School of Mechanical and Manufacturing Engineering

MMAN2130 Design and Manufacturing

Term 3 – 2019

Weeks 8 and 9

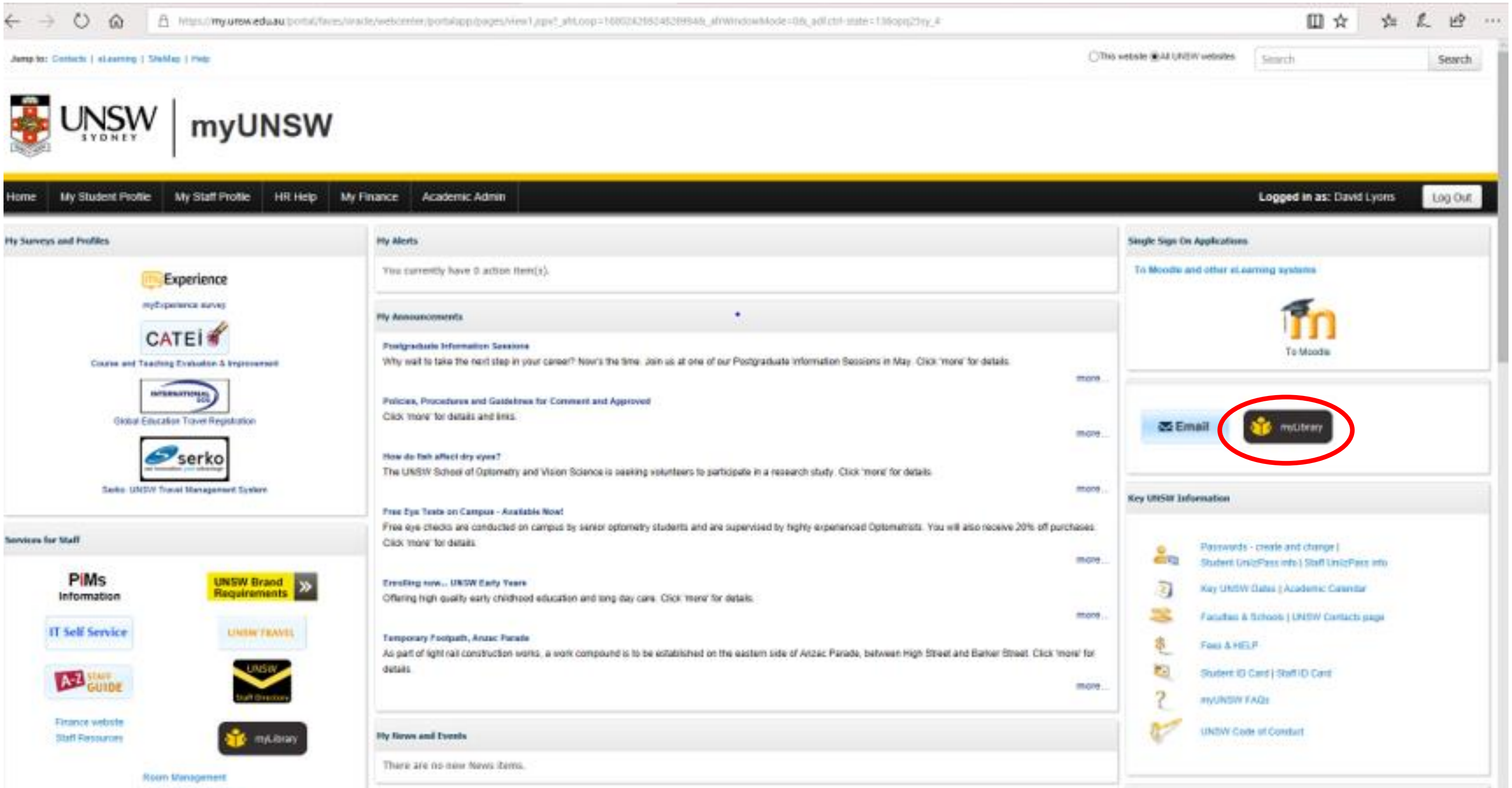
Today/next week:

1. Accessing eBooks in the UNSW library

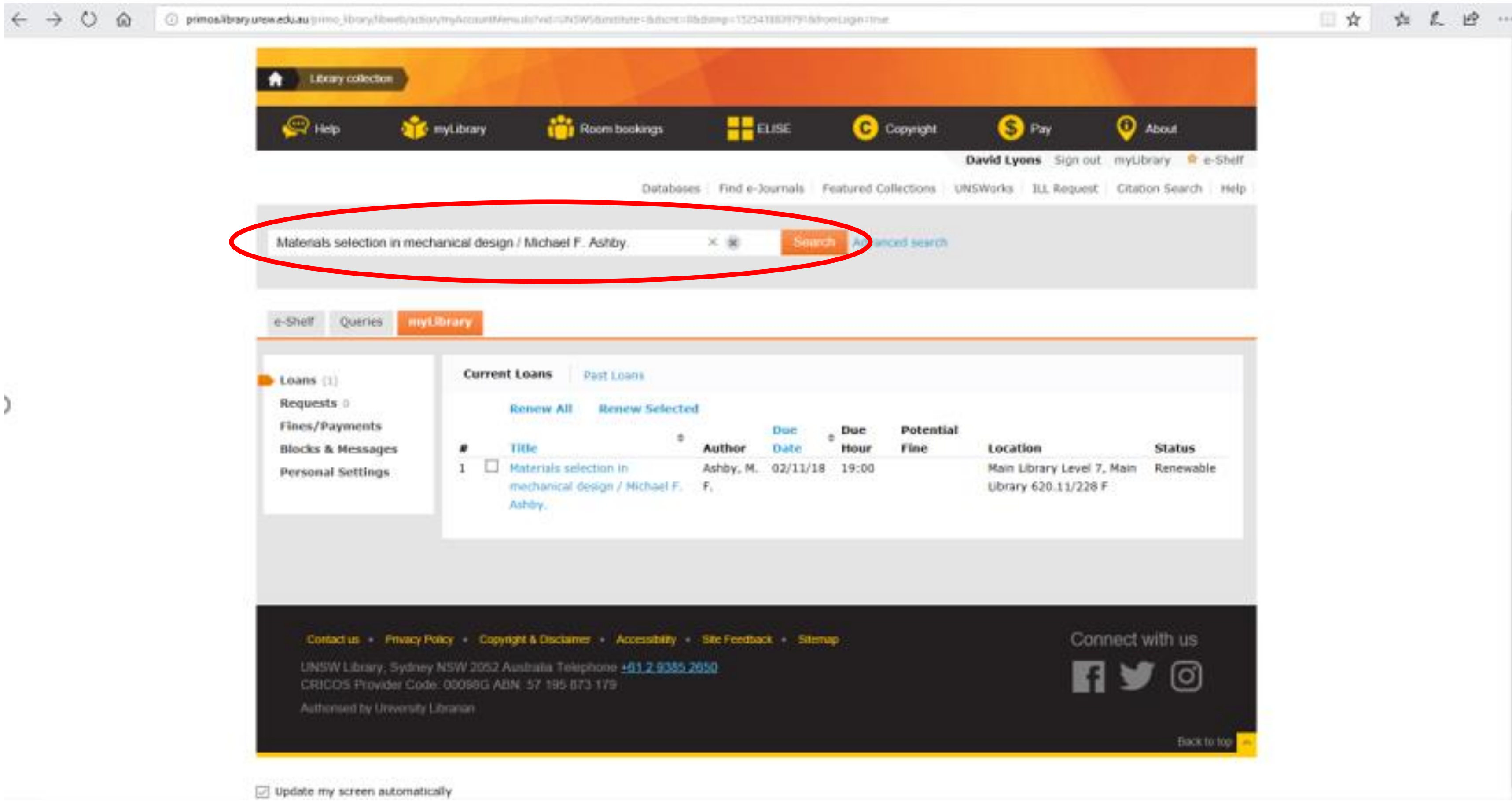
2. Materials Selection | Detail

3. Materials Selection | Case studies

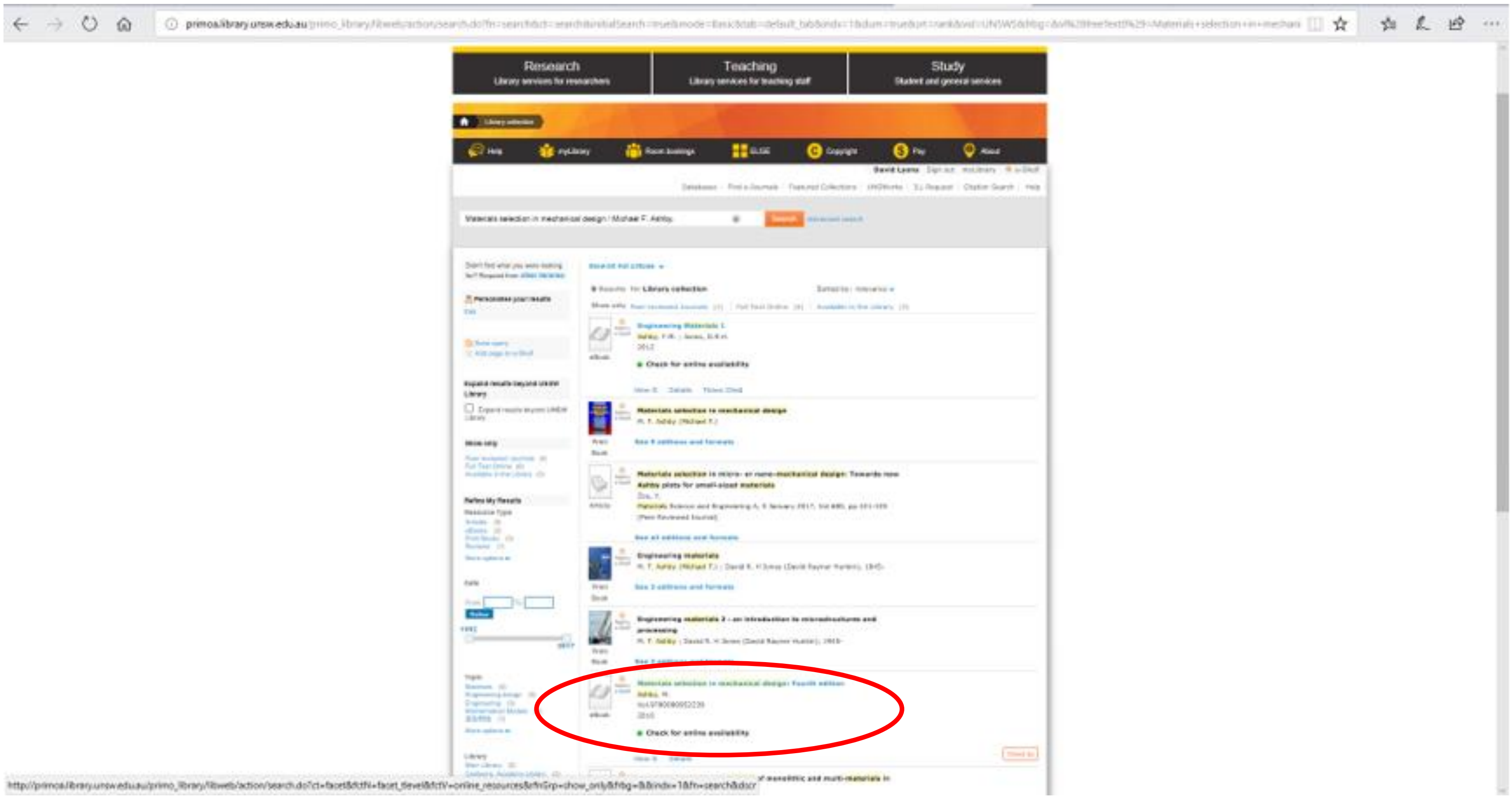
Accessing eBooks in the UNSW library




UNSW LIBRARY
User ID:
Password:
Login
Back
Login



Library collection
Help
myLibrary
Room bookings
ELISE
Copyright
Pay
About
David Lyons
Sign out
myLibrary
e-Shelf
Databases
Find e-Journals
Featured Collections
UNSWorks
ILL Request
Citation Search
Help
Materials selection in mechanical design / Michael F. Ashby.
Search
e-Shelf
Queries
myLibrary
Loans (1)
Requests 0
Fines/Payments
Blocks & Messages
Personal Settings
Current Loans
Past Loans
Renew All
Renew Selected
Title Author Due Date Due Hour Potential Fine Location Status
1 Materials selection in mechanical design / Michael F. Ashby. Ashby, M. F. 02/11/18 19:00 Main Library Level 7, Main Library 620.11/228 F Renewable
Contact us • Privacy Policy • Copyright & Disclaimer • Accessibility • Site Feedback • Sitemap
UNSW Library, Sydney NSW 2052 Australia Telephone +61 2 9385 2650
CRICOS Provider Code: 00098G ABN: 57 195 873 179
Authorised by University Librarian
Connect with us
Back to top
Update my screen automatically


