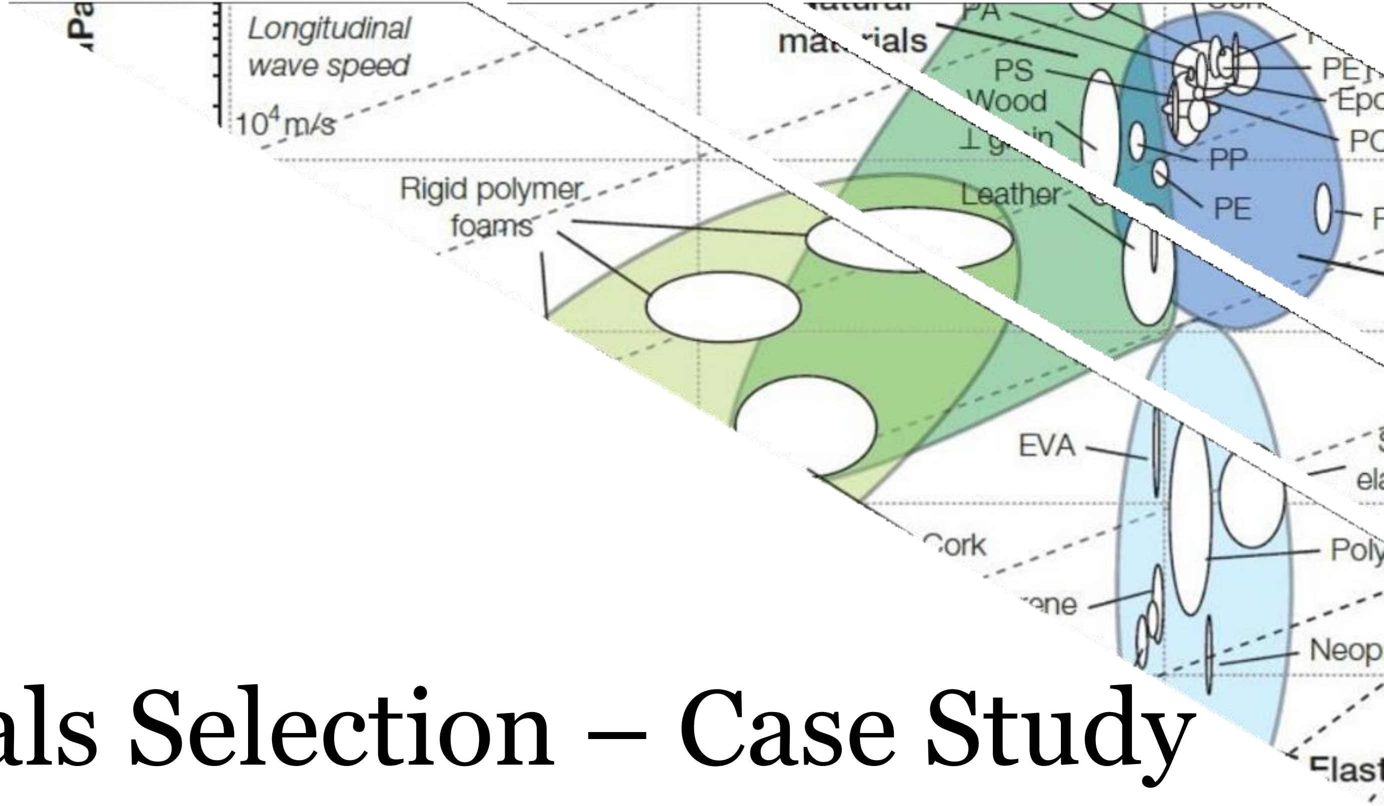


Materials Selection – Case Study Bases and Mechanical Properties

Materials :“Drivers” of our Society

✔Rooted in our culture and have influence over virtually every segment of our daily lives –

- ❖ Transportation
- ❖ Housing
- ❖ Clothing
- ❖ Communication
- ❖ Recreation, etc.

✔Early civilizations have been design by materials development:

- ❖ Stone Age
- ❖ Bronze Age
- ❖ Iron Age

VIT, Pune

Fighter Craft
Image: Ontario sea plane association

Home

Antenna
Image: www.goes-r.gov

World of materials

Stone Age

- The term “**Stone Age**” was coined in the late 19th century by the Danish scholar **Christian J. Thomsen.**
- Roughly extended between **15000-2000 BC**.
- Characterized by creation and use of **stone tools**.
- Wood, bones and other materials were also used as tools but have shorter life.

Image: Canadian Anglo-Boer War Museum, Canada

Image: Nubian Museum, Egypt

Image : Wesleyan University, USA

Image: Government Museum, Chennai, India

<u>Stone Age Tools</u>

Bronze Age

- Roughly extend between 3500-500 BC.
- Beginning of **metal working**.
- Copper was mixed with tin, to create a new alloy - **BRONZE**, which was stronger than the other two metals individually.
- Used for tools, weapons, armor, decoration, etc.

Neck collar of Gold
Image: http://www.britishmuseum.org/

Daggers (kind of knife) and Swords
Image : The Archaeology Gallery at West Stow, England

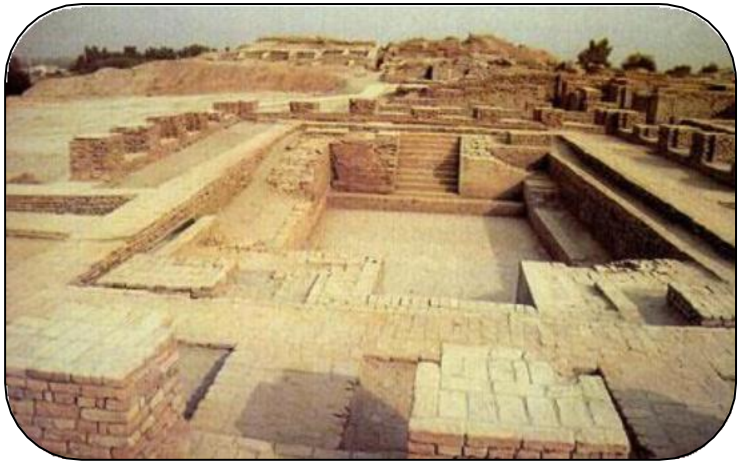
Axe Head

Image: Kenilworth Abbey Barn Museum, UK

Spartan Armor
Image: Metropolitan Museum of Art, New York

Bronze Age – India

- Begins around 3000 BC.
- Development of Indus valley Civilisation/ Harappa Culture, first ever urban civilisation.

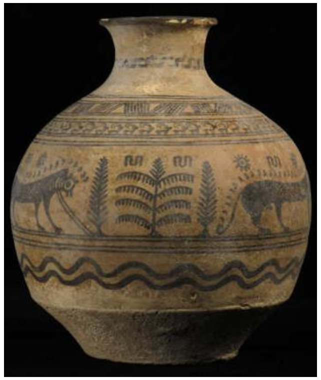


Indus valley civilization
Image: NCERT

- The famous **Dancing Girl** is a **bronze statuette** (10.5 cm high) casted using the lost wax method and dating around 2500 B.C., from the Mohenjo-daro site, Sindh (now in Pakistan) of the Indus Valley Civilization.
- Found by Ernest Mackay in 1926.
- Although it is in standing position, it was named *"Dancing Girl"* with an assumption of her profession – 25 bangles in left and 4 bangles in her right hand.

Dancing Girl

(**Image:** National Museum, New Delhi, India)



Ceramic Pot, Indus valley
Image: www.antiques.com

Iron Age

- It is the **last stage** of the archaeological sequence known as the three-age system
  (Stone Age, Bronze Age, & Iron Age).

- The Iron Age began about 3000 years ago and **continues till today**. Use of iron and steel has changed drastically the human development.

- Witnessed **industrial revolution**.

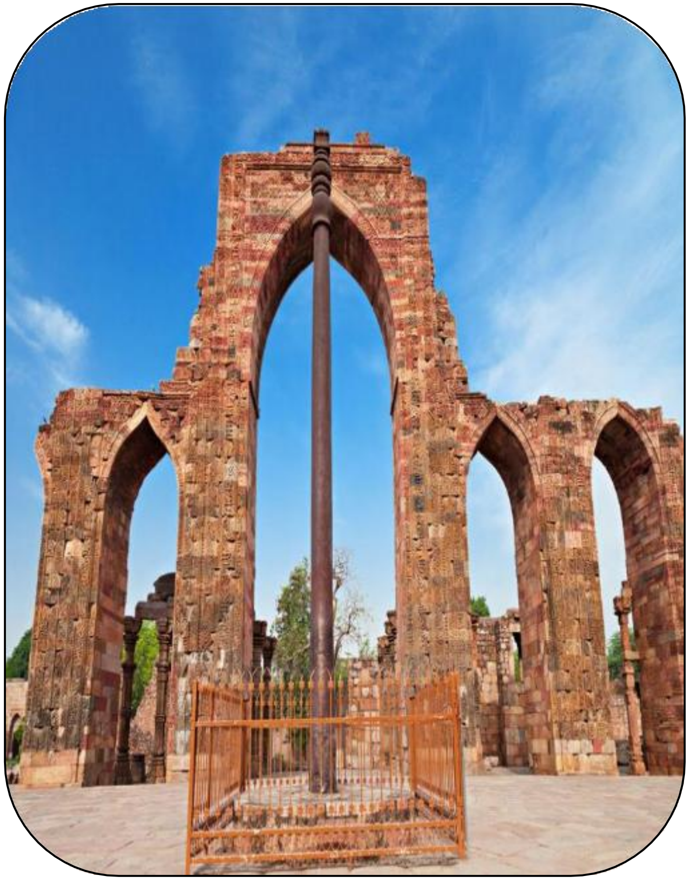
- Improved modes of transportation –Automobiles, Railways and aero

Transportation modes

Image: www.pinterest.com

IRON PILLAR OF DELHI

- Iron age in South-Asia begins around 1200 B.C
- IRON PILLAR OF DELHI (around 1600 year old) called as "a testament to the skill of ancient Indian blacksmiths".
- Solid shaft of **wrought iron** (high **phosphorous** content) about 7m tall, 0.4 m diameter weighing over 6,000 kg.
- High resistance to corrosion results from an even layer of crystalline iron hydrogen phosphate hydrate, which serves to protect it from the effects of the local Delhi climate.



Iron Pillar, Qutab Minar Complex, New Delhi, India

In-depth study, book and papers published by Late **Prof. R. Balasubramaniam**, Department of Materials Science and Engineering, IIT Kanpur, http://www.iitk.ac.in/infocell/Archive/dirnov1/iron_pillar.html

Howrah Bridge

- Howrah Bridge is a **suspension type Balanced Cantilever bridge** over the Hooghly River in Kolkata, West Bengal, India.
- **World's 6^{th} longest cantilever bridge** **(Longest span = 457 m)**. 1^{st} - Quebec Bridge (1917), Canada (longest span - 549m span).
- Official name: **Rabindra Setu**, named after Gurudev "**Rabindranath Tagore**" (**first Asian Nobel laureate**).
- Commissioned in 1943.
- Total length - 705m
  Height - 82 m
- **Material – Steel, supplier TATA Steel**
- Consumed about 26,500 tons of steel, no bolts and nuts used - **only Rivets.**

Howrah Bridge, Kolkata

Materials selection

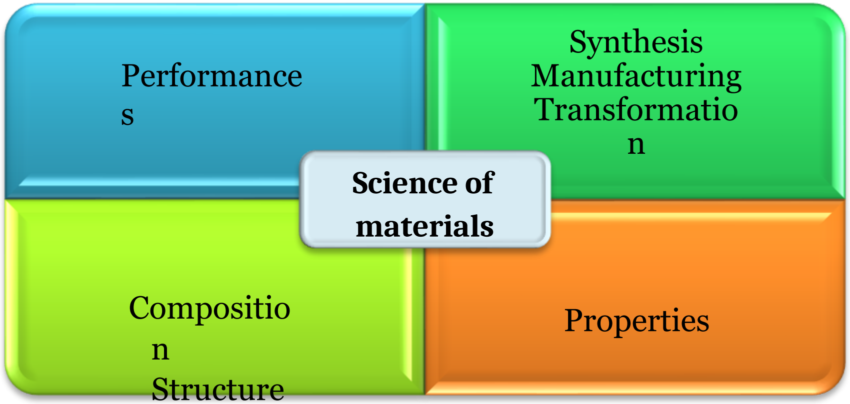
- **Mechanical properties**: tensile test, fatigue, hardness, toughness, creep…
- **Physical properties**: density, conductivity, coefficient of thermal expansion
- **Chemical properties** : corrosion
- **Microscopic characteristics**: anisotropy of properties, hardening, microstructure, grain size, segregation, inclusions…

Materials selection

- **Process linked aspects**: formability, machinability, weldability, stampability
- **Aestethic aspects**: colour and surface roughness

<u>Notice</u>: surface properties ≠ volume properties

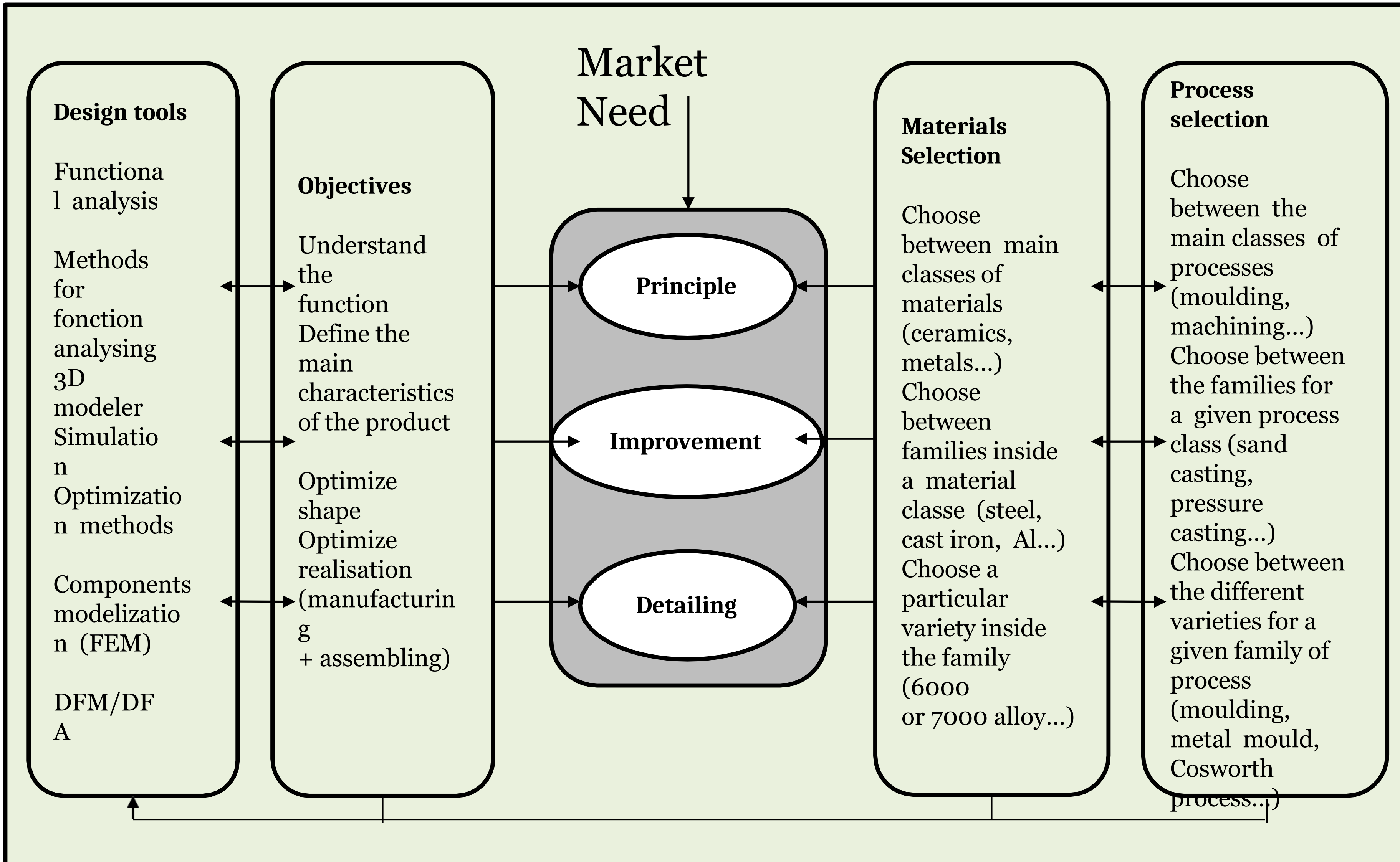
4 poles for engineering and material science →



