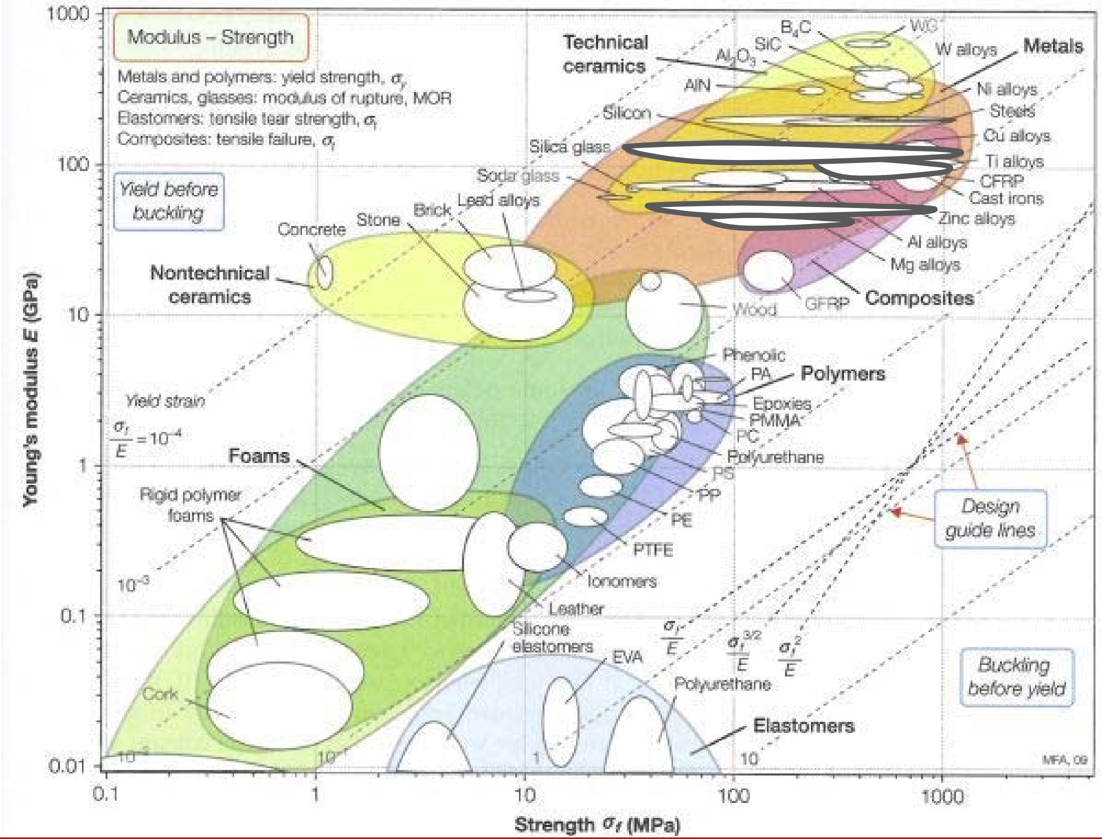
8	3	4.2 Hybrid Composite Materials and Structures (part 2) Mechanical, Thermal and Adhesive Bonding Technologies State of Technology and novel Approaches



Metallic Materials
Strengthening potential



[1]

The large potential for strengthening is indicated by the elongated ellipses

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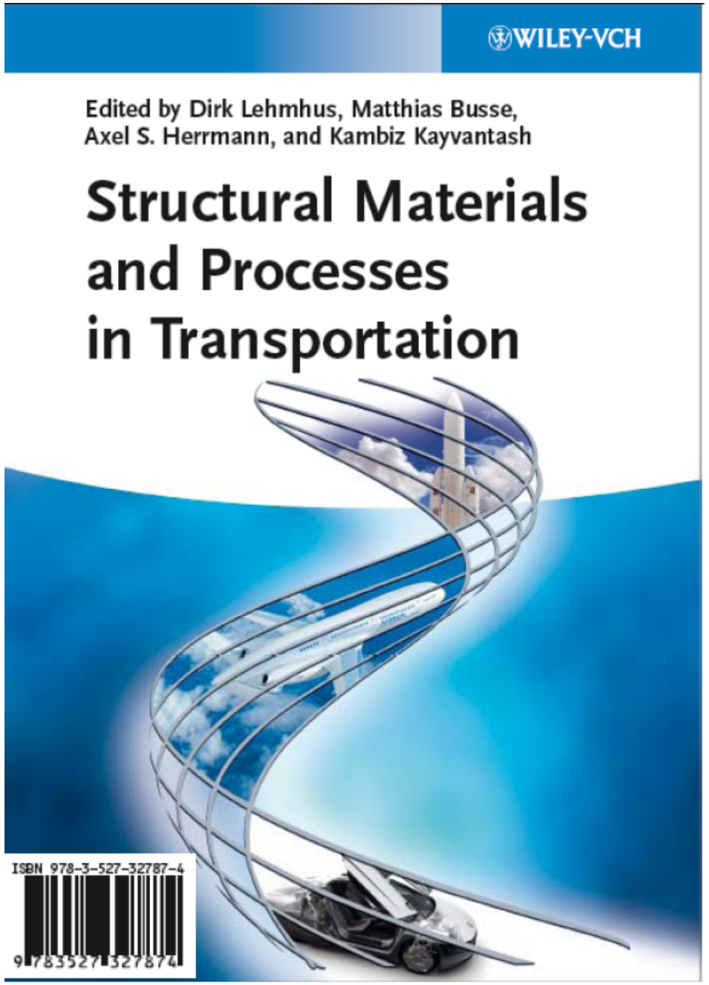
Further reading



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