Research
Library services for researchers
Teaching
Library services for teaching staff
Study
Student and general services

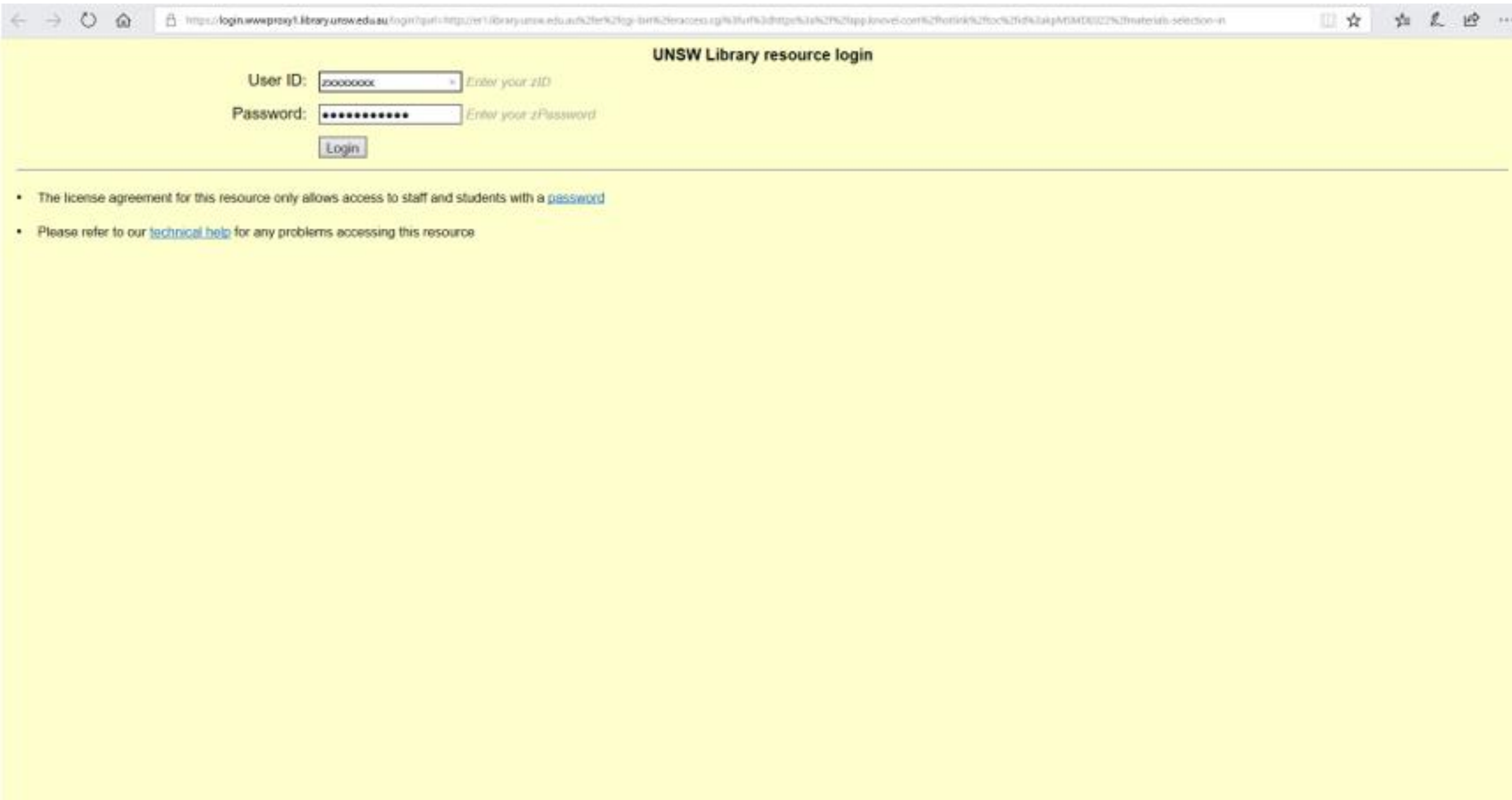
Full text available Knovel General Engineering & Project Administration Academic Show license

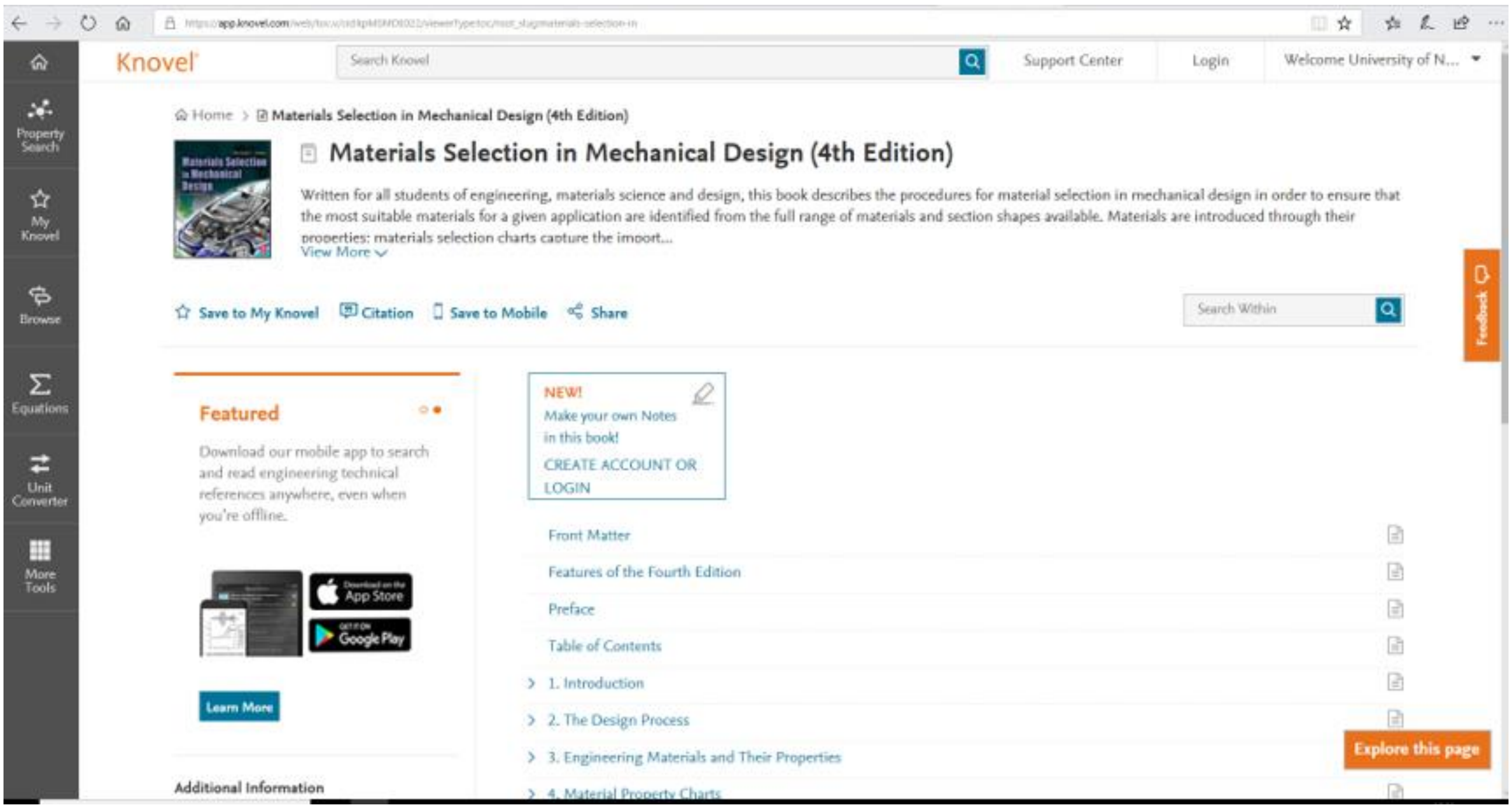
Full text available Knovel Mechanics & Mechanical Engineering Academic Show license

Additional services

Problem accessing online resource? Report it here

UNSW SYDNEY


UNSW Library resource login
User ID:
Enter your zID
Password:
Enter your zPassword
Login
The license agreement for this resource only allows access to staff and students with a password
Please refer to our technical help for any problems accessing this resource


Knovel
Search Knovel
Support Center
Login
Welcome University of N...
Property Search
My Knovel
Browse
Equations
Unit Converter
More Tools
Home
Materials Selection in Mechanical Design (4th Edition)
Materials Selection in Mechanical Design (4th Edition)
Written for all students of engineering, materials science and design, this book describes the procedures for material selection in mechanical design in order to ensure that the most suitable materials for a given application are identified from the full range of materials and section shapes available. Materials are introduced through their properties; materials selection charts capture the import...
View More
Save to My Knovel
Citation
Save to Mobile
Share
Search Within
Featured
Download our mobile app to search and read engineering technical references anywhere, even when you're offline.
App Store
Google Play
Learn More
Additional Information
NEW!
Make your own Notes in this book!
CREATE ACCOUNT OR LOGIN
Front Matter
Features of the Fourth Edition
Preface
Table of Contents
1. Introduction
2. The Design Process
3. Engineering Materials and Their Properties
4. Material Property Charts
Explore this page
Feedback

Learning Outcomes

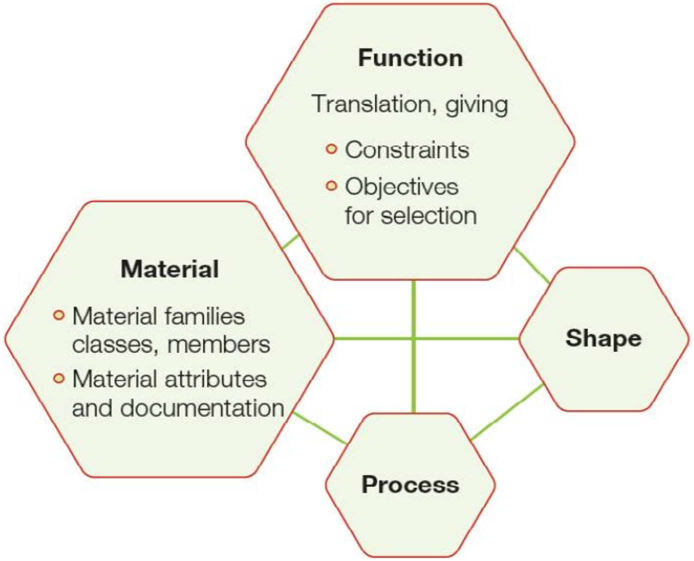
- At the end of this lecture, you should be able to:
  - Understanding the basic selection strategies
  - Appreciate using “material index” for selection
  - Apply the selection procedure for different cases

To follow this material you *must* access the Ashby eBook

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Link between Materials and Function

- The task of Selection:
  1. Identify the desired attribute profile
  2. Comparing this with real engineering materials to find the best match