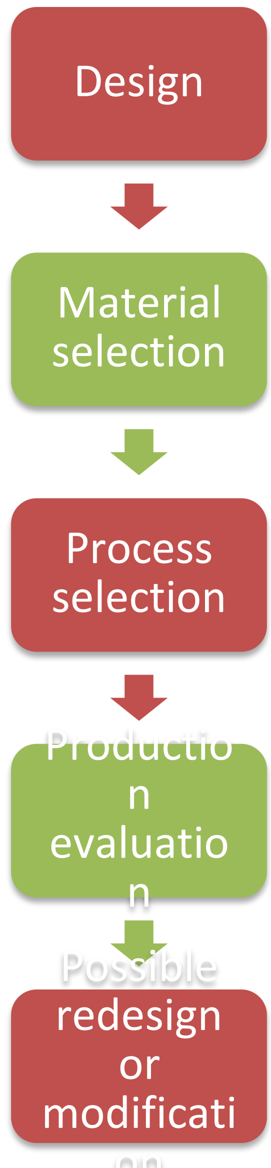
Factors affecting the selection of materials

- Component shape
- Dimensional tolerance
- Mechanical properties
- Fabrication (Manufacturing) requirements
- Service requirements
- Cost
  - Cost of material
  - Cost of processing
- Availability of the material
- Environmental Ascpects

Design steps



Procedure for materials selection



Forecasts

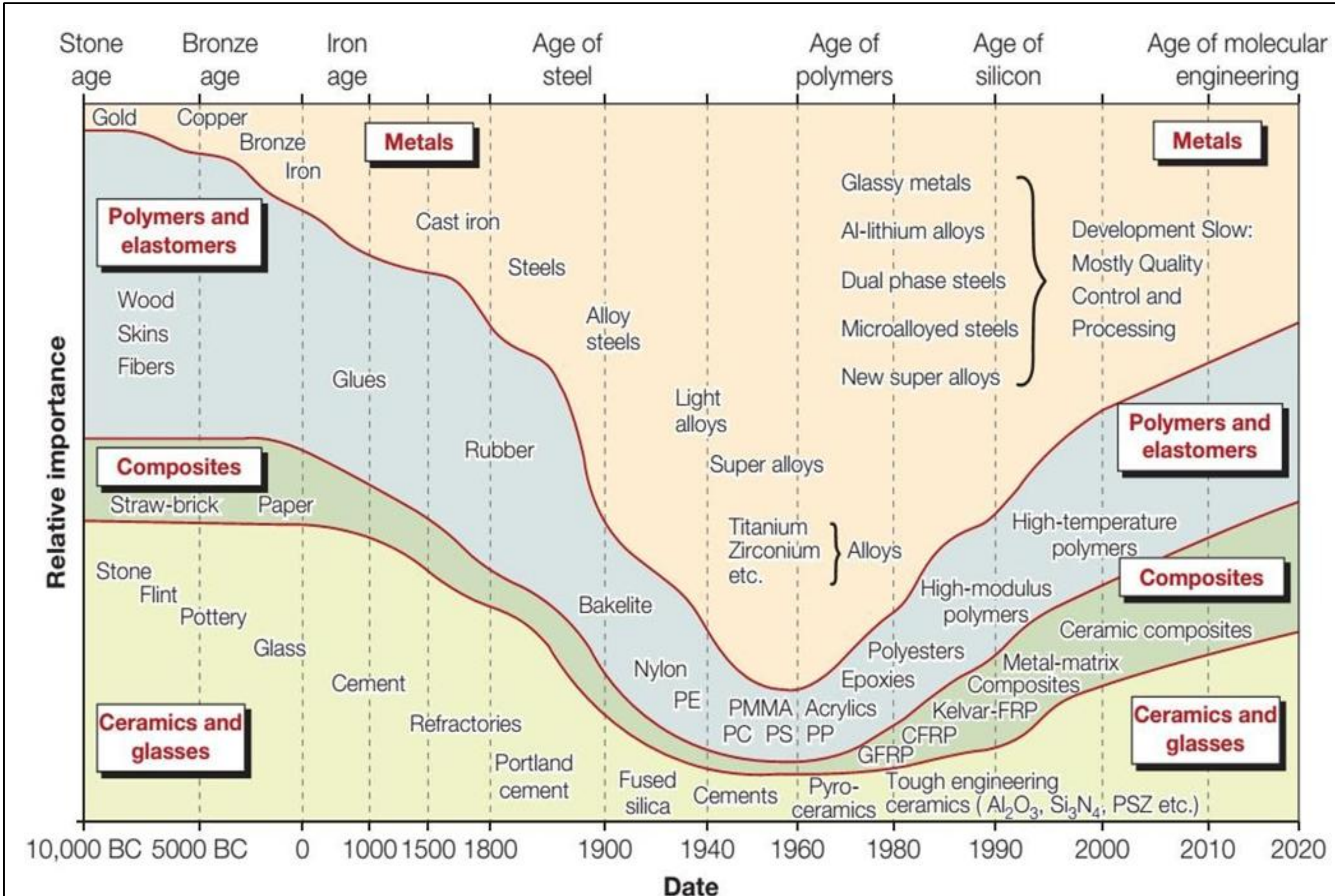
Evolution of materials is challenged by:

- ↗ mechanical properties
- ↗ physical and chemical properties
- ↘ environmental problems ↘ (manufacturing)
- materials ressource

Key Domains : energy (nuclear, solar cells, …)

transport

Summary: Material Evolution



Reference: Ashby, Material Selection in Mechanical Design, 4 Ed.

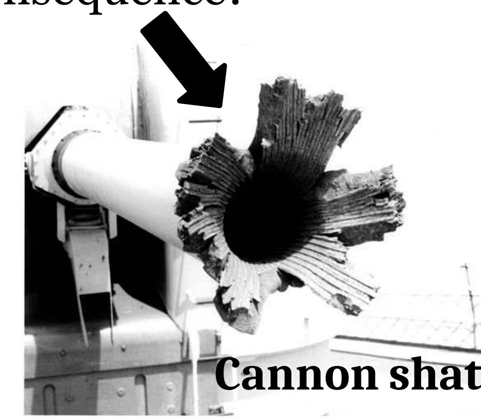
A bit of History

1850s, time of the Crimean War

Napoleon III

French military engineers had found they could control the trajectory applying a rifling or "spinning" in the barrels of guns (cannon)

The spiraling motion added extra stresses Consequence?



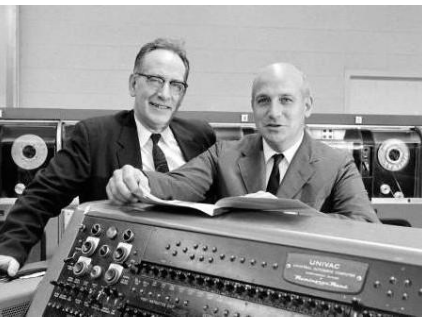
Cannon shatter

Need a higher-strength material

→ **Steel**

A bit of History

1946, University of Pennsylvania
Moore School of Electrical Engineering



Electronic Numerical Integrator Analyser and Computer (**Eniac**) by **John Mauchly and J. Presper Eckert**

The first general-purpose electronic computer

17468 thermionic valves
70,000 resistors
....

Covered 167 square metres of floor space
Weighed 30 tonnes
Consumed 160 kW of electricity

1947,
Discovery of the Transistor (Semiconductors)
Built from materials such as **Silicon and Germanium** which can either behave as an electrical insulator or conductor

Companies spent tens of billion of dollars to squeeze more circuits on to a small 'chip' of material

2010, an Intel X3370 microprocessor – 820 million transistors **Your computer could handle 3 billion instructions /s 600000 more than Eniac**

A bit of History

A bit of History

2012, low cost airlines company

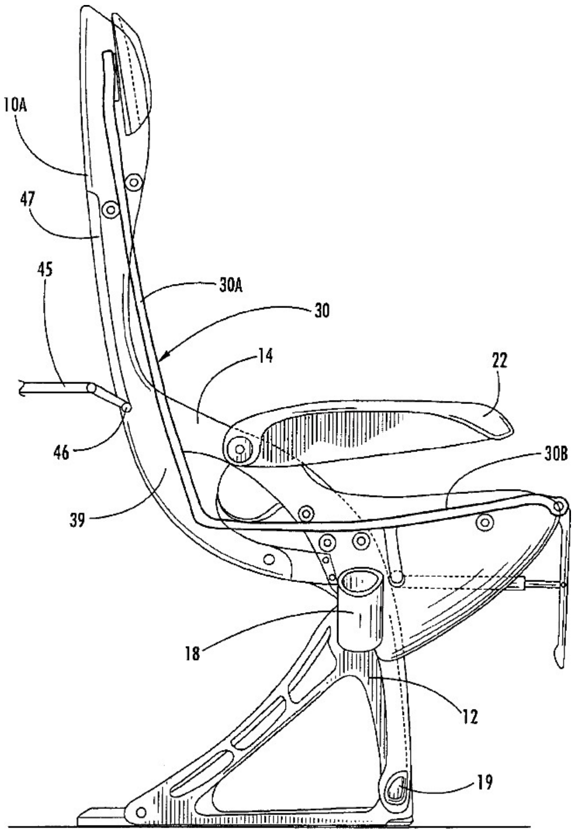
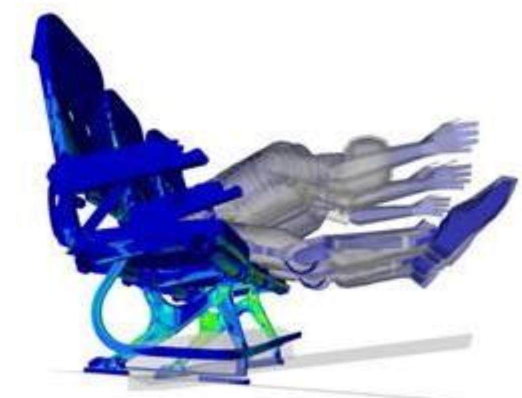


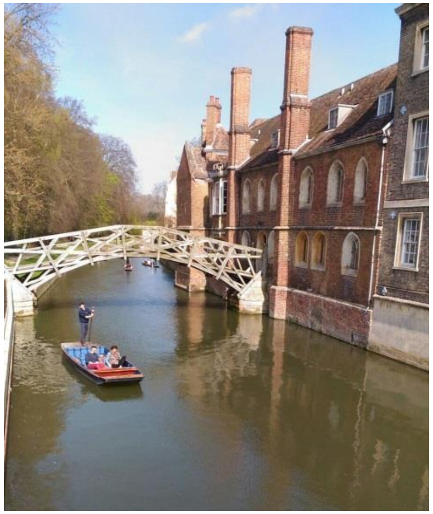
FIG. 2.

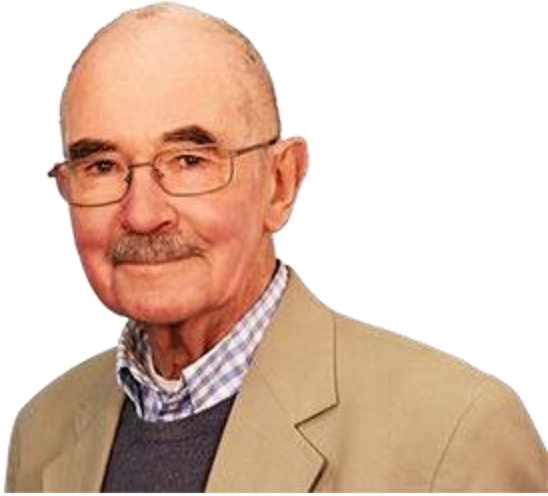


Change the material of a small pivot (46) for each seat

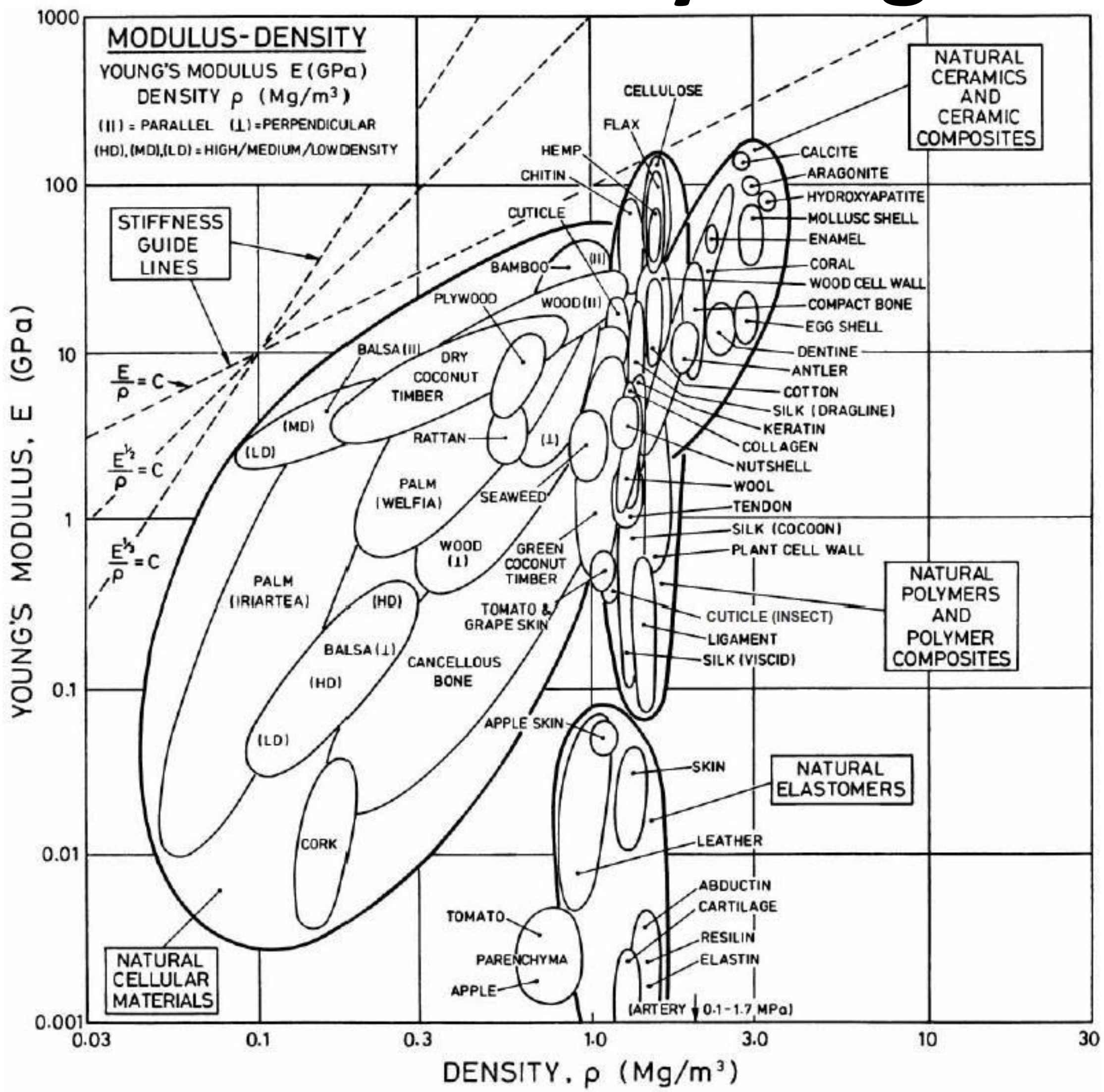
In the air transports
Weight = Costs
Aluminum → PE+ Glass fibers Composite → **10,000,000 dollars saved each year**