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

UNSW SYDNEY

Link between Materials and Function

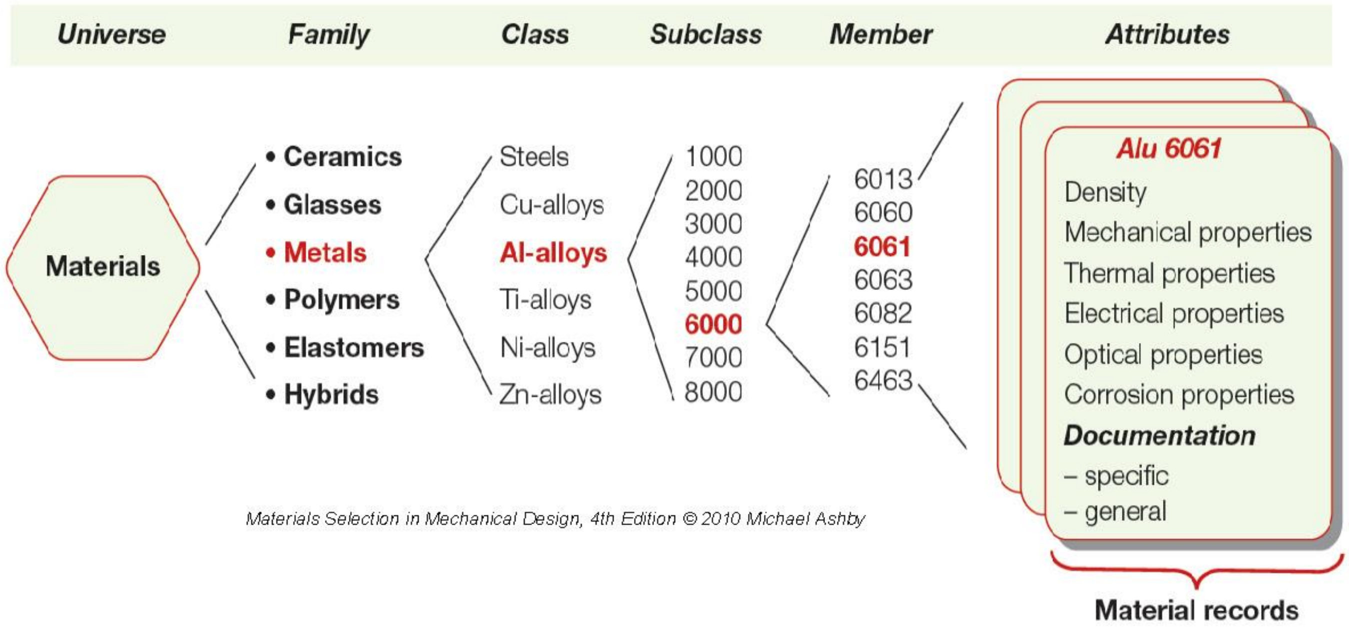
The performance of a structural element is determined by three things:

- the functional requirements,
- the geometry, and
- the properties of the material of which it is made.

$$P = \left[\begin{pmatrix} \textit{Functional} \\ \textit{requirements, F} \end{pmatrix}, \begin{pmatrix} \textit{Geometric} \\ \textit{parameters, G} \end{pmatrix}, \begin{pmatrix} \textit{Material} \\ \textit{properties, M} \end{pmatrix} \right]$$

The Universe of Materials

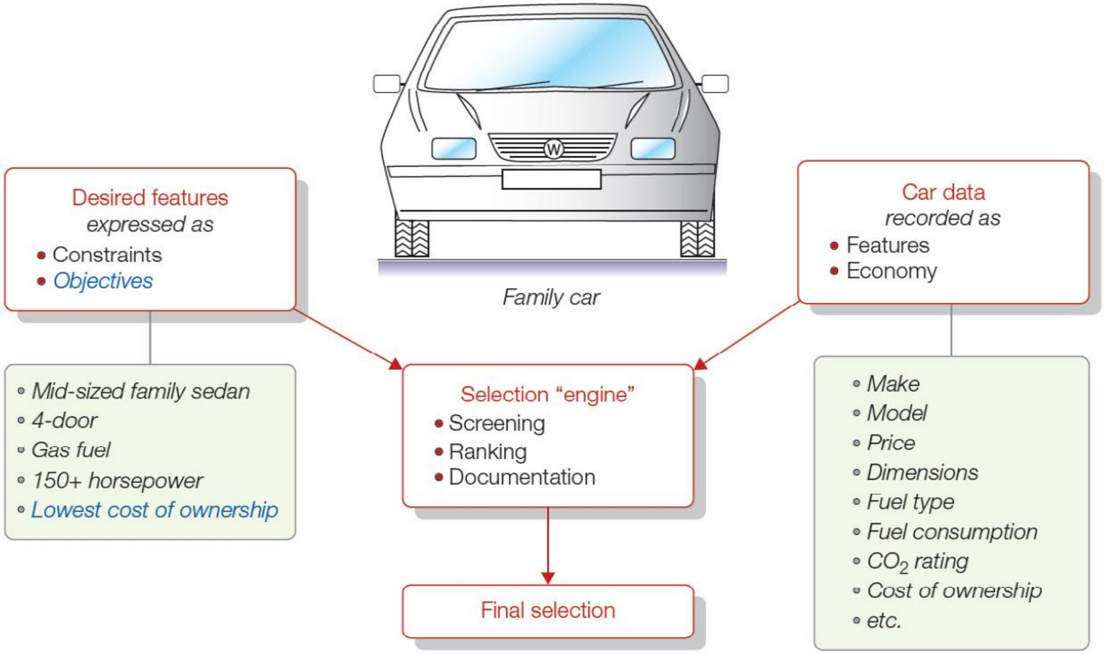
- The universe of materials is divided into families, classes, subclasses, and members; each member is characterized by a set of attributes: its properties



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Selection Strategy

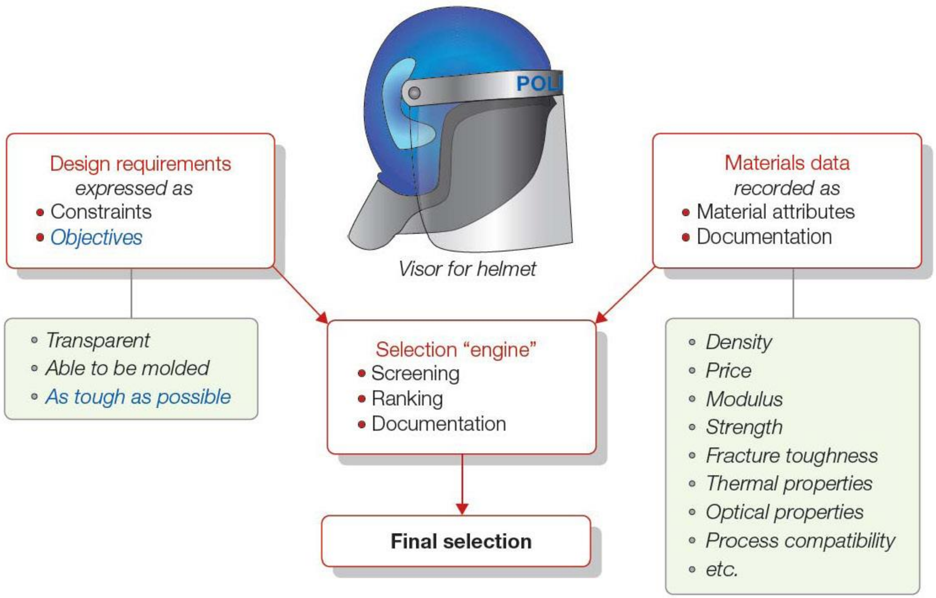
•Required features are constraints; that are used to screen out unsuitable cars. The survivors are ranked by cost of ownership



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Choosing Materials

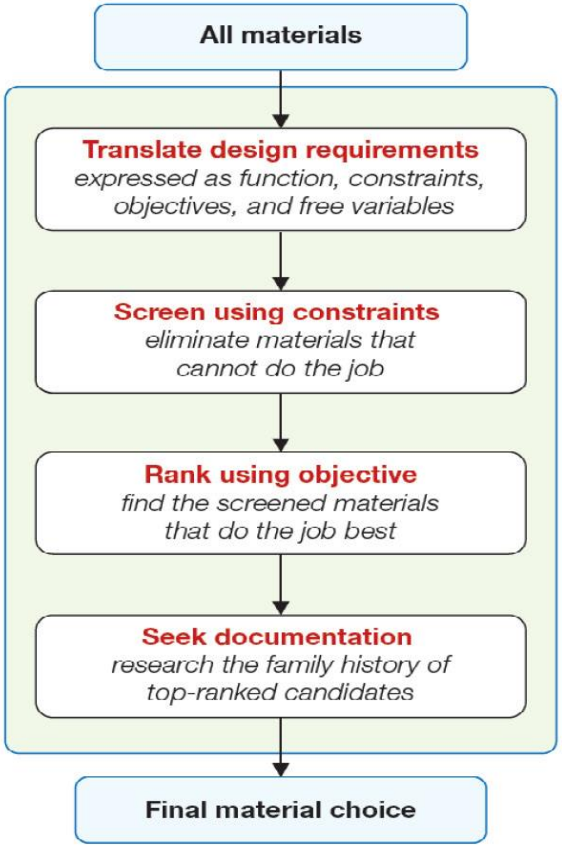
- Design requirements are first expressed as constraints and objectives. The constraints are used for screening. The survivors are ranked by the objective, expressed as a material index.



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Strategy for Material Selection

- The four main steps:
  1. Translation
  2. Screening
  3. Ranking
  4. Documentation



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

1. Translating Design Requirements

- Function, constraints, objectives and free variables

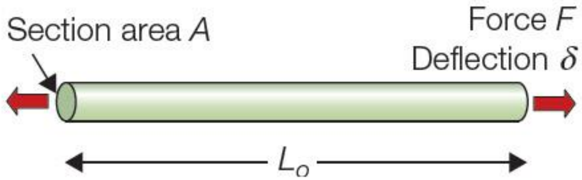
Function	What does the component do?
Constraints*	What nonnegotiable conditions must be met? What negotiable but desirable conditions must be met?
Objective	What is to be maximized or minimized?
Free variable	Which parameters of the problem is the designer free to change?

**It is sometimes useful to distinguish between "hard" and "soft" constraints. Stiffness and strength might be absolute requirements (hard constraints); cost might be negotiable (soft constraint).*

1. Translating Design Requirements

Identifying Desirable Characteristics
(Materials for a light, strong tie)

- **Function**
  - Support a tension load
- **Objective**
  - Minimize mass, *m*
- **Constraints**
  - Length, L_0, specified
  - Carry load, F, without failure
- **Free variables**
  - Cross-section area
  - Material

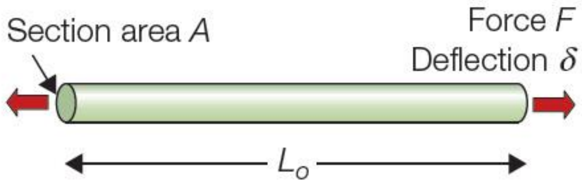


- **Objective**
  - $Min\ m = A\ L\ \rho$
- **Constraints**
  - $F / A < \sigma_y$

1.Translating Design Requirements

Identifying Desirable Characteristics
(Materials for a light, strong tie)

- **Objective**
  - $m = A\,L\,\rho$
- **Constraints**
  - $F / A < \sigma_y$
- **Rearrange to eliminate free variables**
  - $m \geq F\,L\,(\rho / \sigma_y)$
- **Minimize weight by minimizing** (ρ / σ_y)

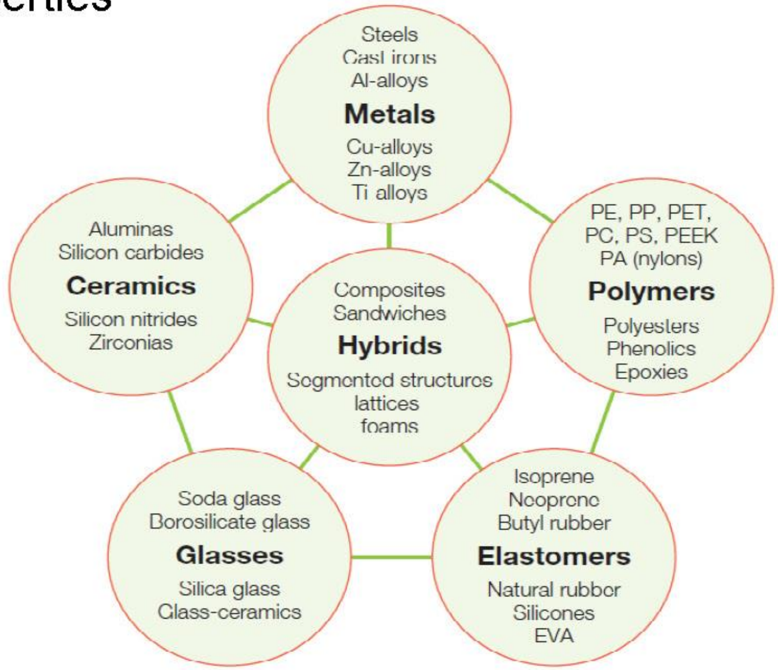


Material Index

$$\left[\frac{\sigma_y}{\rho}\right]$$

2. Screening Materials

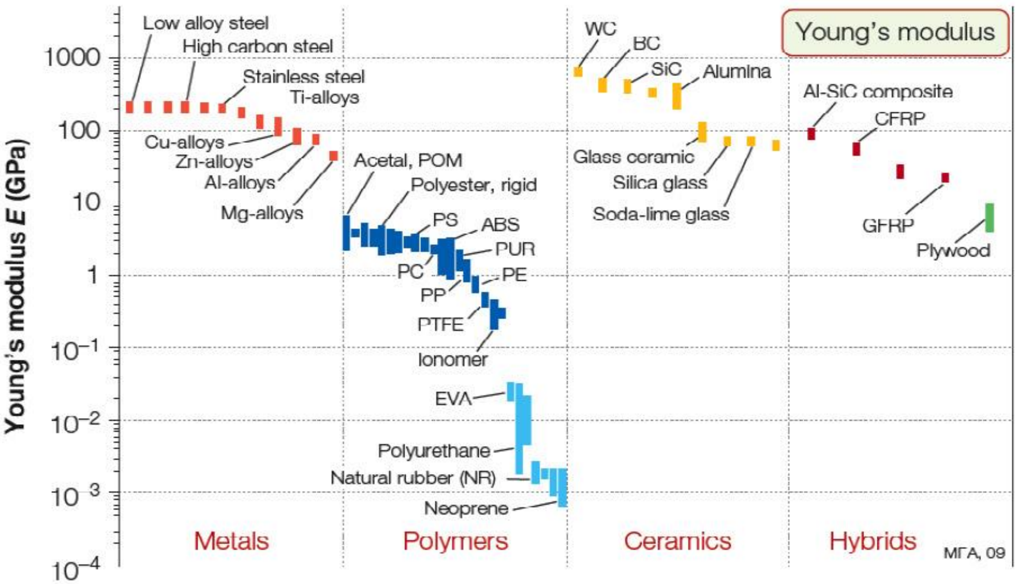
- Eliminate materials that cannot do the job
  - Need an effective way to eliminate large range of material classes and properties