Mike Ashby from Univesity of Cambridge



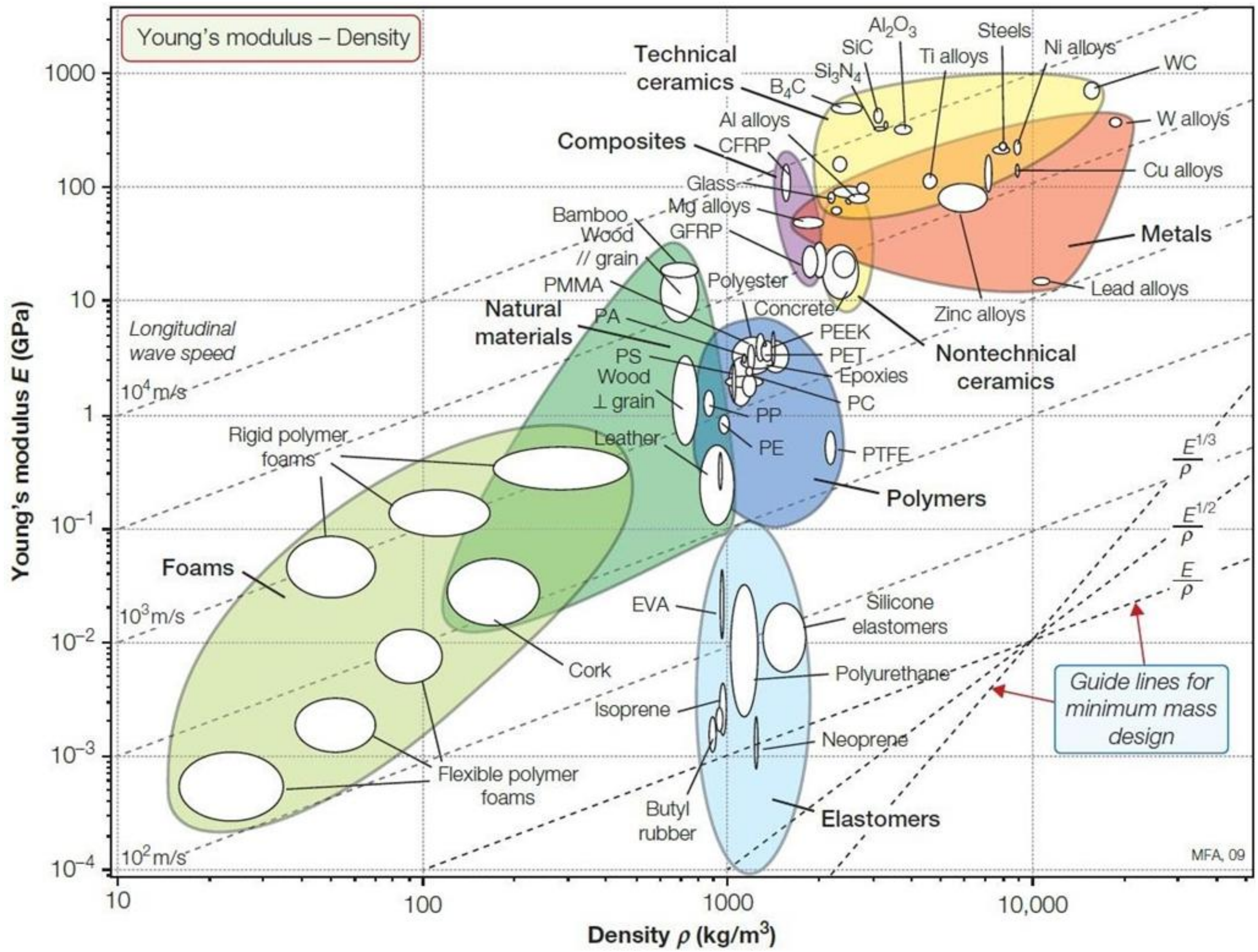


Ashby Diagrams

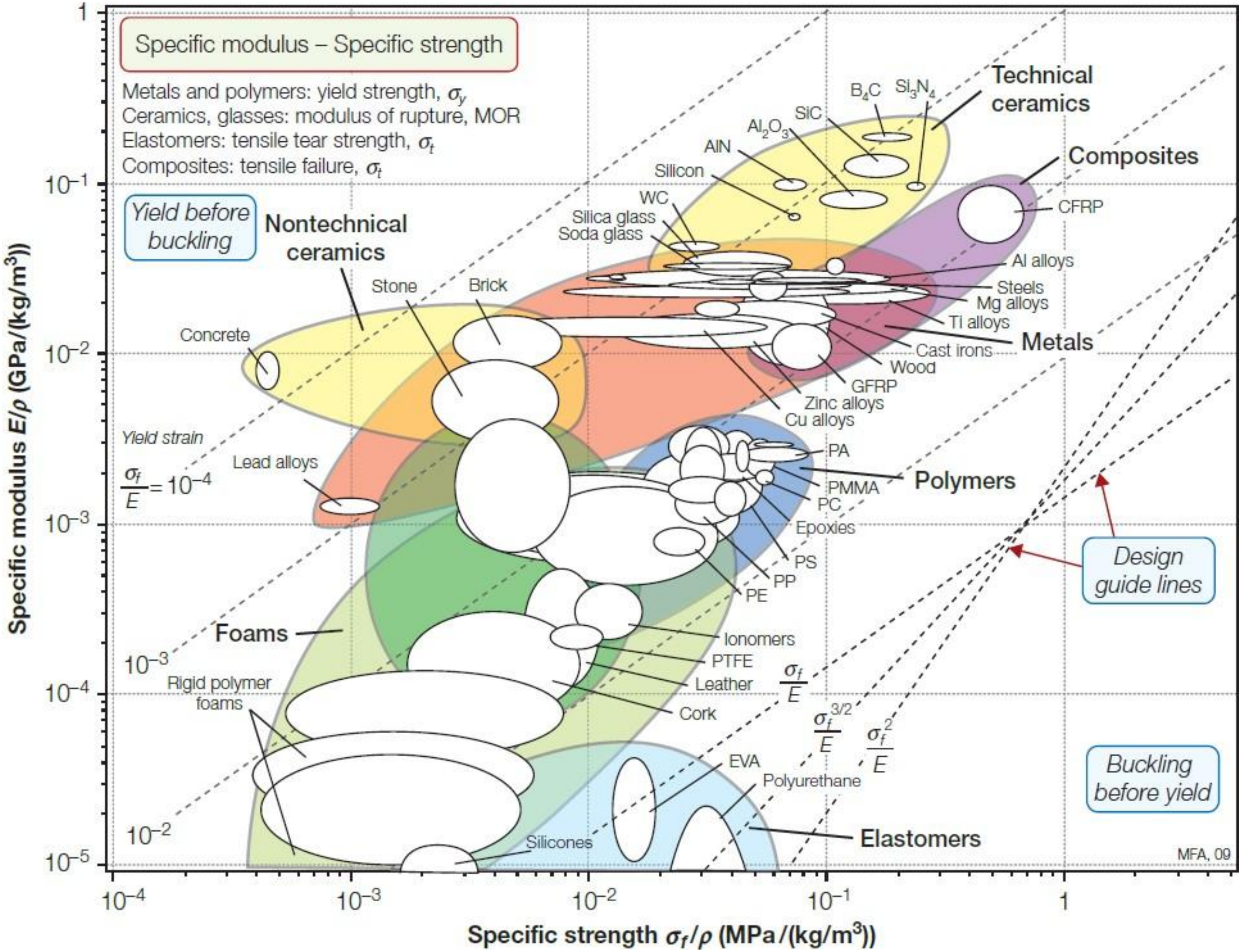


[The mechanical efficiency of natural materials, Mike Ashby, 2003]