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

2. Screening Materials

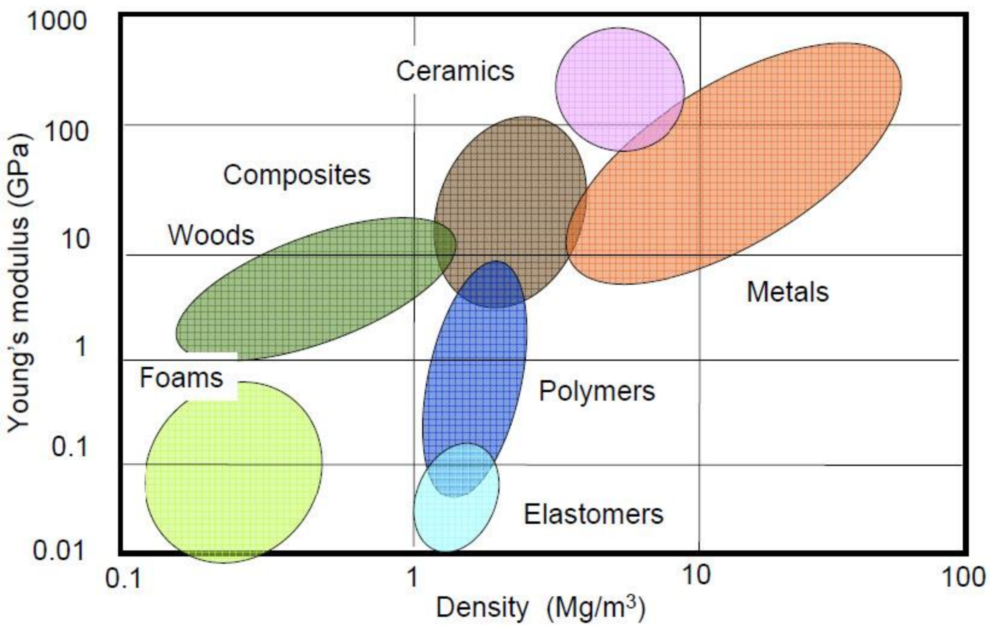
- Comparing material properties – bar charts
  - Good for initial selection e.g. find materials with large modulus



Materials Selection in Mechanical Design, 4th Edition, © 2010 Michael Ashby

2. Screening Materials

- **Comparing material properties – bubble charts**
  - Comparing more than one material properties

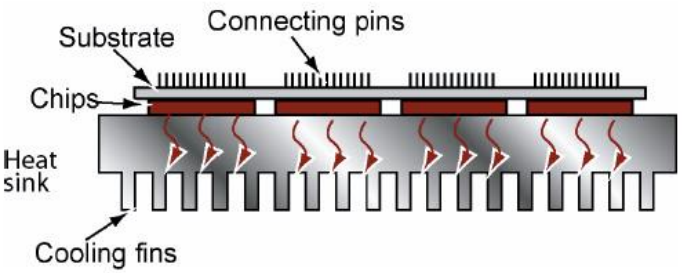


Materials Selection in Mechanical Design, 4th Edition, © 2010 Michael Ashby

2. Screening Materials

•Screening Example

•Heat sink for power electronics



•Function

- •Heat sink

•Constraints

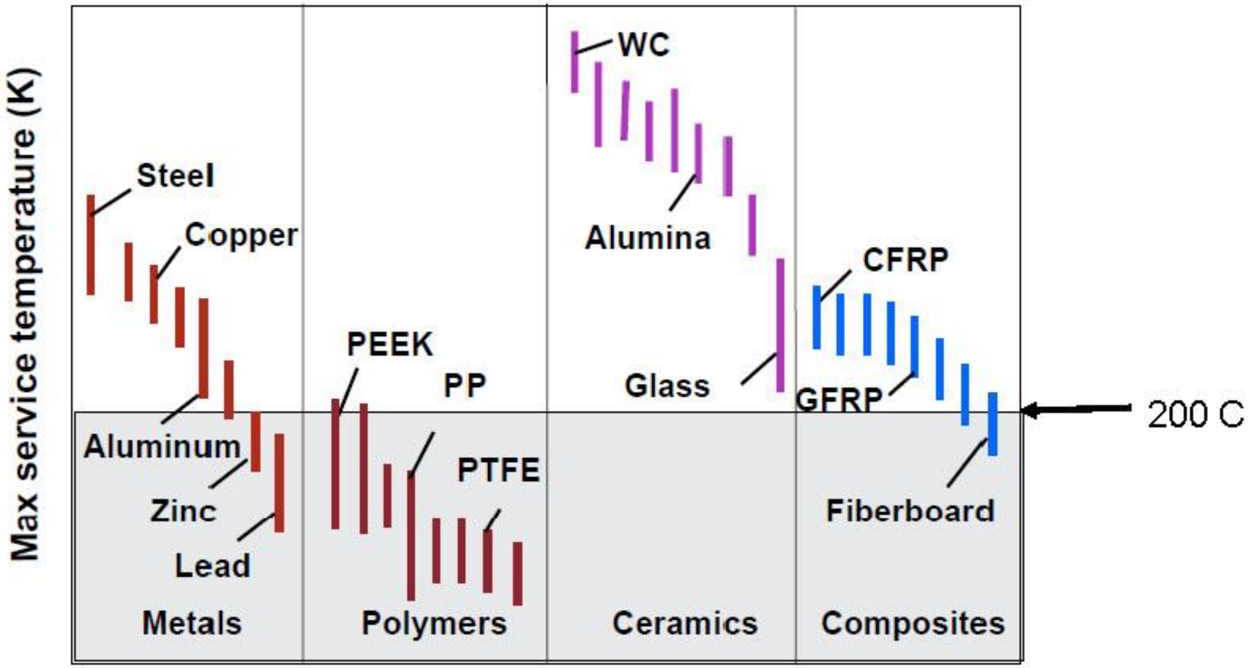
1. Max service temperature > 200C
2. Electrical insulator, R > 10^{20} μohm cm
3. Thermal conductor, l > 100 W/m K
4. Not heavy, r < 3 Mg/m^3

•Free variables

- •Processes
- •Material

2. Screening Materials

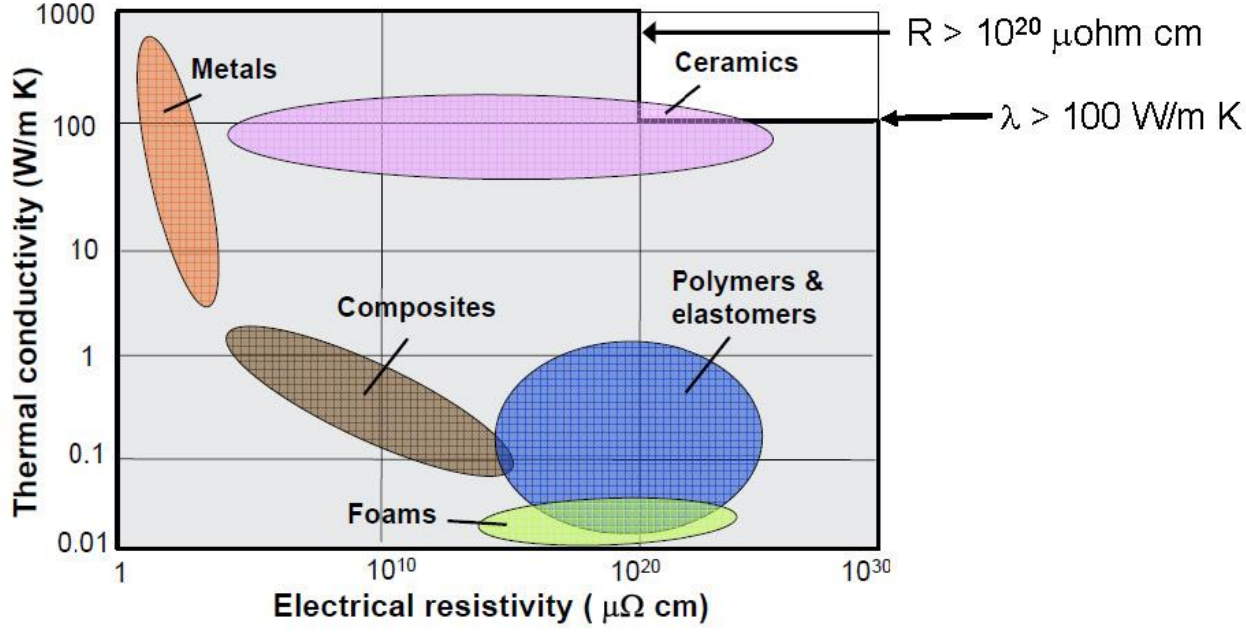
- Screening example
  - Heat sink screening– bar charts



Materials Selection in Mechanical Design, 4th Edition, © 2010 Michael Ashby

2. Screening Materials

- **Screening example**
  - Heat sink screening– property charts charts



3. Ranking Materials

- Find the materials that do the best job
  - What if multiple materials are selected after screening?
  - Which one is better?
  - What if there are multiple material properties for evaluation?