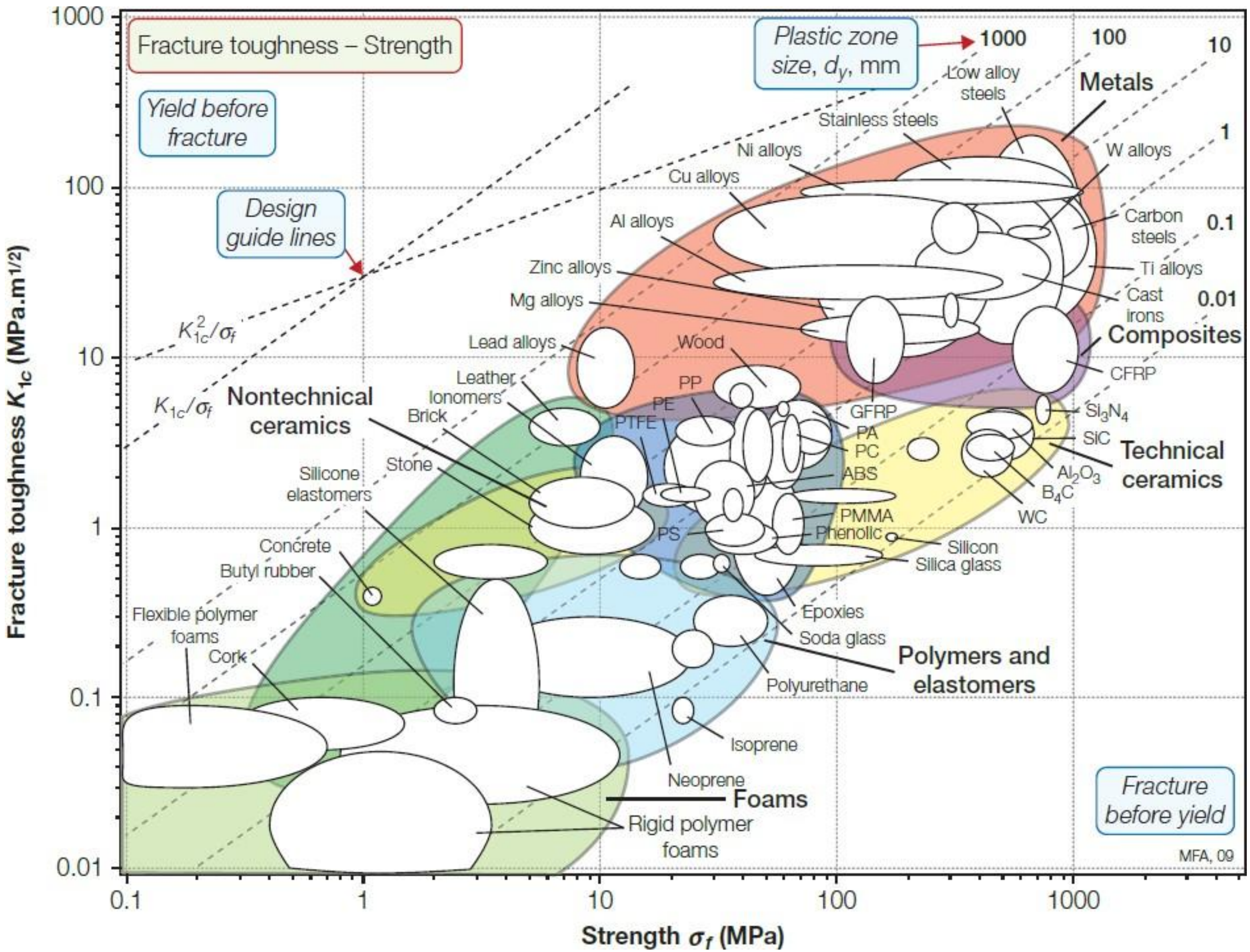
Ashby Diagrams



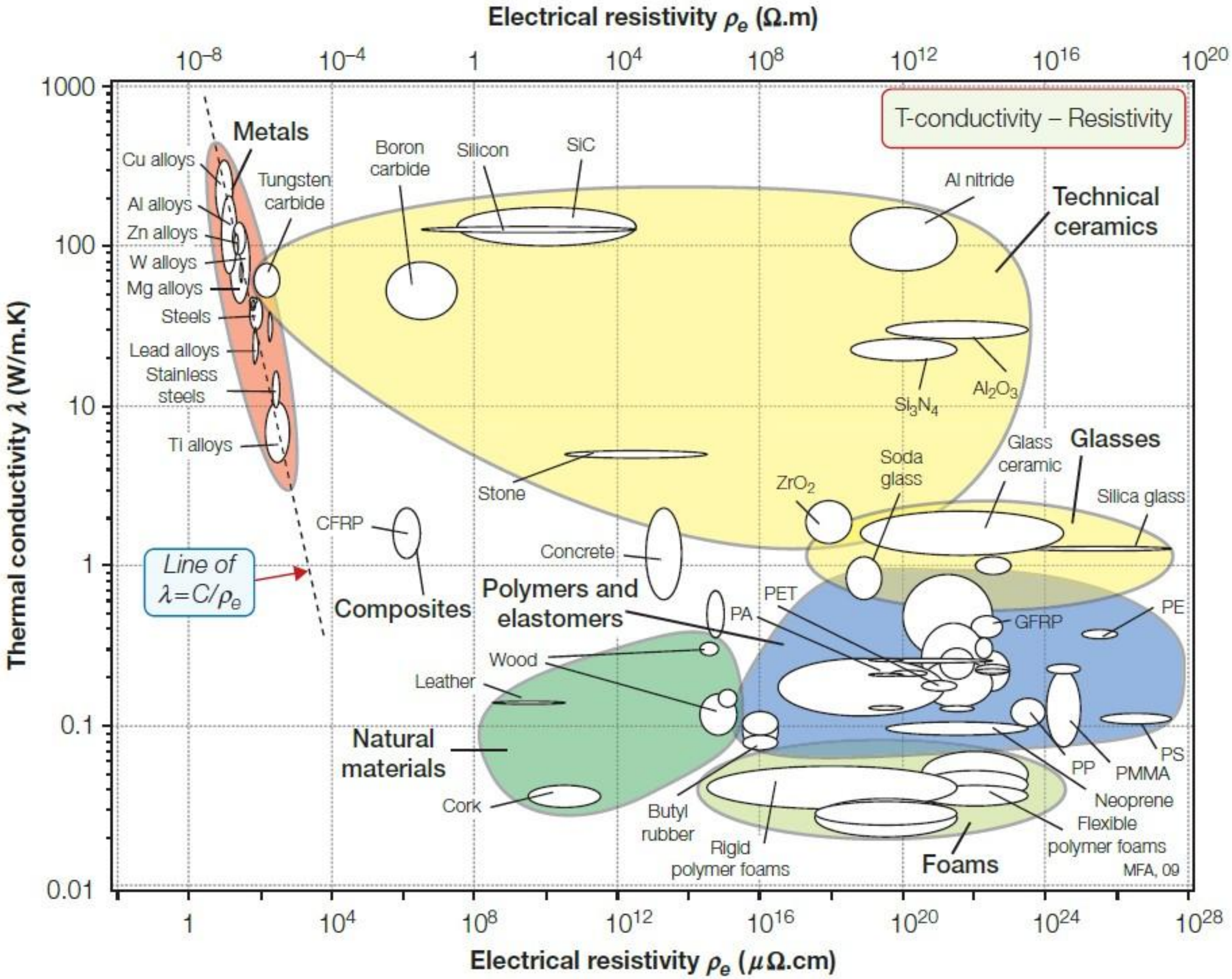
Ashby Diagrams



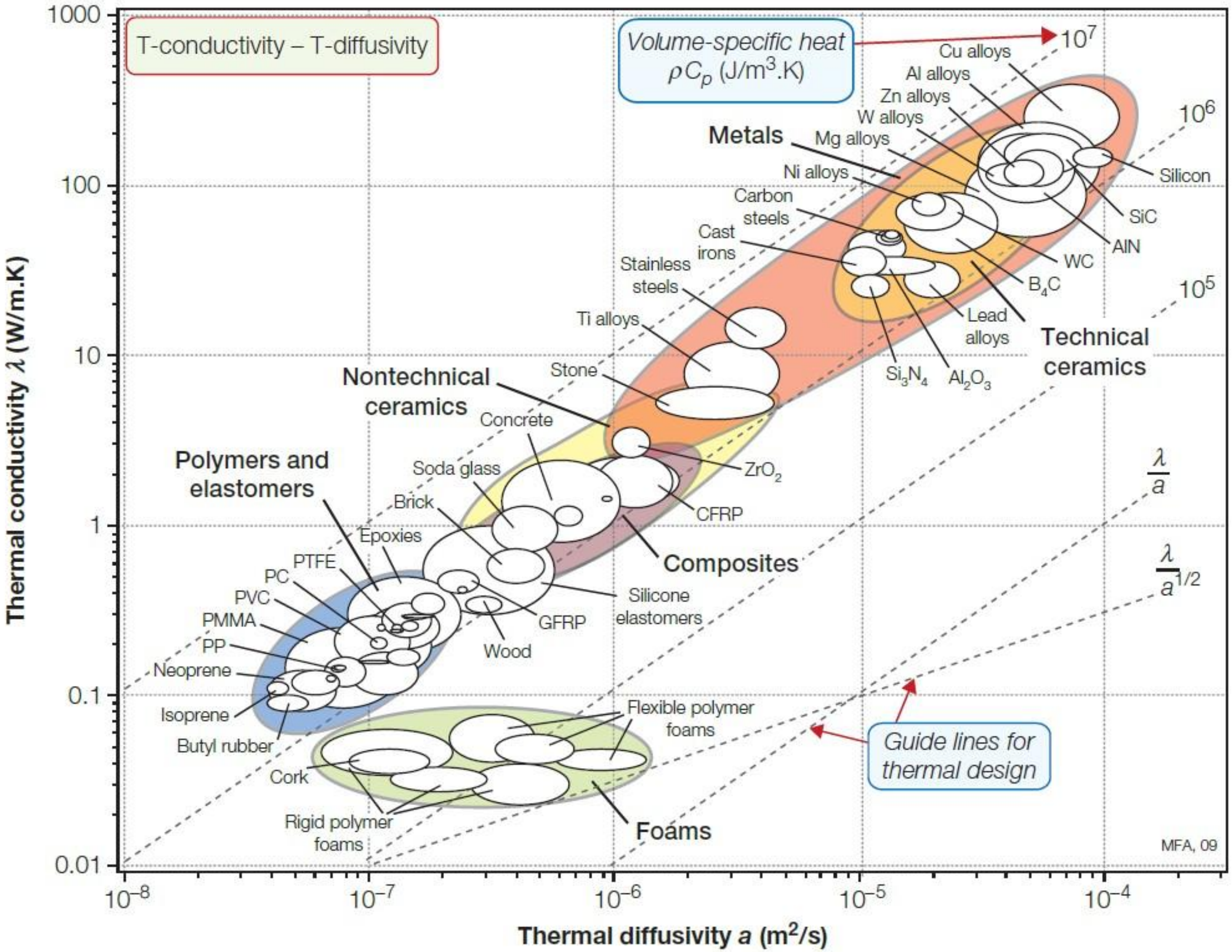
Ashby Diagrams



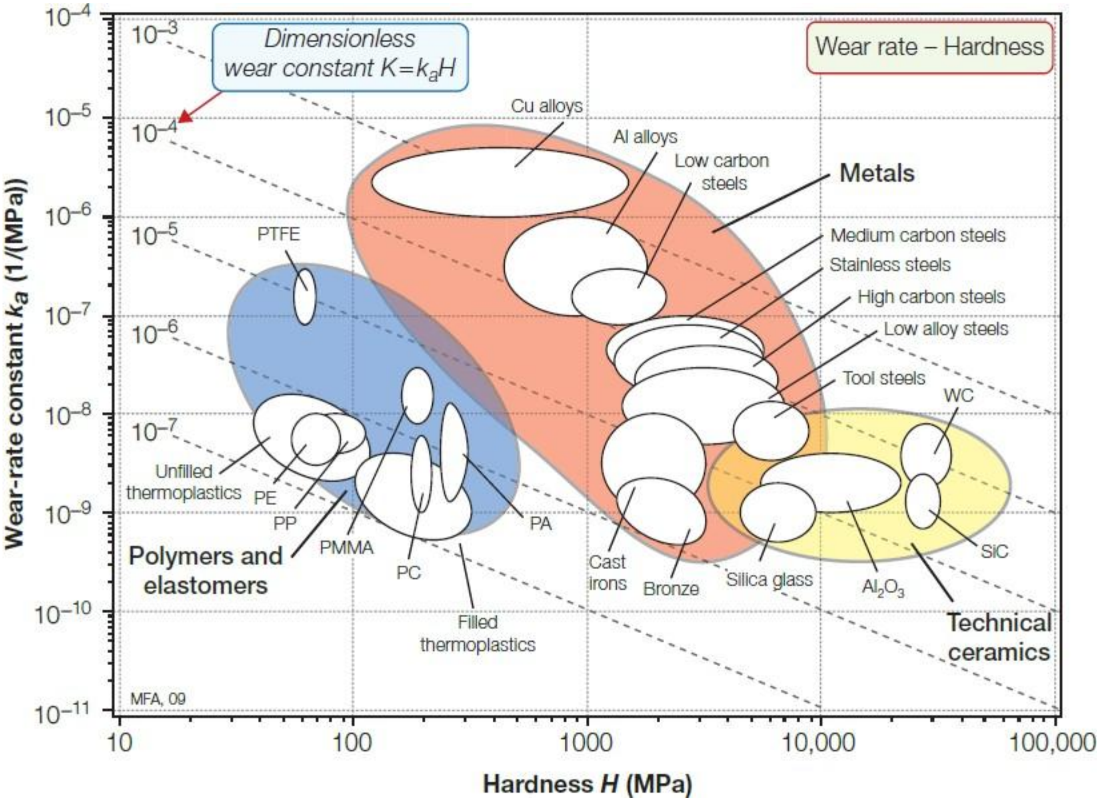
Ashby Diagrams

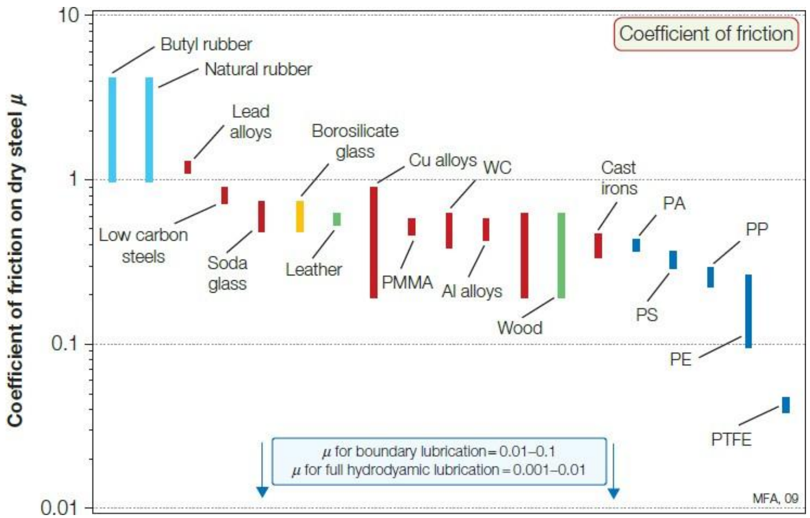


Ashby Diagrams



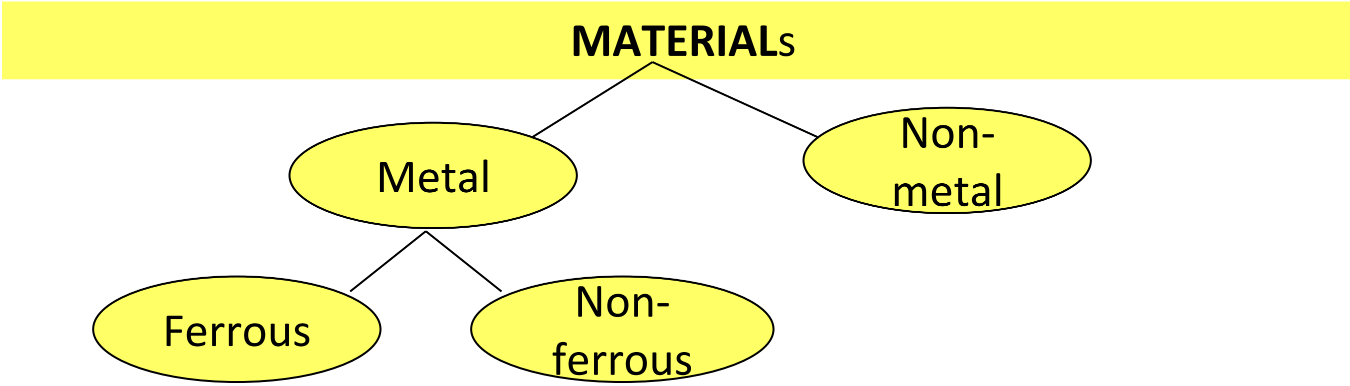
Ashby Diagrams





Properties of Material

MATERIAL SELECTION



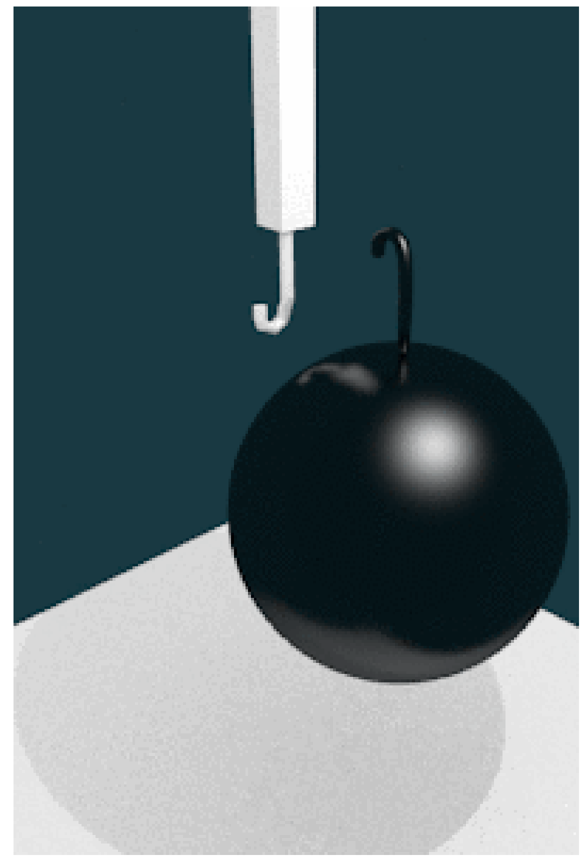
Physical properties: Density, Melting point, Elec/thermal properties

Mechanical properties:

- STRENGTH – resist externally applied loads without breaking or yielding
- STIFFNESS – resist deformation under stress
- ELASTICITY – regain original shape once the force is removed
- PLASTICITY – property which retains deformation (required for forging etc)
- DUCTILITY – ability to be drawn into a wire by a tensile force
- BRITTLENESS – sudden breaking with minimum distortion
- TOUGHNESS – resist fracture due to high impact load
- CREEP – deformation under stress and high temperature
- FATIGUE – ability to withstand cyclic stresses
- HARDNESS – resistance to wear, scratching, deformation, machinability etc

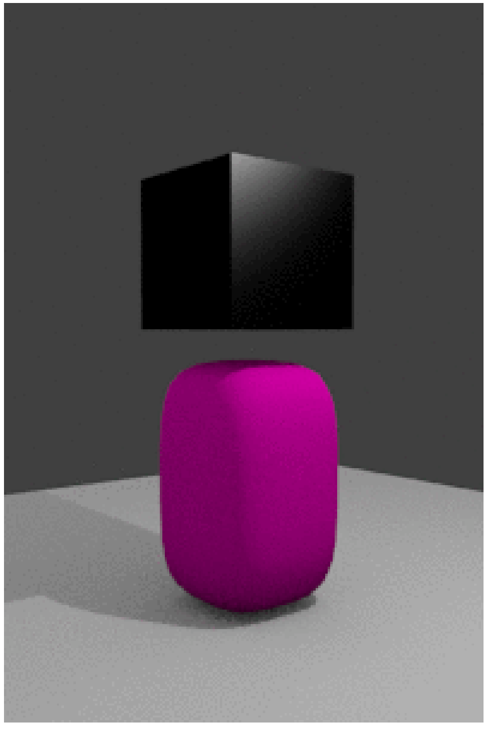
Strength

- It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called *stress.



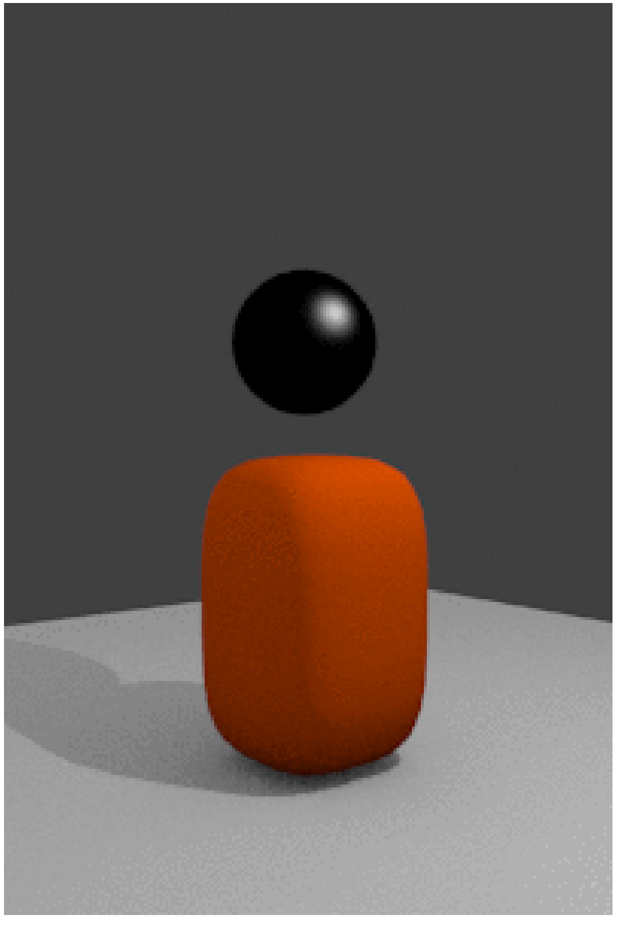
Stiffness

- It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.



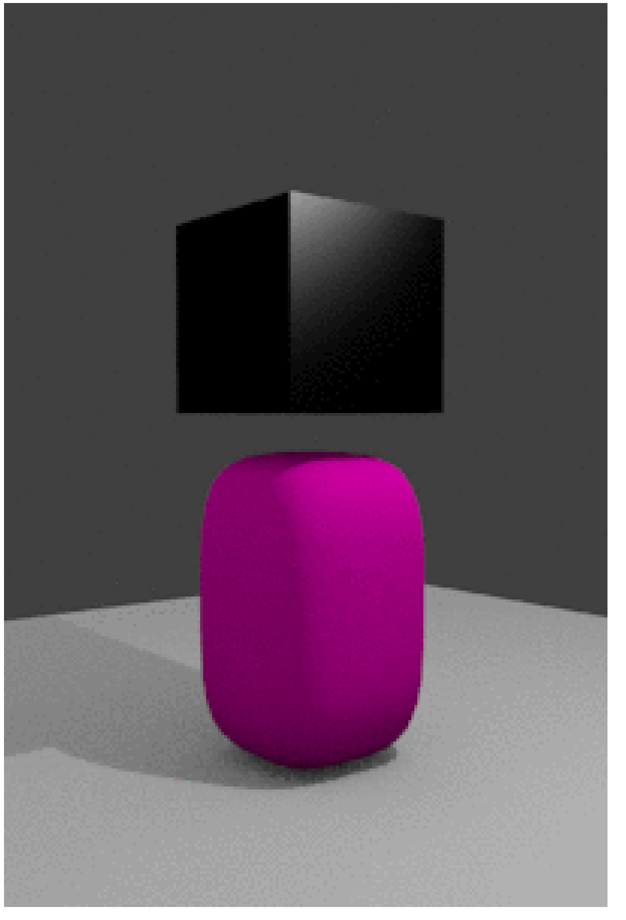
Elasticity

- It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.



Plasticity

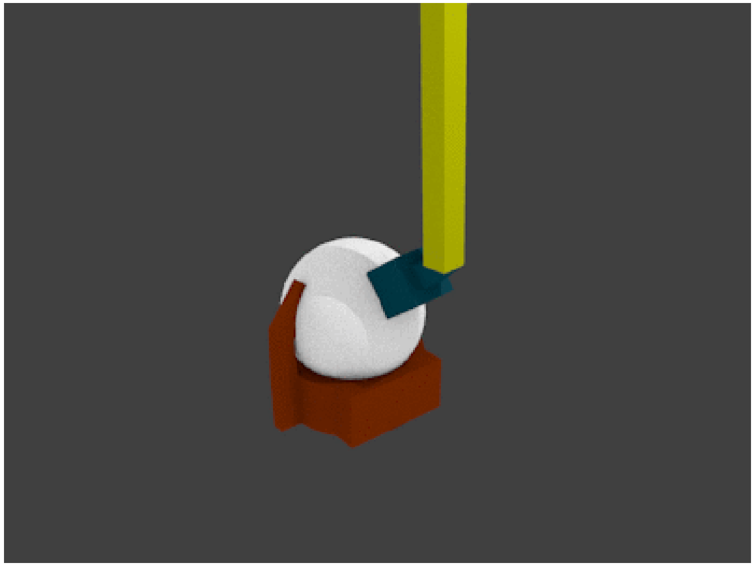
- It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.