Use Material Index

3. Ranking Materials

1. Identify function, constraint, objectives, and free variables
   - List simple constraints for screening
2. Write down equations for objective – the "performance equation"
   - If objectives involve a free variable other than material
     - Identify the constraints that limits it
     - Use this to eliminate the free variable from the performance equation
3. Read off the combination of material properties that maximise the performance – the material index
4. Use this for ranking

3. Ranking Materials – Material Index

$$P = \left[\begin{pmatrix} \textit{Functional} \\ \textit{requirements}, F \end{pmatrix}, \begin{pmatrix} \textit{Geometric} \\ \textit{parameters}, G \end{pmatrix}, \begin{pmatrix} \textit{Material} \\ \textit{properties}, M \end{pmatrix}\right]$$

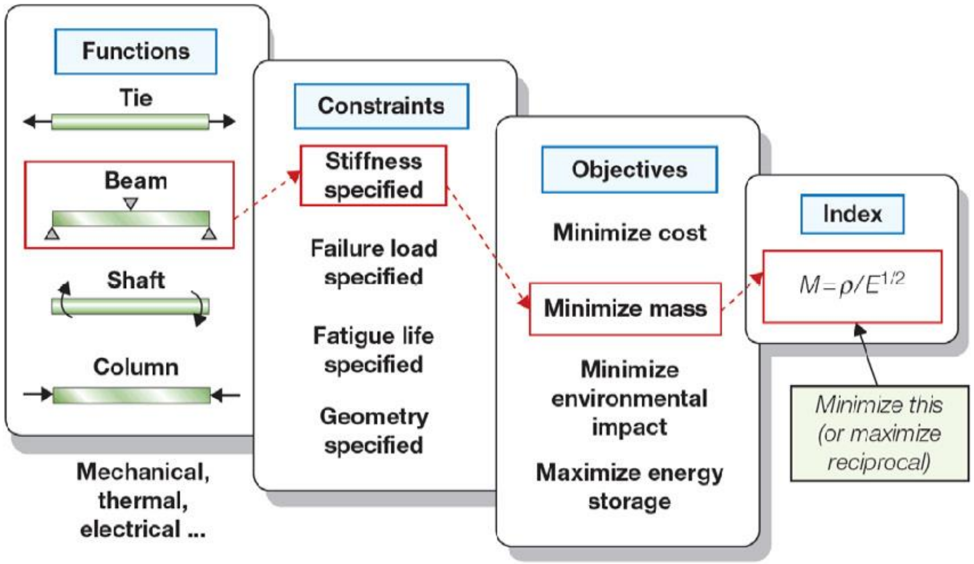
- Use constraints to eliminate free variables
- From previous example, the performance equation for a light, strong tie:

$$m \geq F A \left(\rho / \sigma_y\right)$$

UNSW SYDNEY

3. Ranking Materials – Material Index Process Flow

- The specification of function, objective, and constraint leads to a materials index. The combination in the highlighted boxes leads to the index $E^{1/2}/\rho$



Materials Selection in Mechanical Design, 4th Edition, © 2010 Michael Ashby

3. Ranking Materials – Material Index Examples

Function, Objective, and Constraints	Index
Tie, minimum weight, stiffness prescribed	$\frac{E}{\rho}$
Beam, minimum weight, stiffness prescribed	$\frac{E^{1/2}}{\rho}$
Beam, minimum weight, strength prescribed	$\frac{\sigma_y^{2/3}}{\rho}$
Beam, minimum cost, stiffness prescribed	$\frac{E^{1/2}}{C_m \rho}$
Beam, minimum cost, strength prescribed	$\frac{\sigma_y^{2/3}}{C_m \rho}$
Column, minimum cost, buckling load prescribed	$\frac{E^{1/2}}{C_m \rho}$
Spring, minimum weight for given energy storage	$\frac{\sigma_y^2}{E \rho}$
Thermal insulation, minimum cost, heat flux prescribed	$\frac{1}{\lambda C_p \rho}$
Electromagnet, maximum field, temperature rise prescribed	$\frac{C_p \rho}{\rho_e}$

ρ = density; E = Young's modulus; σ_y = elastic limit; C_m = cost/kg; λ = thermal conductivity; ρ_e = electrical resistivity; C_p = specific heat

Materials Selection in Mechanical Design, 4th Edition, © 2010 Michael Ashby

UNSW SYDNEY

3. Ranking Materials – Material Index Examples

Selection Using Material Indices & Property Charts: Strength

•Example: tension load, strength limited

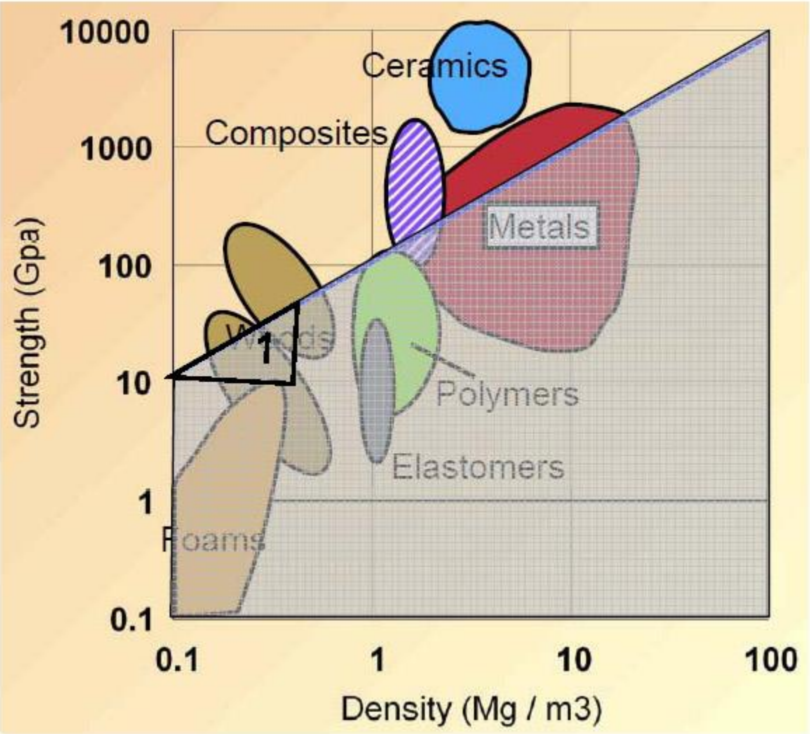
•Maximize: $m = \left[\frac{\sigma_y}{\rho}\right]$

•In log space

$$\log\sigma = (\log\rho + \log m)$$

•This is a set of lines with slope 1

•Materials above the line are candidates



3. Ranking Materials – Material Index Examples

Selection Using Material Indices & Property Charts: Strength

•Example: Stiff beam Stiffness

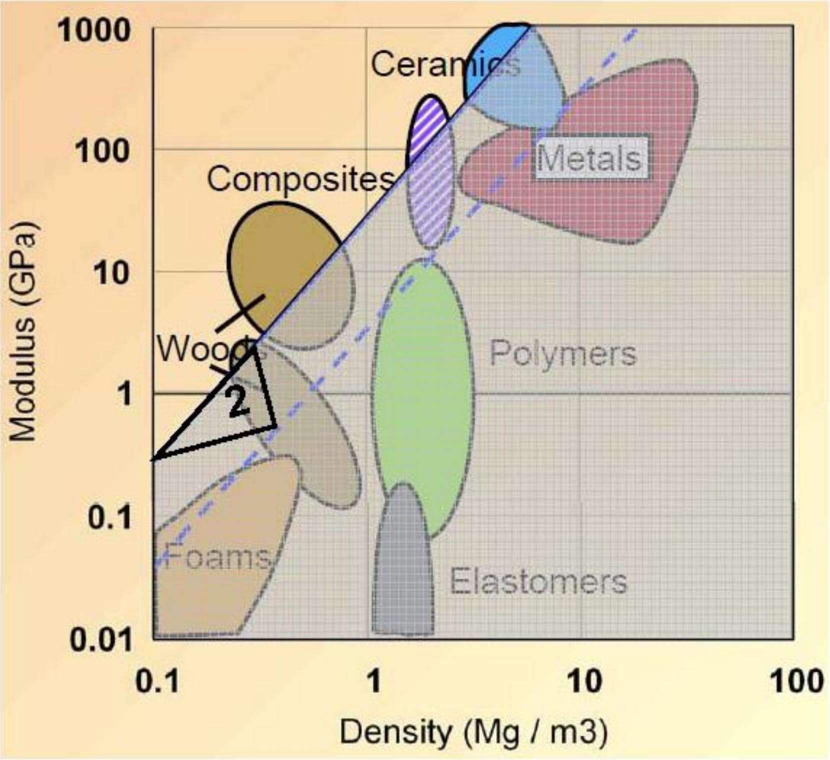
•Maximize: $m = \left[\dfrac{E^{1/2}}{\rho} \right]$

•In log space

$$\log E = 2(\log \rho + \log m)$$

•This is a set of lines with slope 2

•Candidates change with the objective



3. Ranking Materials – Material Index Examples

Selection Using Material Indices & Property Charts: Strength

•Example: Toughness

•Load-limited, $m = K_{IC}$

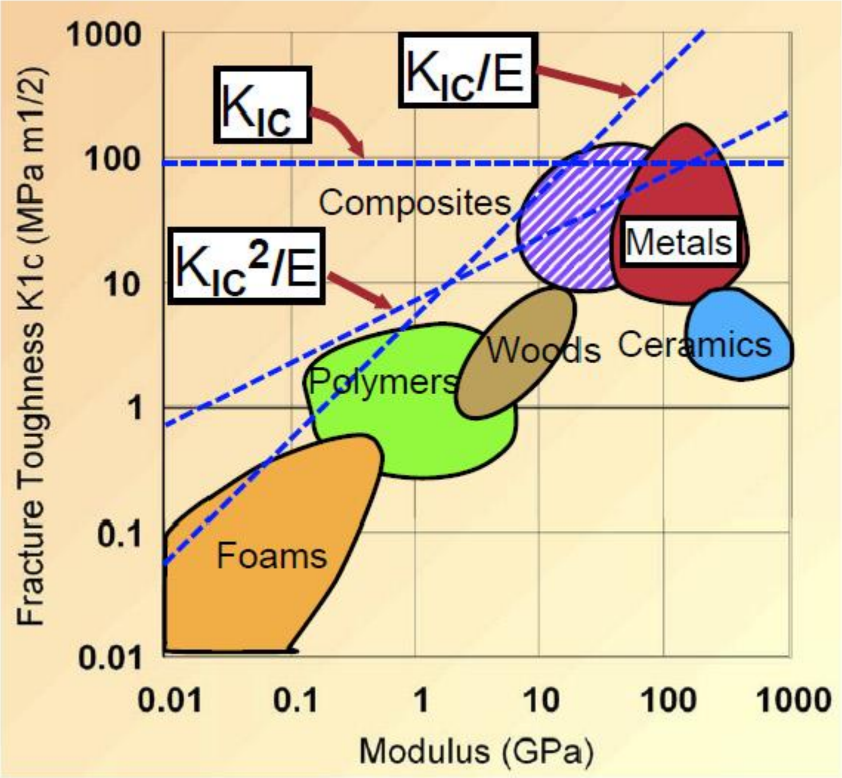
- Choose tough metals e.g. Ti

•Energy-limited, $m = \frac{K_{IC}^{2}}{E}$

•Composites and metal composites

•Displacement-limited, $m = \frac{K_{IC}}{E}$

•Polymers and foams



https://www.youtube.com/watch?v=xMOXTT6_-3c

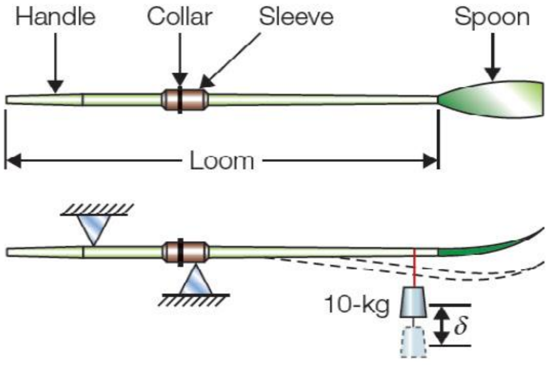
Case Study: Oars

- Credit for inventing the rowed boat seems to belong to the Egyptians.
- The real stimulus for development of boats and oars came in 1900 with the establishment of rowing as an Olympic sport.
- Since then both have drawn the fullest craftsmanship and materials of their day.

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case Study: Oars

- Translation:
  - An oar is essentially a beam loaded in bending
  - Oars must be strong enough not to break, but they are designed on stiffness – to give a specified elastic deflection under a given load
  - Must also be light – extra weight increases the drag on the hull
  - Oars must also be tough enough to withstand being dropped or clashing together



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

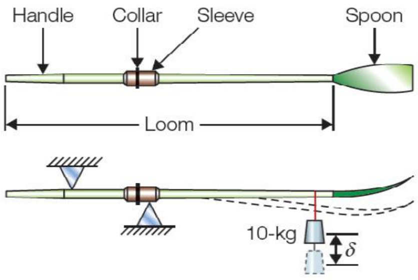
Case Study: Oars

- Design requirement for oars:

Function	Oar—meaning light, stiff beam
Constraints	Length L specified Bending stiffness S^* specified Toughness $G_{1c} > 1$ kJ/m^2
Objective	Minimize the mass m
Free variables	Shaft diameter Choice of material

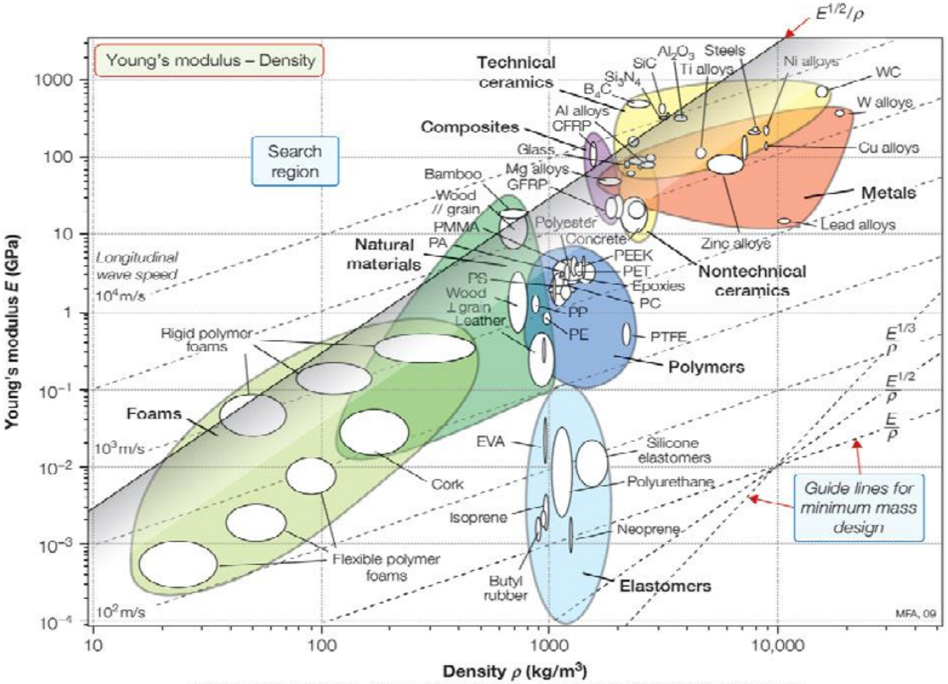
- The material index for the oar is that for a light, stiff beam:

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



Case Study: Oars

•Appropriate selection chart plots Young's modulus against density :



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Woods, carbon-reinforced polymers, and certain ceramics are the best choices based on their location relative to the selection line

Case Study: Oars

•Ceramics are brittle and fail to meet the toughness constraint of the design. Composite blades are lighter than wood for the same stiffness and offer greater control of properties. Until recently a CFRP oar cost more than a wooden one, but the price of carbon fibers has fallen sufficiently that the two cost about the same.