Ductility

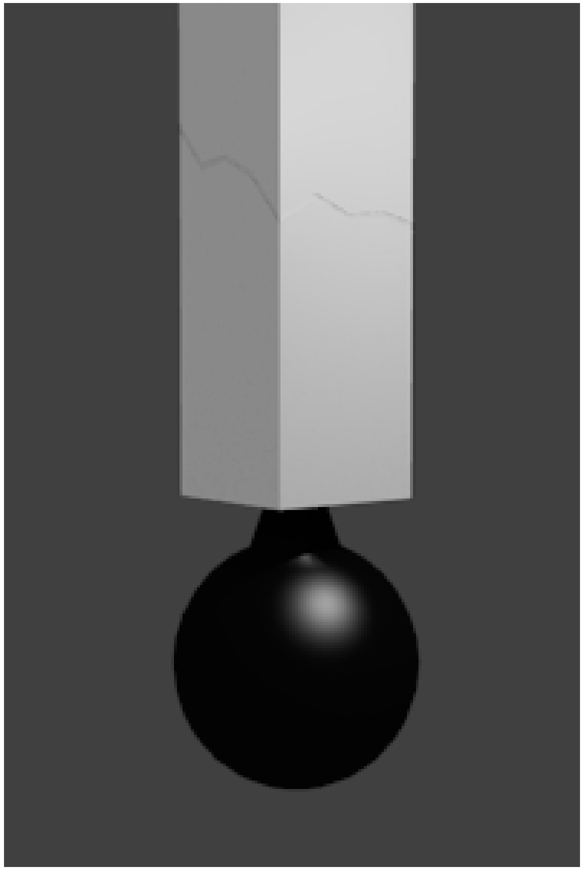
- It is the property of a material enabling it to be drawn into wire with the application of a tensile force.

  A ductile material must be both strong and plastic.



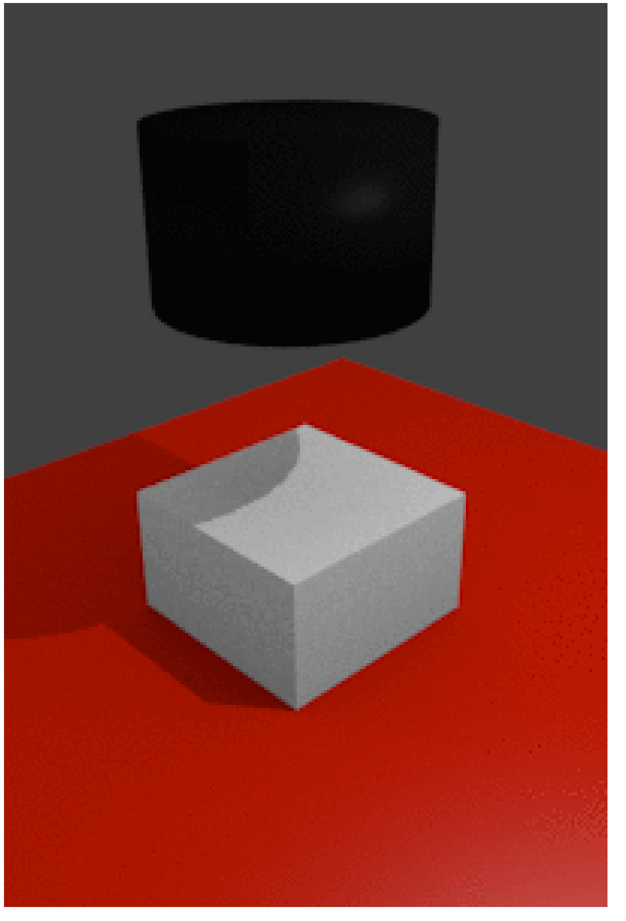
Brittleness

- It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads, snap off without giving any sensible elongation. Cast iron is a brittle material.



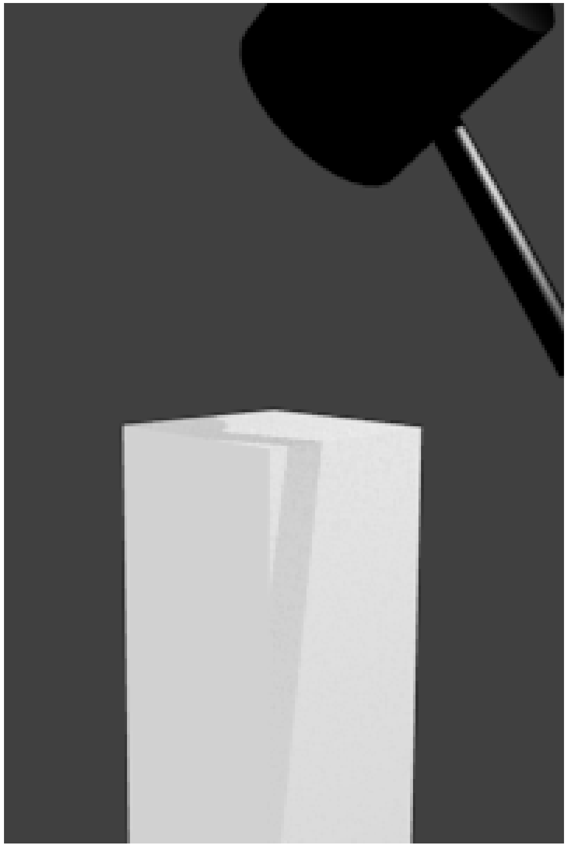
Malleability

- It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong.



Toughness

- It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated..

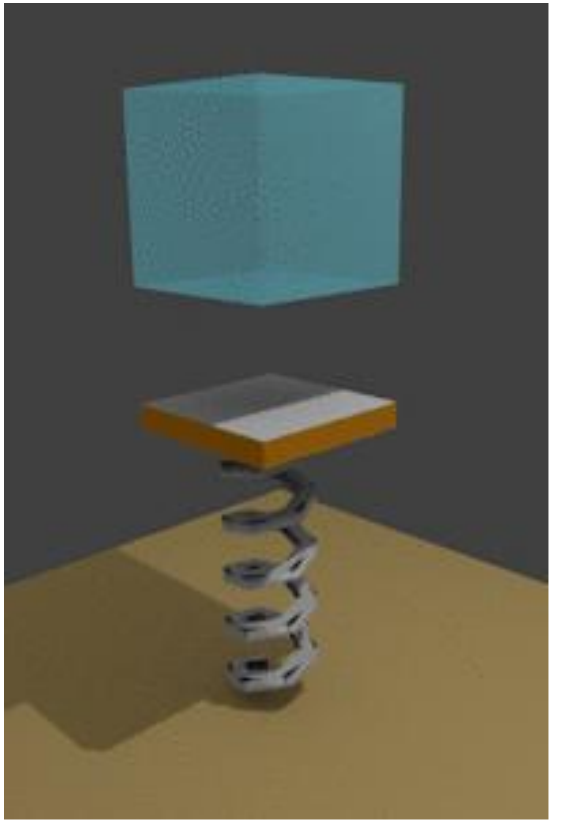


Machinability

- It is the property of a material which refers to a relative case with which a material can be cut. It may be noted that brass can be easily machined than steel.

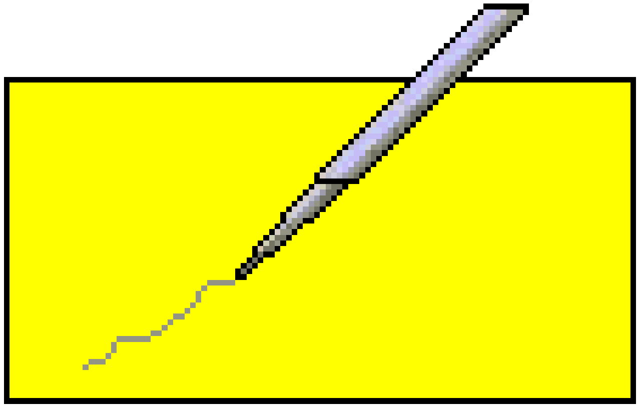
Resilience

- It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.



Hardness

- **Hardness is the ability of a material to withstand scratching or penetration.**



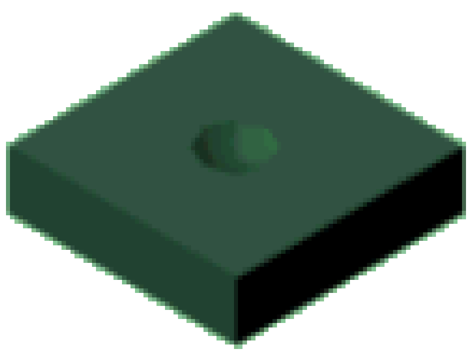
- Glass is an example of a hard material.
- If you try to scratch it with a Scriber you will find that it takes more effort on your part than scratching plastic.

Hardness

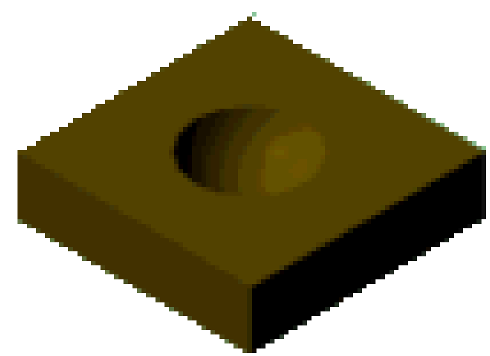
- It is a very important property of the metals and has a wide variety of meanings.
- It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc.
- It also means the ability of a metal to cut another metal.
- The hardness is usually expressed in numbers which are dependent on the method of making the test.

- This simple method is the way Engineers use to find the Hardness of different materials.
- Engineers use machines like the

  Rockwell or **Brinell** Indenter for this purpose.
- These machines press a hardened ball or point into a material using a limited force, and then measure the depth of the indentation



The harder material showing where the hardened steel ball penetrated less.

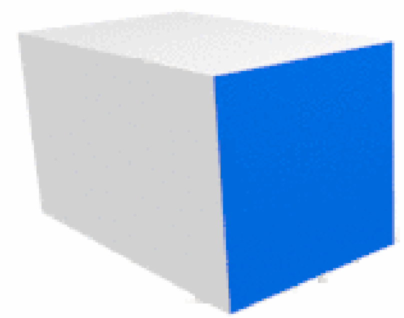


The softer material showing where the hardened steel ball penetrated more.

STRESS AND STRAIN

Direct Stress

- Stress = $\dfrac{\text{Force applied to a material}}{\text{Resisting area}}$



Tensile and compressive forces are called DIRECT FORCES
Stress is the force per unit area upon which it acts.

$$Stress = \sigma = \frac{Force}{Area} = \frac{F}{A}$$

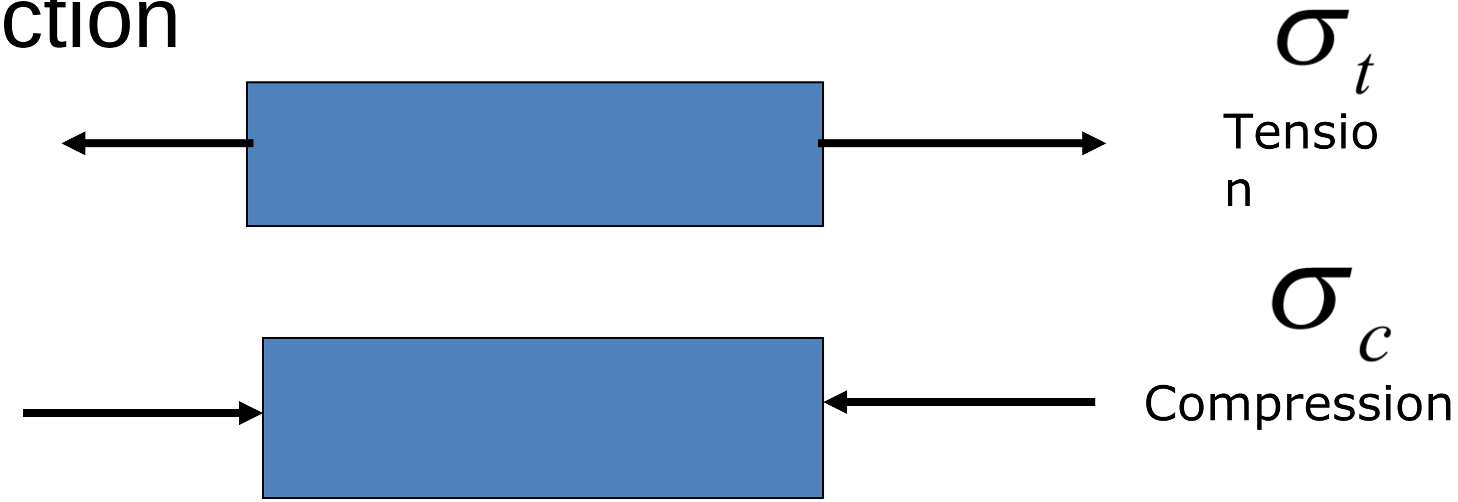
….. Unit is Pascal (Pa) or N/m^2

(Simbol – Sigma)

Note: Most of engineering fields used kPa, MPa, GPa.

Direct Stress Contd.

- Direct stress may be tensile or compressive, and result from forces acting perpendicular to the plane of the cross-section



Direct or Normal Strain

- When loads are applied to a body, some deformation will occur resulting to a change in dimension.
- Consider a bar, subjected to axial tensile loading force, F. If the bar extension is dl and its original length (before loading) is L, then tensile strain is:

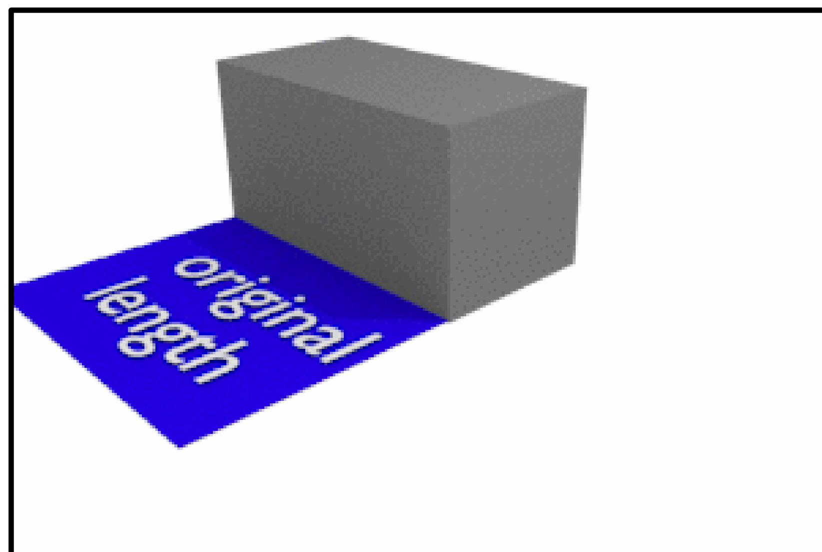
DIRECT STRAIN , ε

In each case, a force F produces a deformation x. In engineering, we usually change this force into stress and the deformation into strain and we define these as follows:
Strain is the deformation per unit of the original length.

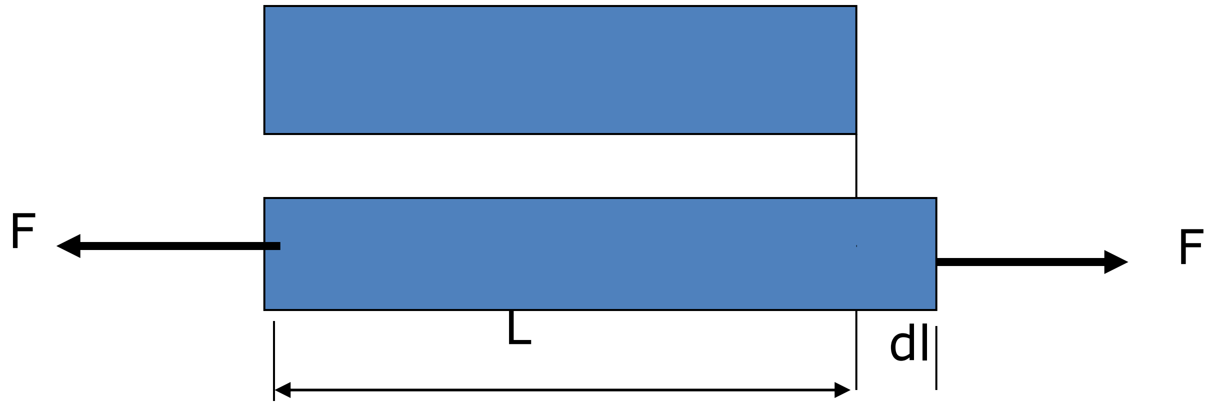
$$Strain = \varepsilon = \frac{dl}{L}$$

The symbol ε called EPSILON

- Strain $= \dfrac{\text{change in length}}{\text{Original length}}$



Direct or Normal Strain Contd.