Material	Index *M* $(GPa)^{1/2}/(Mg/m^3)$	Comment
Bamboo	4.0–4.5	The traditional material for oars for canoes
Woods	3.4–6.3	Inexpensive, traditional, but with natural variability
CFRP	5.3–7.9	As good as wood, more control of properties
Ceramics	4–8.9	Good *M* but toughness low and cost high

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

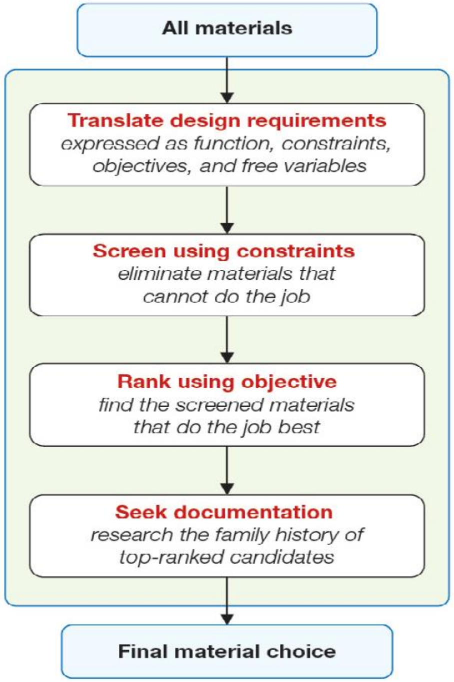
UNSW SYDNEY

Selection of Material Indices

Considering multiple objectives/constrains:

- With multiple constraints
  - Solve each individually
  - Select candidates based on each
  - Evaluate the performance of each
  - Select performance based on most limiting
- With multiple objectives
  - Required utility function to map multiple metrics to common performance measures

- Ashby's method for early material selection

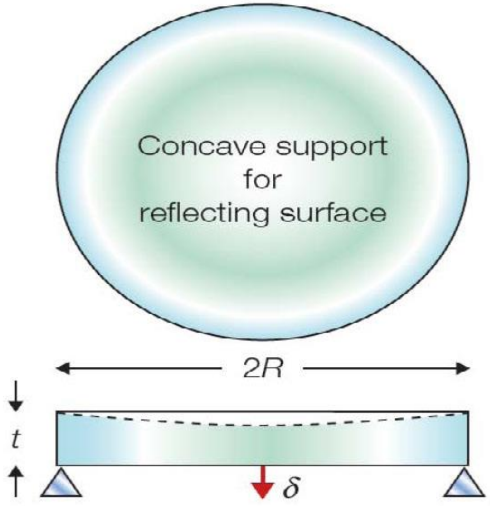


Materials Selection in Mechanical Design, 4th Edition, © 2010 Michael Ashby

- Materials impacts design based on
  - Geometric specification
  - Load requirements
  - Design constraints
  - Performance objectives
- Effect can be assessed analytically
- Keep candidate range large as long as it is feasible
- Strategic consideration can alter best choice
- Materials chart can give quick overview; software tools can be used to find more accurate options (CES Selector)

Case: Mirrors for Large Telescopes

The total cost of a large (236”) telescope is about $300 million. The mirror itself accounts for only about 5% of the overall cost; the rest of the cost is the mechanism that holds, positions and moves it as it tracks across the sky. As the mass of the mirror increases, the sections of the support structure have to increase as m^2, and so does the cost.



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Mirrors for Large Telescopes – Translation

- At its simplest, the mirror is a circular disk with diameter 2R and thickness t
- When horizontal, it will deflect under its own weight ; when vertical, it will not deflect significantly
- This distortion must be small so it does not interfere with performance – this means that the deflection of the midpoint of the mirror be less than the wavelength of light
- Additional requirements are high dimensional stability and low thermal expansion

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Mirrors for Large Telescopes

Design Requirements for the Telescope Mirror	
Function	Precision mirror
Constraints	Radius R specified Must not distort more than δ under self-weight High dimensional stability: no creep, low thermal expansion
Objective	Minimize the mass, m
Free variables	Thickness of mirror, t Choice of material

Mass of mirror…………………….. $m = \pi R^2 t \rho$

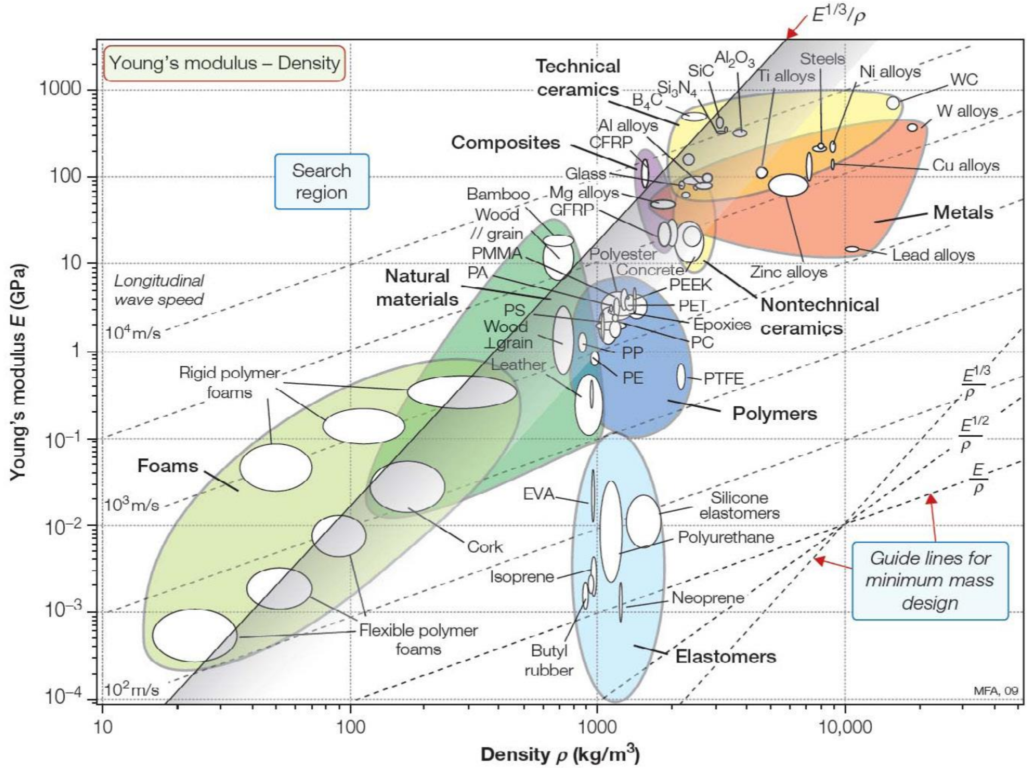
Deflection of horizontal disk due to its own weight………………….. $\delta = \dfrac{3}{4\pi} \dfrac{m g R^2}{E t^3}$

Material index to identify the lightest mirror…………………….. $M = \dfrac{E^{1/3}}{\rho}$

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

UNSW SYDNEY

Case: Mirrors for Large Telescopes



Glass is better than most metals, among which magnesium is a good choice. Carbon-fiber-reinforced polymers give, potentially, the lowest weight of all, but may lack adequate dimensional stability. Foamed glass is a possible candidate.

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Mirrors for Large Telescopes

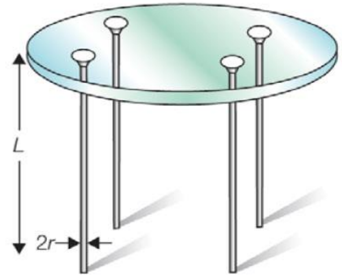
Mirror Backing for 200-inch (5.1m) Telescope

Material	$M = E^{1/3}/\rho$ $(\text{GPa})^{1/3}.\text{m}^3/\text{Mg}$	***m* (tonne) 2*R* = 5.1 m (from Eq. 6.4)**	**Comment**
Steel (or speculum)	0.74	73.6	Very heavy—the original choice
GFRP	1.5	25.5	Not dimensionally stable enough—use for radio telescope
Al-Alloys	1.6	23.1	Heavier than glass, and with high thermal expansion
Glass	1.7	21.6	The present choice
Mg-Alloys	1.9	17.9	Lighter than glass but high thermal expansion
CFRP	3.0	9	Very light, but not dimensionally stable; use for radio telescopes
Foamed polystyrene	4.5	5	Very light, but dimensionally unstable. Foamed glass?

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Table Leg

Design Requirements for the Table leg	
Function	Column (supporting compressive loads)
Constraints	Length *L* specified Must not buckle under design loads Must not fracture if accidentally struck
Objectives	Minimize mass, *m* Maximize slenderness
Free variables	Diameter of legs, 2*r* Choice of material



Minimize Weight

$$m \geq \left(\frac{4F}{\pi}\right)^{1/2} (L)^2 \left[\frac{\rho}{E^{1/2}}\right]$$

$$m < \frac{E^{1/2}}{\rho}$$

Minimize Slenderness

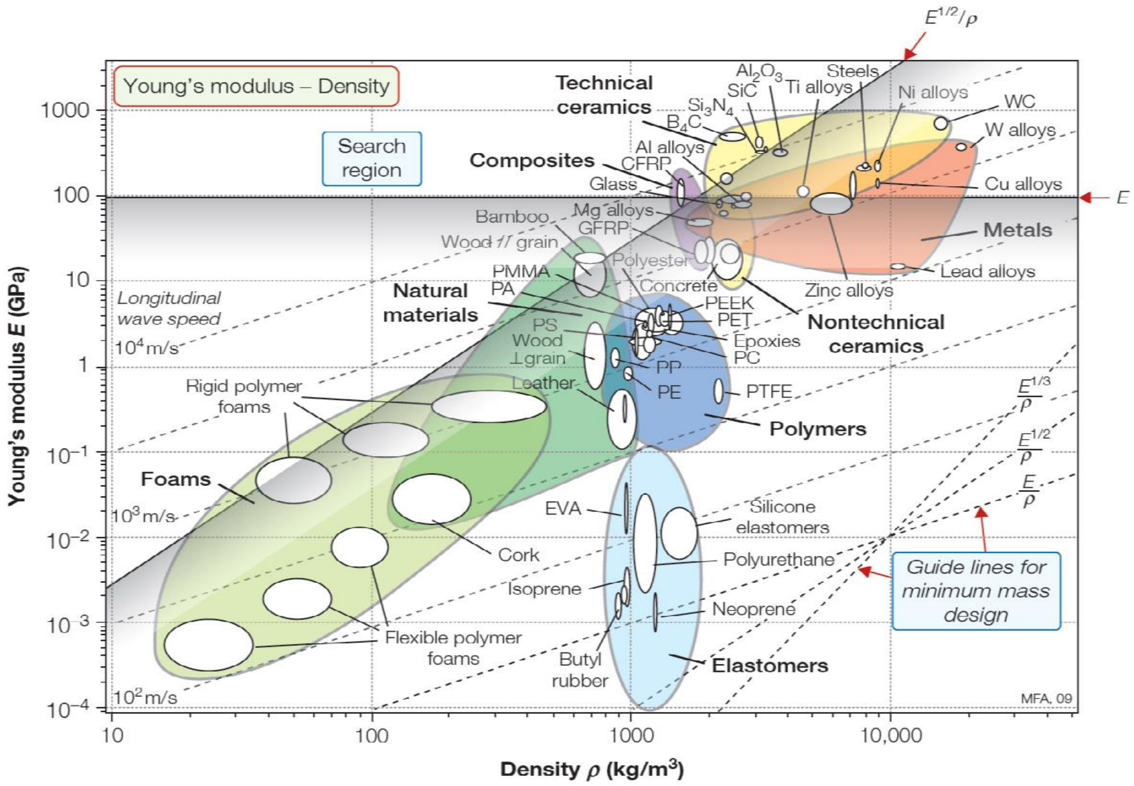
$$r \geq \left(\frac{4F}{\pi^3}\right)^{1/4} (L)^{1/2} \left[\frac{1}{E}\right]^{1/4}$$

$$M_2 = E$$

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

UNSW SYDNEY

Case: Materials for Table Leg



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Table Leg

Materials for Table Legs

Material	Typical M_1 ($GPa^{1/2}.m^3/Mg$)	Typical M_2 (GPa)	Comment
GFRP	2.5	20	Less expensive than CFRP, but lower M_1 and M_2
Woods	4.5	10	Outstanding M_1; poor M_2 Inexpensive, traditional, reliable
Ceramics	6.3	300	Outstanding M_1 and M_2 Eliminated by brittleness
CFRP	6.6	100	Outstanding M_1 and M_2, but expensive

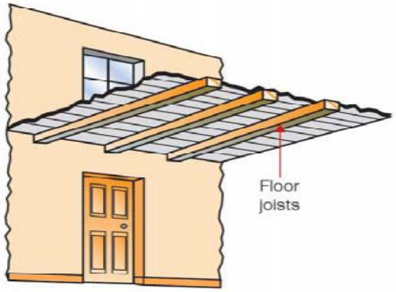
Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Structural Materials for Buildings

Table 6.7 Design Requirements for Floor Beams	
Function	Floor beam
Constraints	Length *L* specified Stiffness: must not deflect too much under design loads Strength: must not fail under design loads
Objective	Minimize cost, *C*
Free variables	Cross-section area of beam, *A* Choice of material

$$M_1 = \frac{E^{1/2}}{\rho C_m}$$

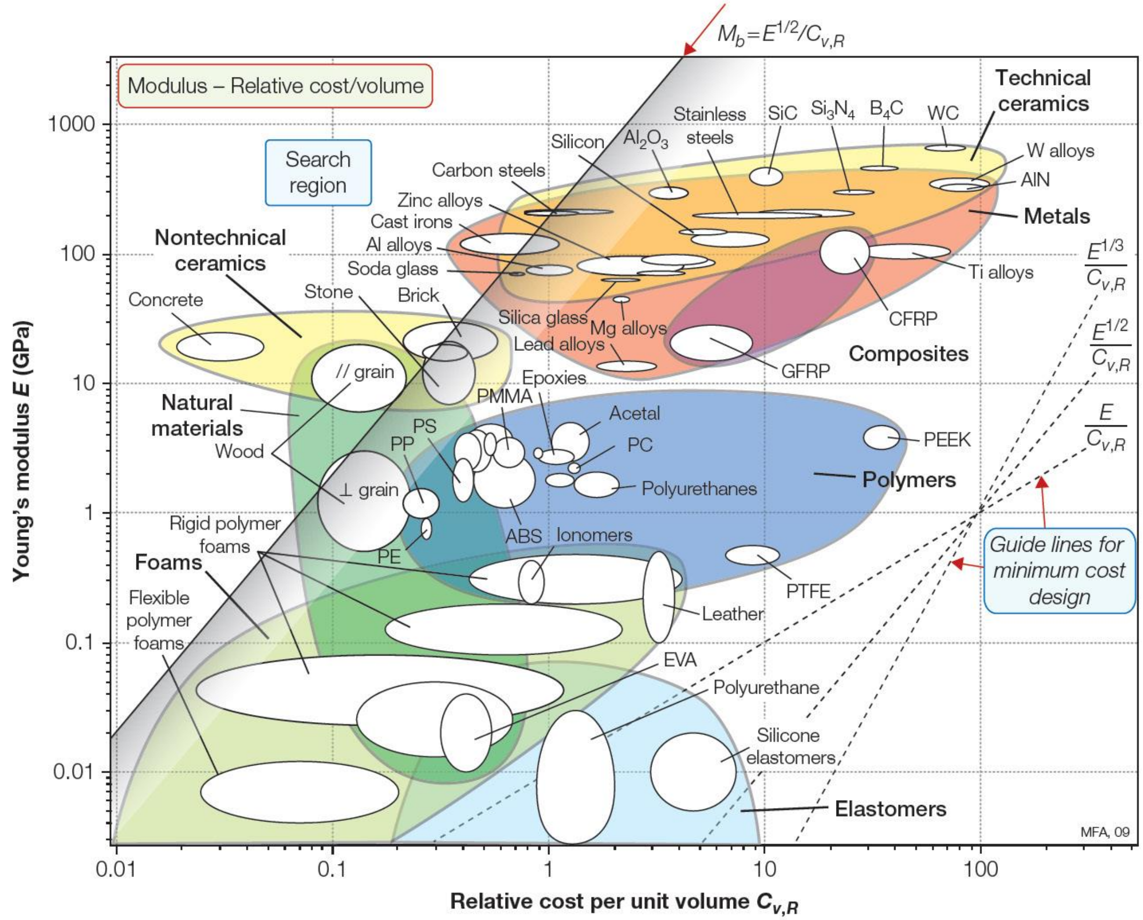
$$M_2 = \frac{\sigma_f^{2/3}}{\rho C_m}$$



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

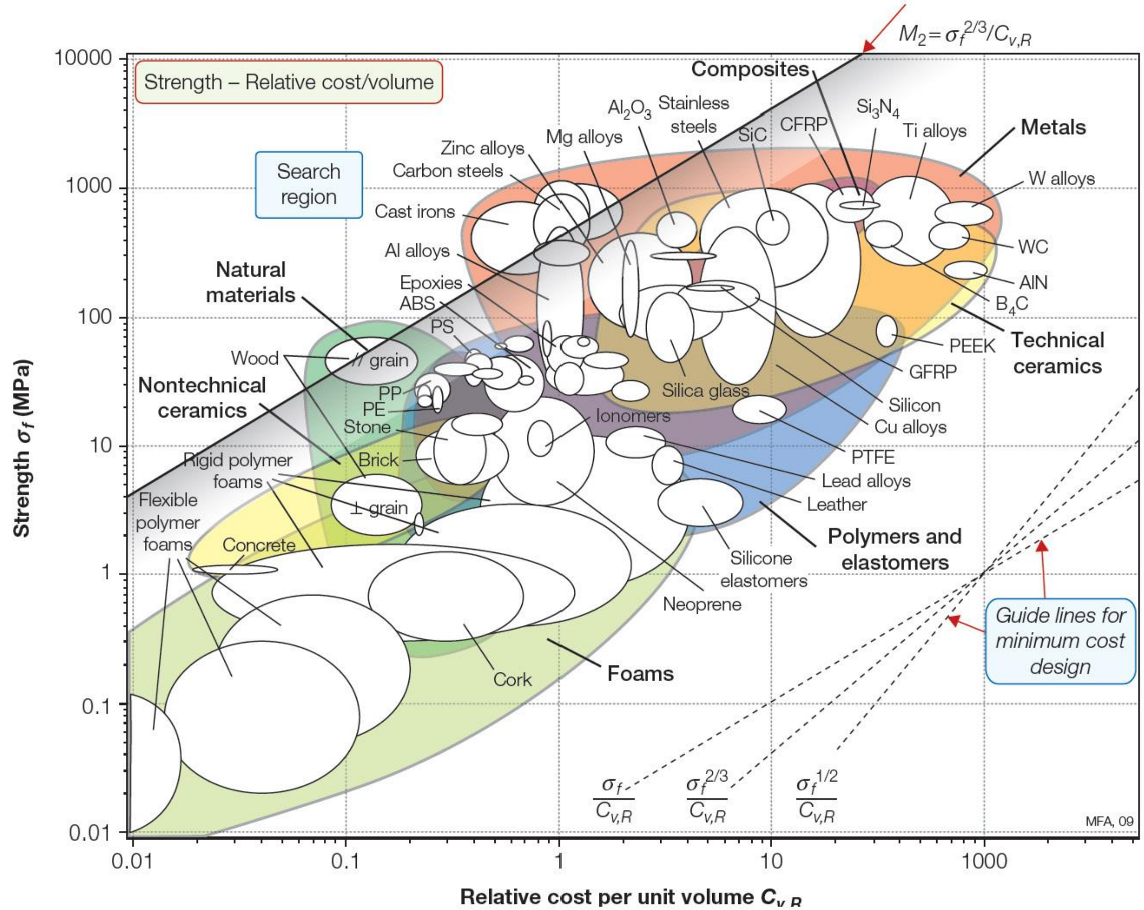
UNSW
SYDNEY

Case: Structural Materials for Buildings



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Structural Materials for Buildings



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Structural Materials for Buildings

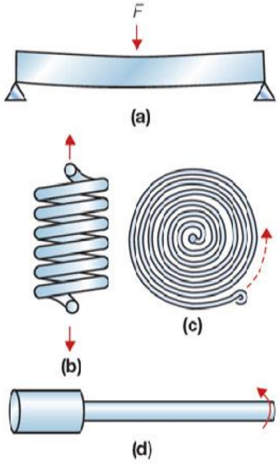
Table 6.8 Structural Materials for Buildings

Material	M_1 (GPa$^{1/2}$)/(kg/m^3)	M_2 (MPa$^{2/3}$)/(kg/m^3)	Comment
Concrete	160	14	Use in compression only
Brick	12	12	
Stone	9.3	12	
Woods	21	90	Can support bending and tension as well as compression, allowing greater freedom of shape
Cast iron	17	90	
Steel	14	45	

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Small Springs

Table 6.11 Design Requirements for Springs	
Function	Elastic spring
Constraint	No failure, meaning $\sigma < \sigma_f$ throughout the spring
Objective	Maximum stored elastic energy per unit volume, or maximum stored elastic energy per unit weight
Free variable	Choice of material