- **Direct Strain (ε) = $\dfrac{\text{Change in Length}}{\text{Original Length}}$**

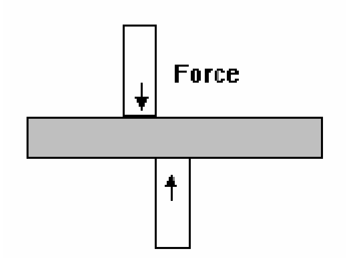
i.e. ε = dl/L

Shear Stress and Shear Strain

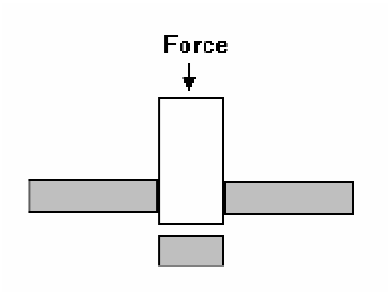
- Shear stresses are produced by equal and opposite parallel forces not in line.
- The forces tend to make one part of the material slide over the other part.
- Shear stress is tangential to the area over which it acts.

Shear Stress and Shear Strain τ

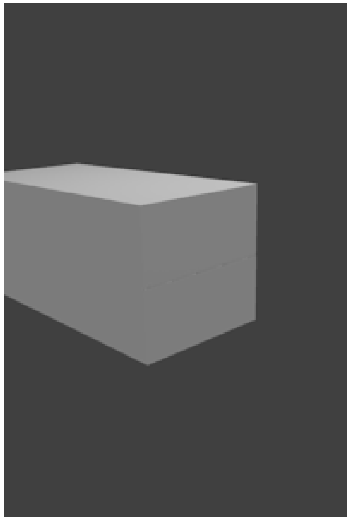
• Shear force is a force applied sideways on the material (transversely loaded).

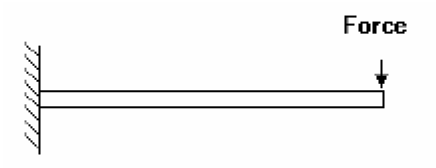


When a pair of shears cut a material



When a material is punched

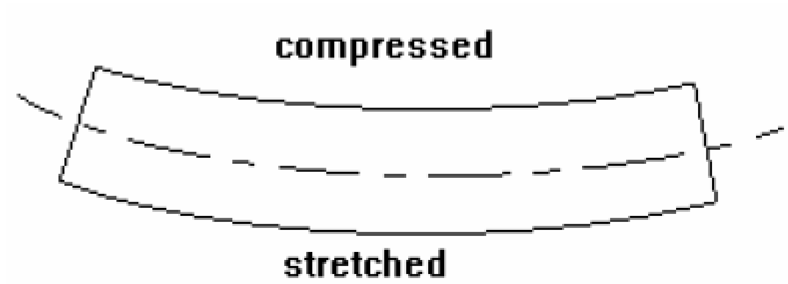




When a beam has a transverse load

SIMPLE BENDING THEORY

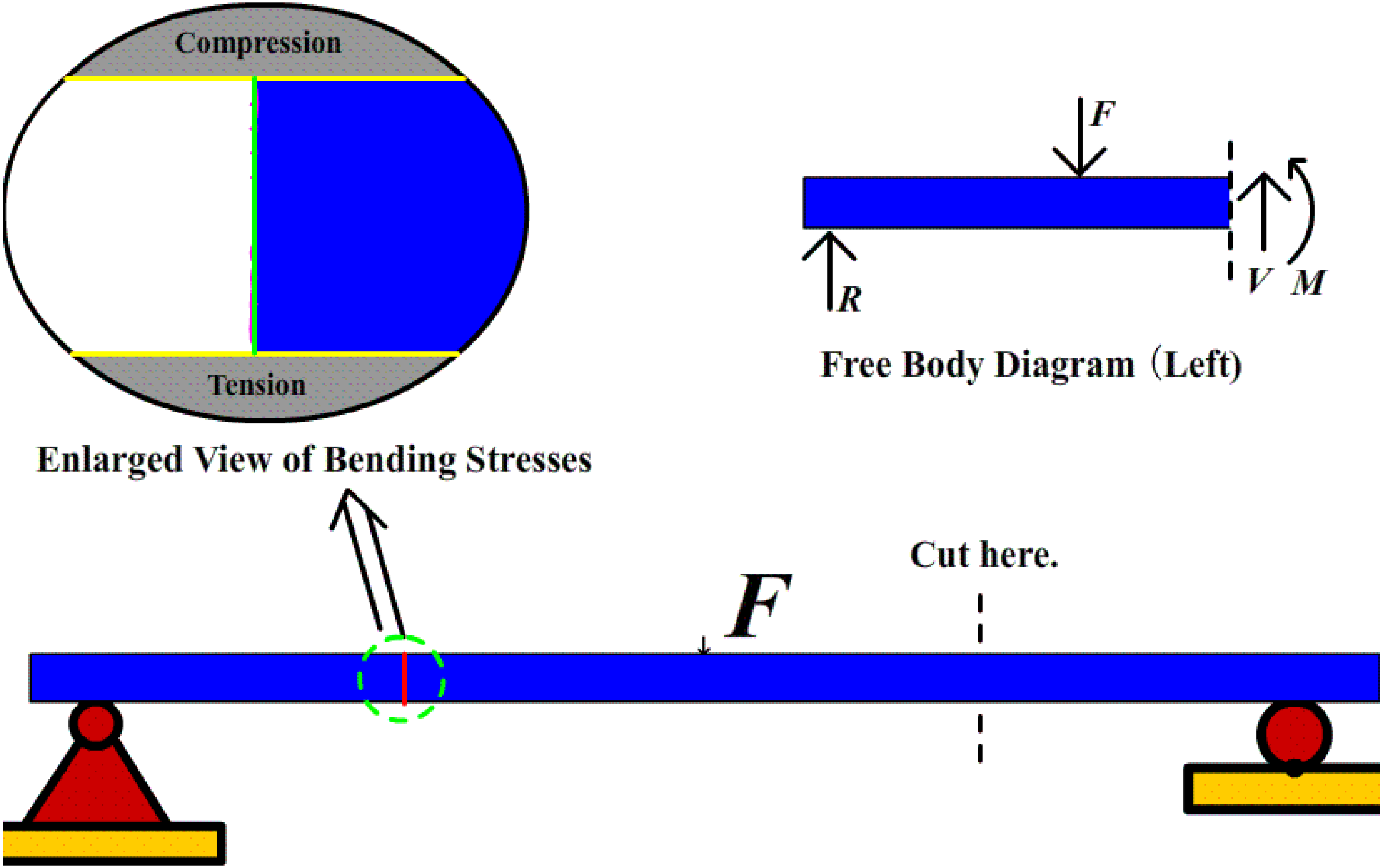
When a beam bends, one side is stretched and goes into tension and the other side is compressed. It follows that there is a layer (called the neutral layer) somewhere in the middle that is neither stretched nor compressed. It is always the tension that causes the material to fail and if the beam is made of something brittle like concrete, it will break very easily.



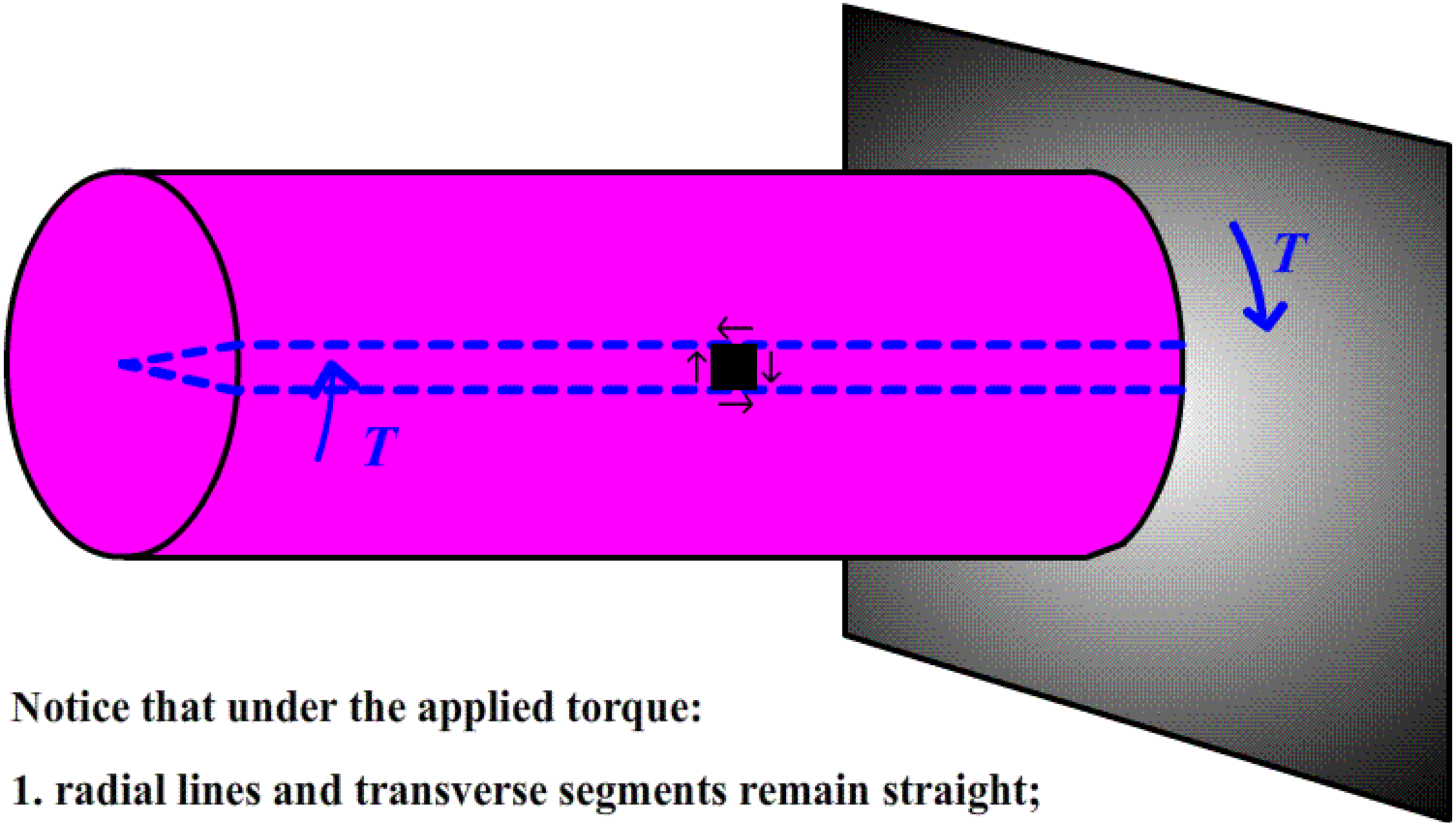
You need to study the relationship between the stress and the things that affect it. The three part formula shown next (the bending formula) expresses this and we need to study this closely.

$$\boxed{\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}}$$

Transverse Bending of a Simply Supported Beam



Torsional Deformation of a Circular Shaft



Notice that under the applied torque:

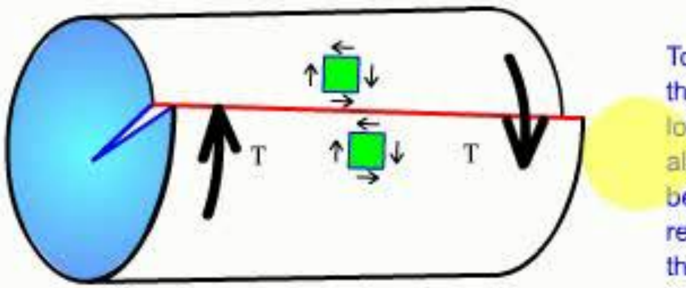
1. radial lines and transverse segments remain straight;

2. longitudinal lines remain straight, but spiral; and

3. the rectangular element deforms to a rhombus.

Torsional Deformation with a Cut

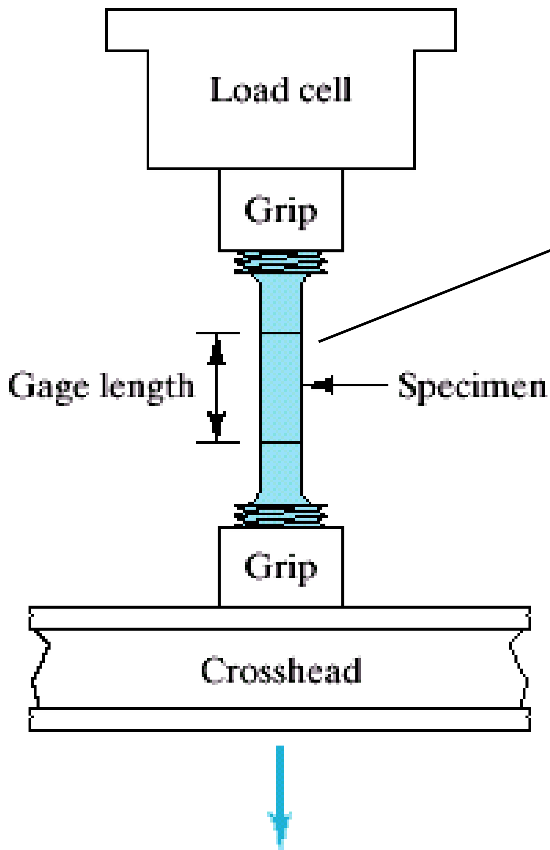
Torsional Deformation of a Circular shaft with a cut.

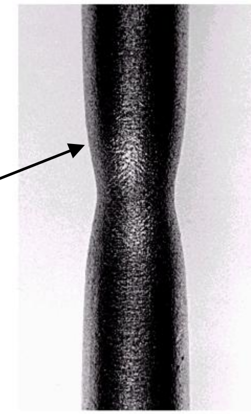


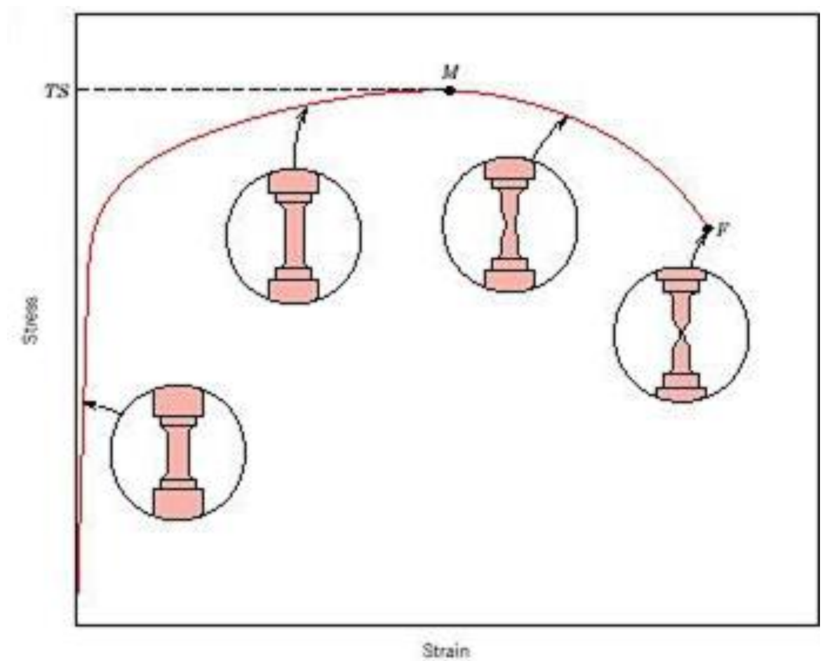
Torsion causes the tube to slip longitudinally along the interface because it cannot resist shear along the cut.

When the shaft is subjected to a torque:
Radially, the cut dislocates to form a screw,
Longitudinally, the cut slips,
The **rectangular element** has reduced deformation.

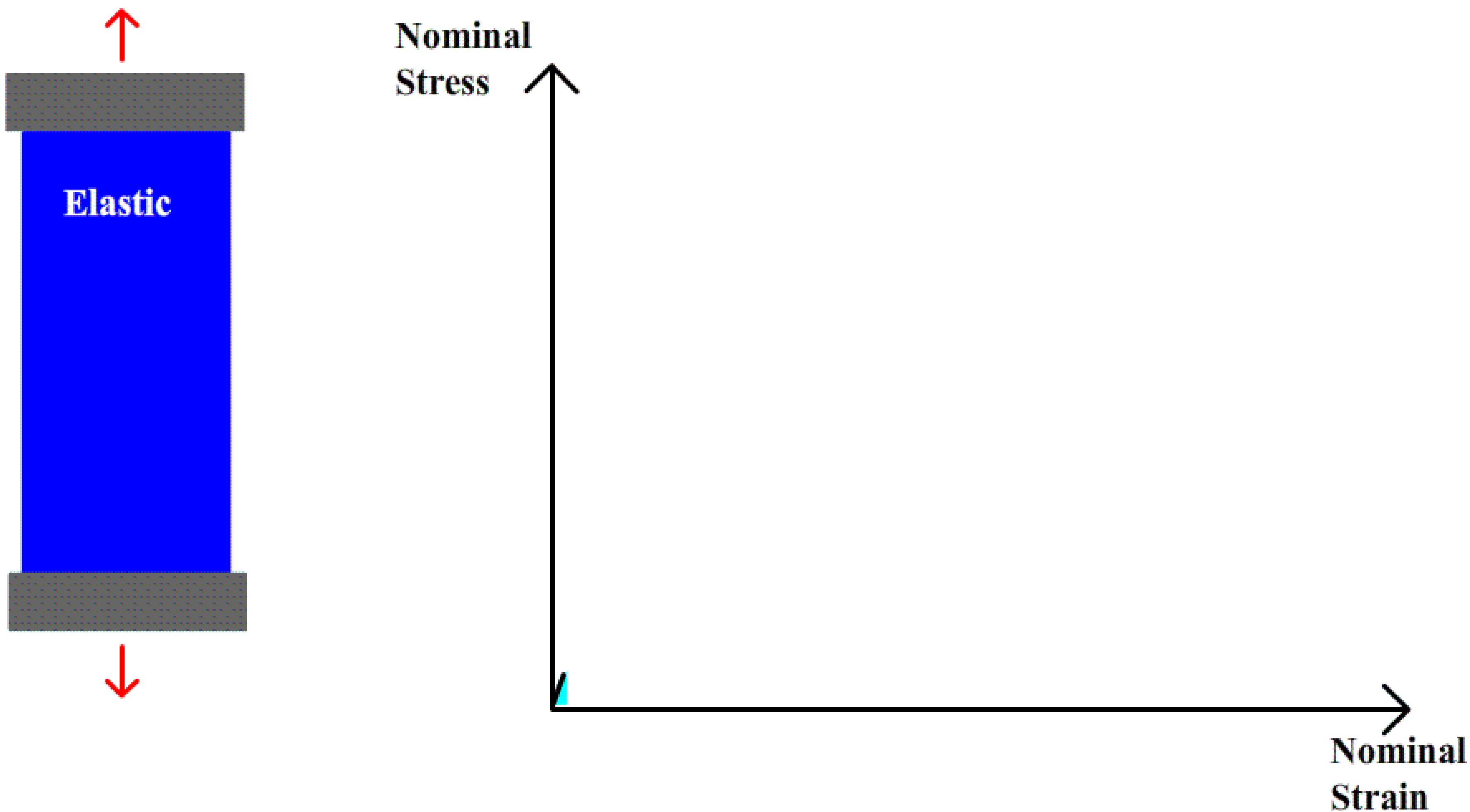
- **Stress and Strain**
    - **Tension**
    - **Compression**
    - **Shear**
    - **Torsion**
- **Elastic deformation**
- **Plastic Deformation**
    - **Yield Strength**
    - **Tensile Strength**
    - **Ductility**
    - **Toughness**
    - **Hardness**

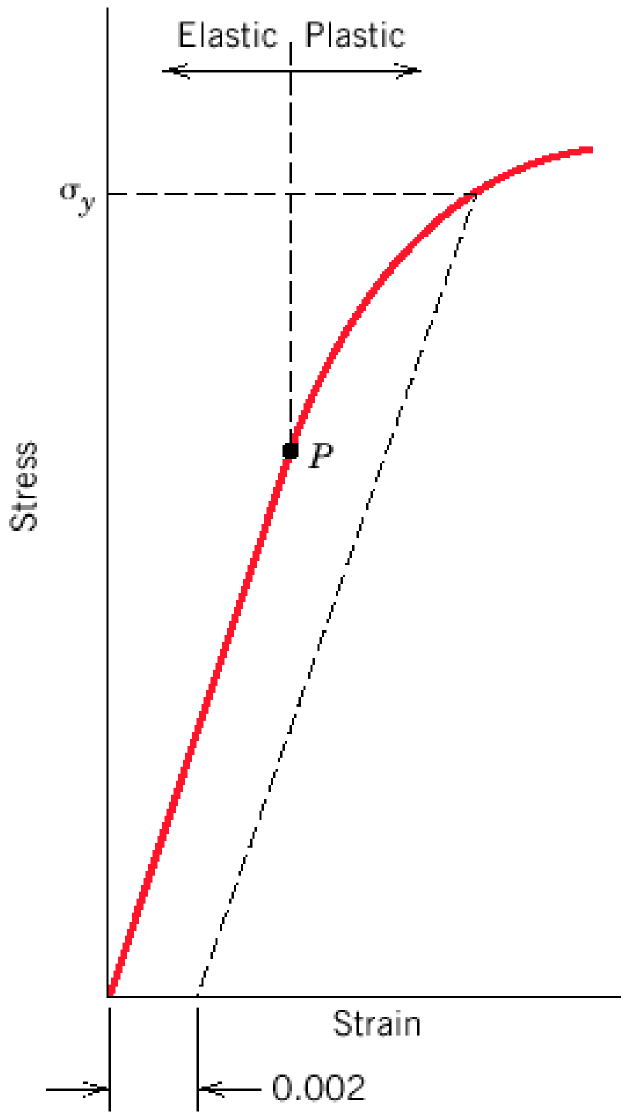

Load cell
Grip
Gage length
Specimen
Grip
Crosshead




TS
M
F
Stress
Strain

Stress-Strain Diagram for a Typical Ductile Material
(Not to Scale)





Yield point: P

Where strain deviates from being proportional to stress

(the proportional limit)

Yield strength: σ_y

Permanent strain= 0.002

A measure of resistance to plastic deformation

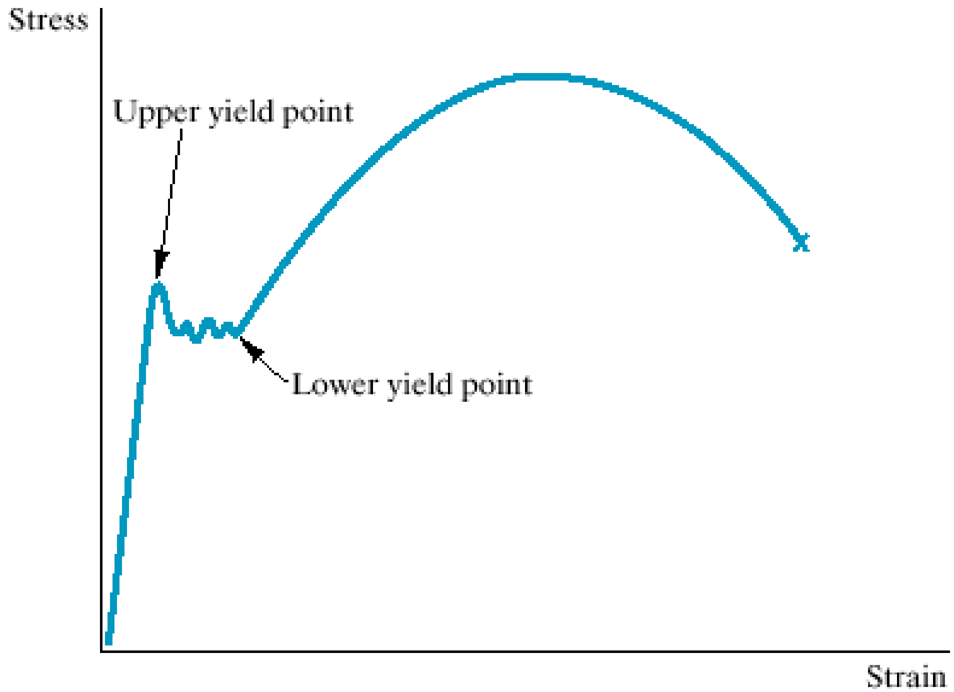
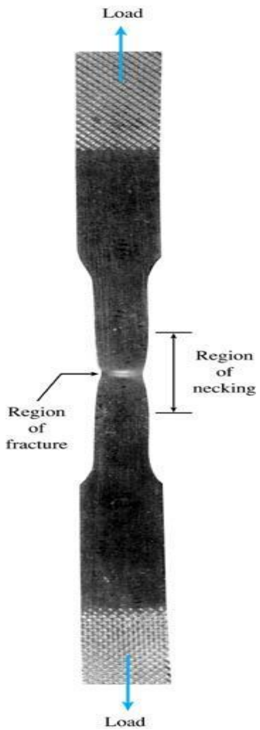


Figure 6-10 *For a low-carbon steel, the stress-versus-strain curve includes both an upper and lower yield point.*

For a low-carbon steel, the stress vs. strain curve includes both an upper and lower yield point.
The yield strength is defined in this case as the average stress at the lower yield point.



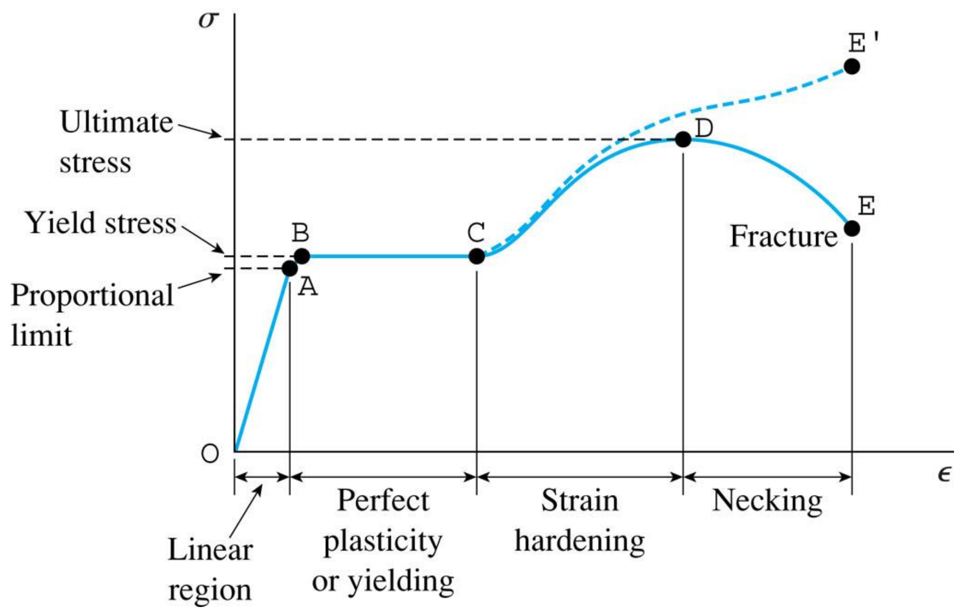


FIG. Stress-strain diagram for a typical structural steel in tension (not to scale)

OA: Initial region which is linear and proportional

Slope of OA is called modulus of elasticity

BC: Considerable elongation occurs with no noticeable increase in stress (yielding)

CD: Strain hardening – changes in crystalline structure (increased resistance to further deformation)

DE: Further stretching leads to reduction in the applied load and fracture

OABCE': True stress-strain curve

Elasticity and Hooke's Law

- All solid materials deform when they are stressed, and as stress is increased, deformation also increases.
- If a material returns to its original size and shape on removal of load causing deformation, it is said to be elastic.
- If the stress is steadily increased, a point is reached when, after the removal of load, not all the induced strain is removed.
- This is called the elastic limit.

Hooke's Law

- States that providing the limit of proportionality of a material is not exceeded, the stress is directly proportional to the strain produced.
- If a graph of stress and strain is plotted as load is gradually applied, the first portion of the graph will be a straight line.
- The slope of this line is the constant of proportionality called modulus of Elasticity, E or Young's Modulus.
- It is a measure of the stiffness of a material.

PHYSICAL PROPERTIES OF METALS

Material	Specific Weight N/cc γ	Melting Point °C	Modulus of Elasticity E, N/mm²	Modulus of Rigidity G, N/mm²	Thermal Conductivity k, cal/s cm°C	Coefficient of Linear Expansion α μm/m°C	Poisson's Ratio ν
Aluminium	0.027	660	0.675×10^5	0.260×10^5	0.530	23.8	0.34
Beryllium	0.0182	1280	2.928×10^5		0.380	12.3	
Brass	0.0845	900—950	0.970×10^5	0.350×10^5	0.310	16.7	0.30—0.40
Bronze	0.0873	910—1040	1.110×10^5		0.160	17.3	
Cast Iron	0.072	1150—1300	1.000×10^5	0.350×10^5	0.130	9.0	0.23
Copper	0.0896	1083	1.230×10^5	0.390×10^5	0.940	16.2	0.26
Lead	0.1134	327	0.160×10^5	0.076×10^5	0.083	28.3	0.45
Monel Metal	0.0858	1315—1350	1.590×10^5	0.670×10^5	0.060	14.0	0.32
Steel C 15	0.0785	1510	2.080×10^5	0.790×10^5	0.120	11.1	
Steel C 35	0.0784	1490	2.060×10^5	to	0.120	11.1	0.30
Steel C 60	0.0783	1470	2.040×10^5	0.890×10^5	0.110	11.1	
Titanium	0.0454	1800	1.050×10^5		0.041	11.8	
Tungsten	0.1930	3410	4.153×10^5	1.770×10^5	0.480	4.5	0.17
Zirconium	0.0650	≃1850	0.697×10^5		0.040	10.0	

Non Mechanical Properties

THERMAL CONDUCTIVITY

Thermal conductivity is the material´s capacity to transmit heat.

Metals transmit heat easily through them, so they are good conductors of heat.
They are called **thermal conductors.**

The cooking pot is made of metal, so the heat of the fire is transmited to the food in order to be cooked.

The handles are made of plastic, so we can hang the cooking pot without burn us.

Wood, plastics or ceramic materials practically prevent heat from passing through them.
They are called **thermal insulators.**

Non Mechanical Properties

ELECTRICAL CONDUCTIVITY

Electrical conductivity is the material´s capacity to allow an electrical current to pass through them.

Metals are good conductors of electricity.
They are called **electrical conductors.**

The handle is made of plastic, so in case of a electrical shock, it doesn´t keep the worker

The tool is made of metal because it´s resistant enough

Wood, plastics or ceramic materials aren´t good conductors of electricity.
They are called **electrical insulators** or **insulators.**

Non Mechanical Properties

ACOUSTIC CONDUCTIVITY

Acoustic conductivity is the capacity of materials to transmit sounds.

Metals are good conductors of sound.
They are called **acoustic conductors.**

The bronze (a metal), is an acoustic conductor.

Cotton fibers or polyurethane are acoustic insulators.

Glass, fiber, plastics, aren´t good conductors of sound.
They are called **acoustic insulators.**

Non Mechanical Properties

ECOLOGICAL PROPERTIES

RECICLABILITY

Recyclable materials can be reused.

They help conserve natural resources and avoid the accumulation of waste products.

Glass, paper, cardboard, metal, plastics…

TOXICITY

Toxic materials are harmful to the environment

They can be poisonous for living as they contamine the soil, the water and the atmosphere.

Mercury, heavy metals, petroleum…

BIODEGRADABILITY

Biodegradable materials are those that descompose naturally and don´t cause damage to the environment.

Paper, water-soluble plastics…

Failure

- Failure happens when a design is no longer able to satisfy any of functional requirements. Failures not only cause costly damage, but may lead to loss of many lives as in airplane crashes.

  A conceptual understanding of failure is necessary to utilize the material properties safely and economically.

- In most design problems, primary concern should be reducing the possibility of a premature failure in service.

  The service life can be in seconds (in case of space applications) or many years (in case of bridges).

Failure

- Possible failure types during service are **excessive deformation**, **fracture**, **inordinate wear** and **deterioration**.

  - In practice, it is impossible to predict failure mode of a part under <u>severe service conditions</u>.

  - Some failures happen soon after the element is in service, which are covered by **a factor of safety**.

- Time dependent failures are difficult or even impossible to avoid by applying factor of safety.