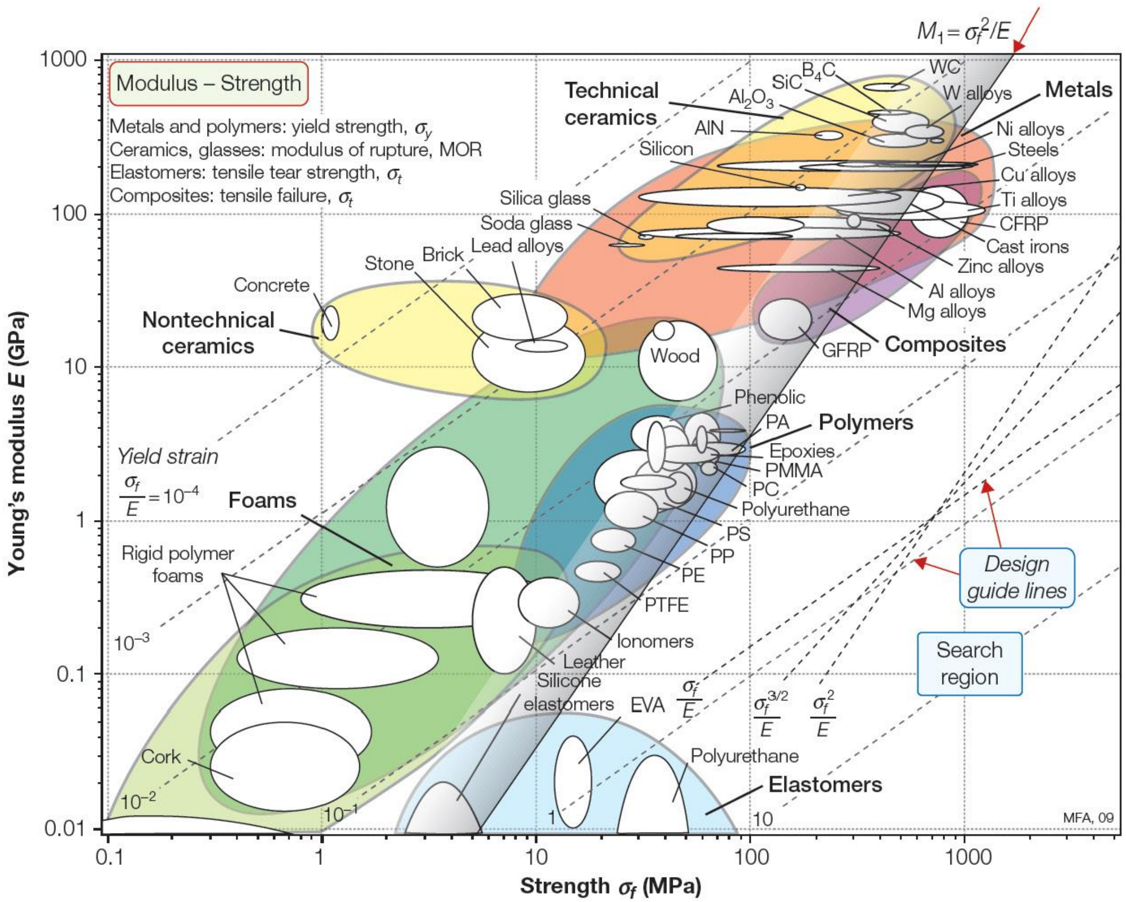


$$M_1 = \frac{\sigma_f^2}{E}$$

$$M_2 = \frac{\sigma_f^2}{\rho E}$$

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Small Springs



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Small Springs

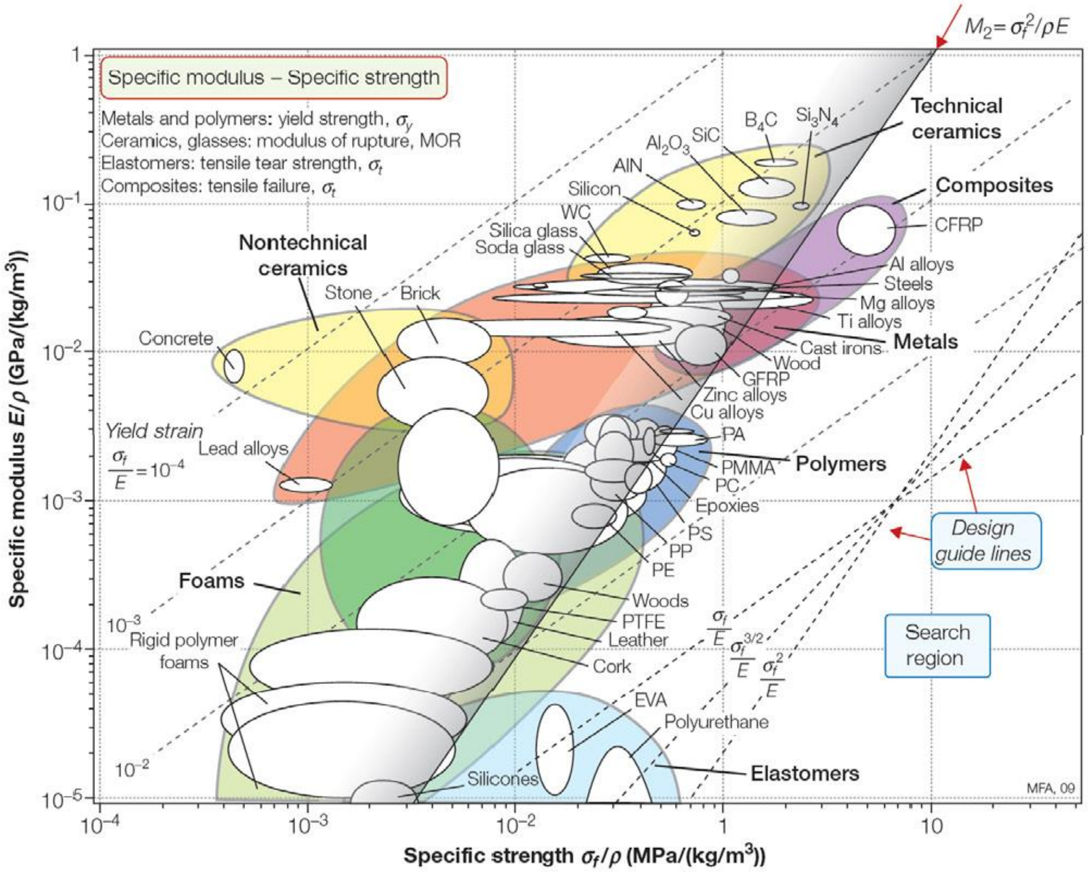
Table 6.12(a) Materials for Efficient Small Springs

Material	$M_1 = \sigma_f^2/E$ (MJ/m^3)	Comment
Ti alloys	4–12	Expensive, corrosion-resistant
CFRP	6–10	Comparable in performance with steel; expensive
Spring steel	3–7	The traditional choice: easily formed and heat treated
Nylon	1.5–2.5	Inexpensive and easily shaped, but high loss factor
Rubber	20–50	Better than spring steel, but high loss factor

High strength ("spring") steel is good. Glass, CFRP, and GFRP all, under the right circumstances, make good springs. Elastomers are excellent. Ceramics are eliminated by their low tensile strength.

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Small Springs



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Materials for Small Springs

Table 6.12(b) Materials for Efficient Light Springs

Material	$M_1 = \sigma_f^2/\rho E$ (kJ/kg)	Comment
Ti alloys	0.9–2.6	Better than steel; corrosion-resistant; expensive
CFRP	3.9–6.5	Better than steel; expensive
GFRP	1.0–1.8	Better than spring steel; less expensive than CFRP
Spring steel	0.4–0.9	Poor, because of high density
Wood	0.3–0.7	On a weight basis, wood makes good springs
Nylon	1.3–2.1	As good as steel, but with a high loss factor
Rubber	18–45	Outstanding; 20 times better than spring steel; but with high loss factor

Metals are disadvantaged by their high densities.
Composites are good; so is wood. Elastomers are excellent

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Elastic Seals

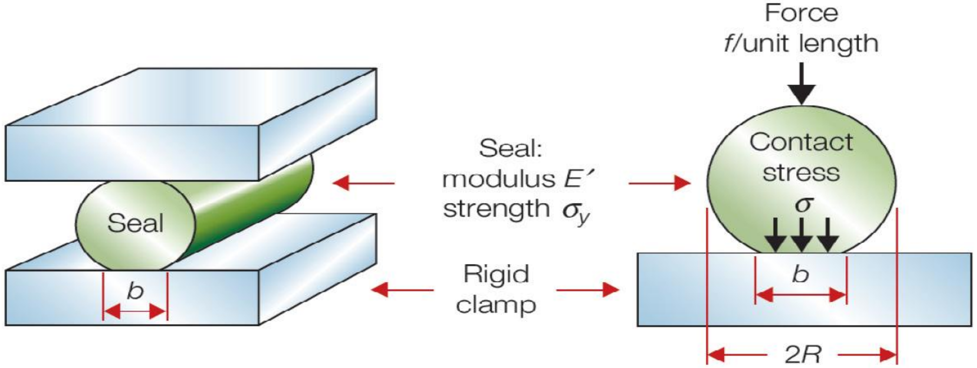


Table 6.15 Design Requirements for Elastic Seals

Function	Elastic seal
Constraints	Limit on contact pressure Low cost
Objective	Maximum conformability to surface
Free variable	Choice of material

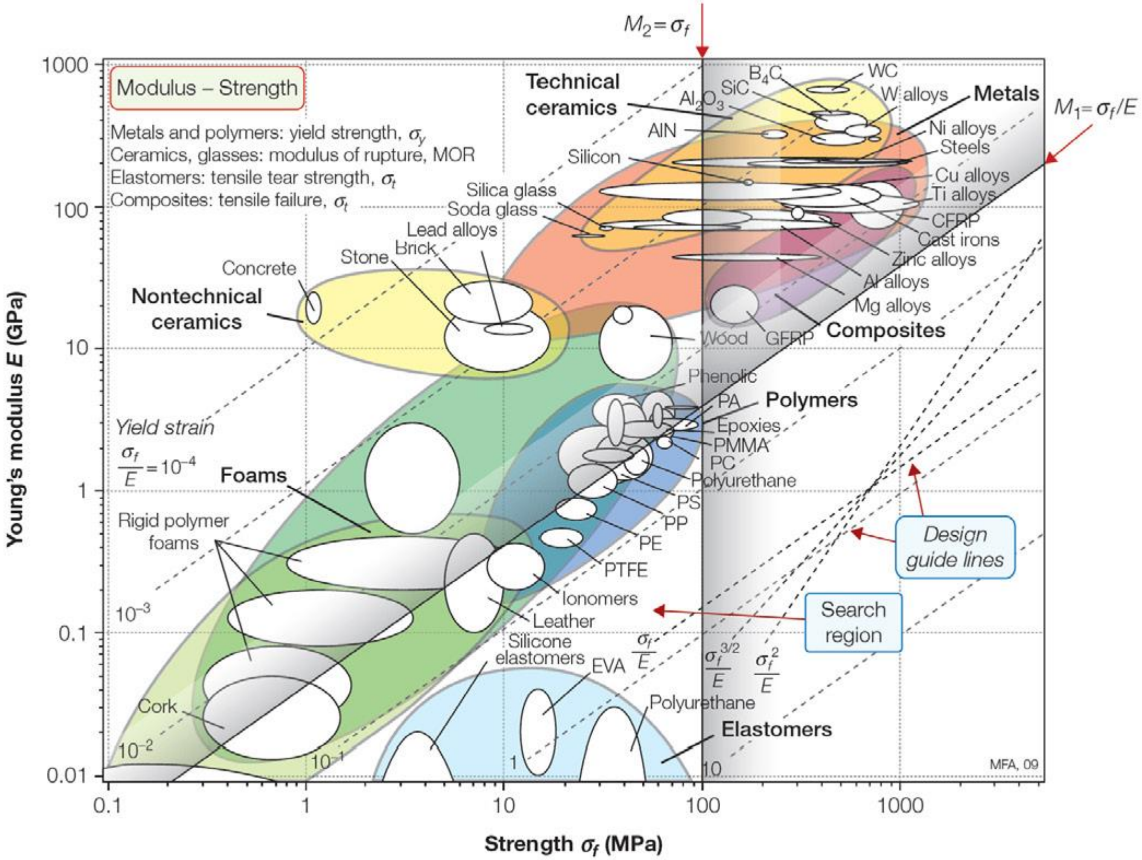
$$M_1 = \frac{\sigma_f}{E}$$

$$M_2 = \sigma_f \leq 100\,\text{MPa}$$

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

UNSW SYDNEY

Case: Elastic Seals



Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Case: Elastic Seals

Table 6.16 Materials for Reusable Seals

Material	$M_1 = \frac{\sigma_f}{E}$	Comment
Elastomeric EVA	0.7–1	The natural choice; poor resistance to heat and to some solvents
Polyurethanes	2–5	Widely used for seals
Silicone rubbers	0.2–0.5	Higher temperature capability than carbon-chain elastomers, chemically inert
PTFE	0.05–0.1	Expensive but chemically stable and with high temperature capability
Polyethylenes	0.02–0.05	Inexpensive but liable to take a permanent set
Polypropylenes	0.2–0.04	Inexpensive but liable to take a permanent set
Nylons	0.02–0.03	Near upper limit on contact pressure
Cork	0.03–0.06	Low contact stress, chemically stable
Polymer foams	Up to 0.03	Very low contact pressure; delicate seals

Elastomers, compliant polymers, and foams make good seals.

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

•Stiffness with strength: the strength of material is the amount of force it can withstand and still recover its original shape;

•Material stiffness with geometric stiffness: the geometric stiffness depends on shape, e.g. the stiffness of an I beam is much higher than that of a spring made of the same steel thus having the same rigidity;

•Stiffness with hardness: the hardness of a material defines the relative resistance that its surface imposes against the penetration of a harder body;

•Stiffness with toughness: toughness is the amount of energy that a material can absorb before fracturing.

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby

Concluding Remarks

- Materials impacts design based on
  - Geometric specification
  - Load requirements
  - Design constraints
  - Performance objectives
- Effect can be assessed analytically
- Keep candidate range large as long as it is feasible
- Materials chart can give quick overview; software tools can be used to find more accurate options
- Strategic consideration can alter best choice

Materials Selection in Mechanical Design, 4th Edition © 2010 Michael Ashby