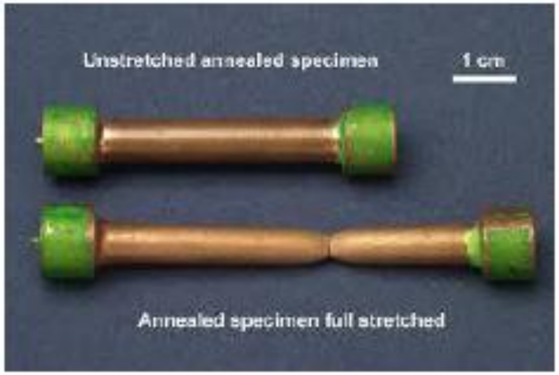
  - In such cases, parts are withdrawn from service and tested for reliability. Such specific data are not found in general reference books.

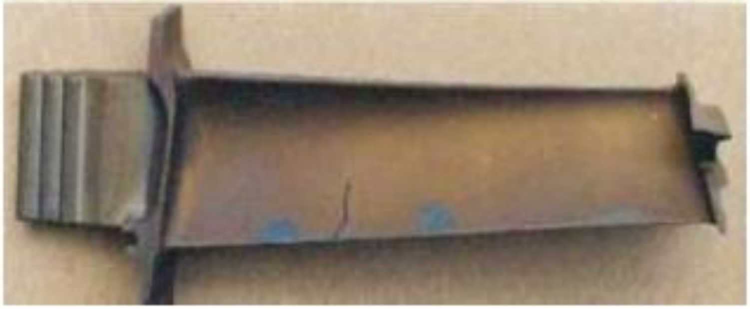
Failure : Excessive Deformation

- Gross scale **yielding** and **buckling** are types of this failure. However, small elastic deformation of an element in a precision machine may cause problem while plastic deformation of an element in a building may be feasible.

- Excessive deformation may also be responsible for the critical vibration of a part under dynamic load, which does not only disturbs the function but also leads to the complete destruction of part.

- In addition, failures by excessive deformation can be immediate or time-dependent (also called **creep** which is significant in high-temp. applications).

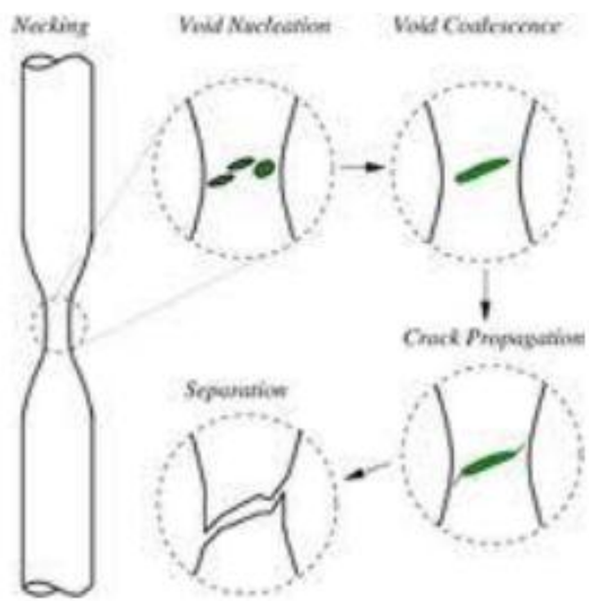




Failure: Fracture

- When analysing the fracture failure modes, the preceding deformation is of importance. If failure occurs following a large deformation, such fractures are called **ductile fracture** (which is not common in engineering applications). In contrast, a fracture with no or very little prior deformation is **brittle fracture**.

- Many materials fail by fracture in three ways: **sudden brittle fracture**, **fatigue (progressive) fracture** and **time dependent (creep) fracture**.



Failure: Fracture

- Brittle fracture is not only experienced by brittle materials. Higher rate or sudden application of load and presence of a complex stress may cause **ductile to brittle transition (embrittlement)** of a material.

- Fatigue failure (the most common failure in applications) is a highly localized microscopic phenomenon. It occurs in parts that are subjected to repeated stresses even if they are below the yield point of material.

- **Creep failure (stress rupture)** occurs when a material is loaded at higher temperatures for a long time. In polymeric materials, it can occur even at normal temperatures and under relatively low stresses.

Failure: Wear

- Wear is result of the action of abrasive or other forces on the surface of a machine part. It is manifested by a loss of surface material (either in regular or irregular form) which causes change in the part dimensions.

- Wear is a complex subject due to many variables involved in the process where lubrication, condition of surface and type of material with which part is in contact are the most effective factors.

- There is no a quantitative test or criterion of wear. Thus, design evaluations are based on past experience more than anything else.

Classification of Materials

Classification of Materials

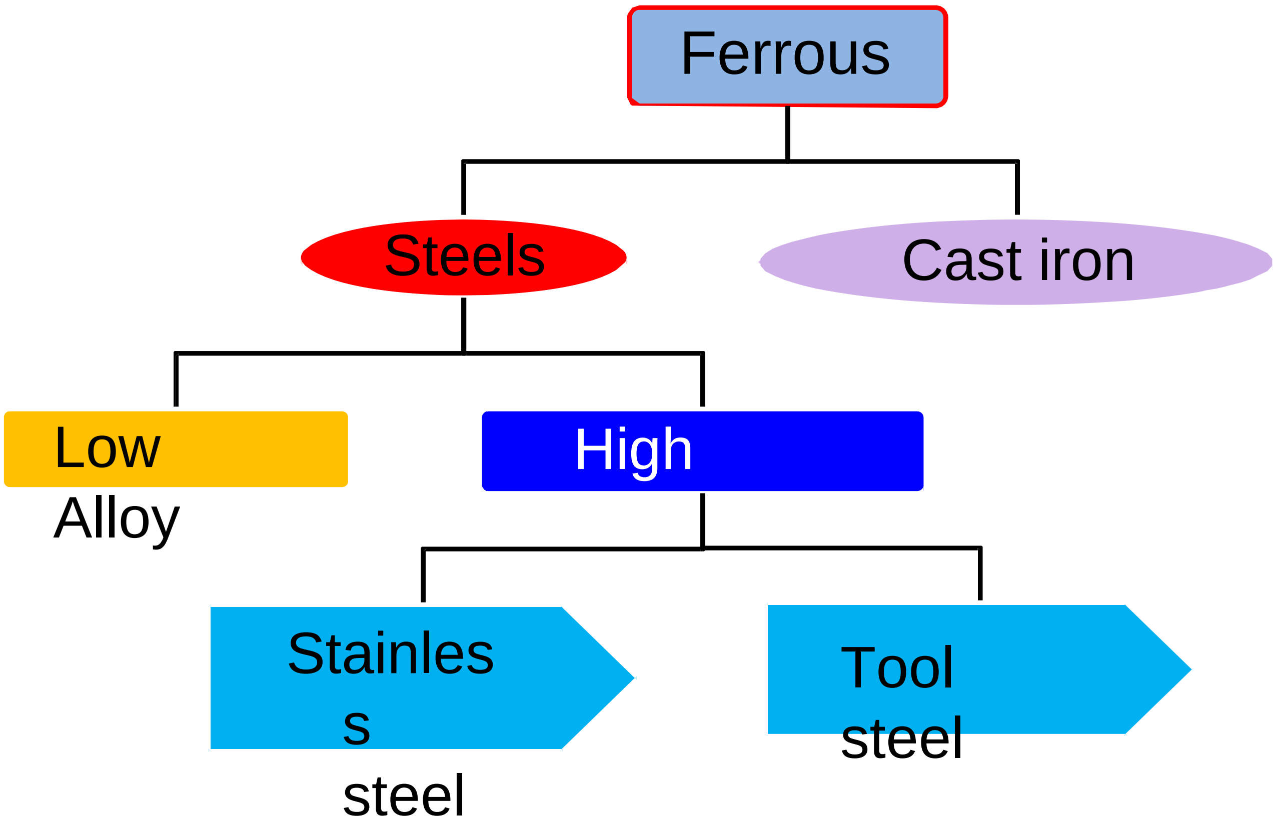
- Materials
  - Metals
  - Polymers
  - Ceramics
  - Composite Materials

Metals

Metals

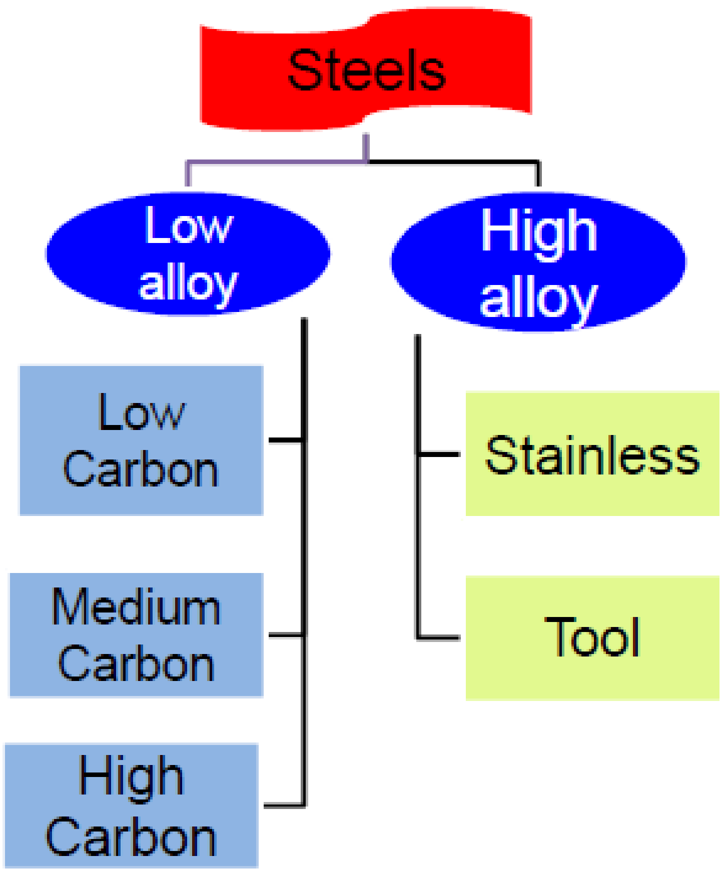
- Ferrous
  - Steel and Cast Irons
- Non-Ferrous
  - Al, Cu, Mg etc.

Ferrous Materials



Ferrous Materials - Steels

- Steels - alloys of iron-carbon. May contain other alloying elements.
- Several grades are available.
- Low Alloy (<10 wt%)
  - –Low Carbon (<0.25 wt% C)
  - –Medium Carbon (0.25 to 0.60 wt%)
  - –High Carbon (0.6 to 1.4 wt%)
- High Alloy
  - –Stainless Steel (> 11 wt% Cr)
  - –Tool Steel



General properties

- High electrical conductivity.
- High thermal conductivity.
- Ductile and relatively high stiffness.
- Toughness and strength.
- They are ready to machining, casting, forming, stamping and welding.
- Nevertheless, they are susceptible to corrosion

Carbon steels

- Effects of carbon in the **carbon steel**,
  - increased hardness
  - increased strength
  - decreased weldability
  - decreased ductility
  - Machinability - **about 0.2 to 0.25% C provides the best machinability**

LOW CARBON STEEL

Properties of Low carbon steel

- Carbon contain less than 0.25 wt%
- Microstructures consist of ferrite (α-Fe) and pearlite
- Machinable ,weldable and heat treatable

Typical applications

- Body panels for vehicles
- Low strength wire products
- Sheets that are used in pipelines, buildings and bridges

MEDIUM CARBON STEEL

Properties of Medium carbon steel

- Carbon contents between 0.25 and 0.6 wt%
- Cr, Ni, Mo improve the heat treating capacity
- Heat treatment reduce ductility and toughness

Typical applications

- Rails, Railway wheels, Rail axles
- Gears, Shafts, Crankshafts, Couplings
- Forgings, Castings

HIGH CARBON STEEL

Properties of High carbon steel

- ❖ Carbon contents between 0.60 and 1.40 wt%
- ❖ Hardest , strongest and yet least ductile carbon steel
- ❖ Especially wear resistant and capable of holding a sharp cutting edge

Typical applications

- ❖ Cutting tools
- ❖ Drills, Lathe tools, Reamers
- ❖ Dies, anvil faces

- ## Alloy steels:

  - Steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the follower limits

    Mn 1.65 %   Si 0.60% Cu 0.60%

  - In which a definite rang or a definite maximum quantity of any of the following elements is specified or required within the recognized field of constructional alloy steels. Al, B, Cr, Up to 3.99% Co, Mo, Ni, Ti, W, V or any other alloying elements aided to obtain a desired alloying effect.
  - Given below is the composition of a typical alloy steel.

    C 0.2 – 0.4%   Mn 0.5 – 1.0%

    Si 0.3 – 0.6%   Ni 0.4 – 0.7%

    Cr 0.4 – 0.6%   Mo 0.15 – 0.3%

    Fe Balance

  - Alloying elements after the properties of steel and put in to a slightly different class from carbon steel.

- # Advantage Disadvantage of alloy steel:
  - The important advantages and disadvantages in the choice of alloy steel from the general point of view in relation to plain carbon steel are listed in the following.

Advantage:

- Greater hardenability.
- Less distortion and cracking
- Greater stress relief at given hardness
- Less grain growth
- Higher elastic ration and endurance strength
- Greater high temperature strength
- Batter machinability at high hardness
- Greater ductility at high strength.

Disadvantage:

- That may be encountered:
- Cost
- Special handling
- Tendency toward austenite retention
- Temper brittleness in certain grades.

- **Purpose of alloying:**
- The purpose of alloying steels are:
  - Strengthening of the ferrite.
  - Improved corrosion resistance.
  - Better hardenability
  - Grain size control
  - Greater strength
  - Improved machine ability
  - Improved high or low temperature stability
  - Improved ductility
  - Improved toughness
  - Better wear resistance.

• Effect of alloying elements:

- **Carbon:**
  - Carbon content is steel affects:
  - Hardness
  - Tensile strength
  - Machine ability
  - Melting point

- **Nickel:**
  - Increases toughness and resistance to impact
  - Lessens distortion in quenching
  - Lowers the critical temperature of steel and widens the range of successful
    heat treat indent
  - Strengthens steels.
  - Renders high – chromium iron alloy austenitic.
  - Does not unite with carbon.

- **Chromium:**
  - Joint with carbon to form chromium carbide, thus adds to depth harden ability
    with improved resistance to abrasion and wear.

- **Silicon:**
  - Improves oxidation resistance
  - Strengthens low alloy steels
  - Acts as a deoxidizes.

- **Titanium:**
  - Prevents localized depletion of chromium in stainless steels during long heating.
  - Prevent formation of austenite in high chromium steels.
  - Reduces martens tic hardness and harden ability in medium chromium steels.

- **Molybdenum:**
  - Promotes harden ability of steels
  - Makes steel fine grained.

- Counteracts tendency towards temper brittleness
- Raises tensile and creep strength at high temperatures.
- Enhances corrosion resistance in stainless steel
- Forms abrasion resisting particles.

- **Vanadium:**
  - Promotes fine grains in steel
  - Increases hardenability
  - Imparts strength and toughness to heat-treated steel\
  - It is a powerful carbide former
  - Stabilizes cementite and improves the structure of the chill.

- **Tungsten:**
  - Increases hardness (and also red hardness)
  - Promotes fine grain
  - Resists heat
  - Promotes strength at elevated temperature.

- **Manganese:**
  - Contributes markedly to strength and hardness
  - Counteracts brittleness from sulphur.
  - Lowers both ductility and weldability if it is presents in high percentage with high carbon content in steel.

- **Copper:**
  - Increases resistance to atmospheric corrosion
  - Acts as a strengthening agent.

- **Boron:**
  - Increases hardenability or depth to which steel will harden when quenched.

- **Aluminum:**
  - Acts as a de-oxidizer
  - Produced fine austenitic grain size
  - If present in an amount of about 1% it helps promoting nitriding.

- **Cobalt:**
  - Contributes to red-hardness by hardening Ferrite.
  - Improves mechanical properties such as tensile strength, fatigue strength and hardness.
  - Refines the graphite and pearlite.
  - Is a mild stabilizer of carbides.
  - Improves heat resistance.
  - Retard the transformation of austenite and thus increase hardenability and freedom from cracking and distortion.

Effects of Alloying Elements on Steel

•Manganese – strength and hardness; decreases ductility and weldability; effects *hardenability* of steel.
•Phosphorus – increases strength and hardness and decreases ductility and notch impact toughness of steel.
•Sulfur decreases ductility and notch impact toughness Weldability decreases. Found in the form of sulfide inclusions.
•Silicon – one of the principal deoxidizers used in steel making. In low-carbon steels, silicon is generally detrimental to surface quality.
•Copper – detrimental to hot-working steels; beneficial to corrosion resistance (Cu>0.20%)
•Nickel - ferrite strengthener; increases the *hardenability* and impact strength of steels.
•Molybdenum increases the *hardenability*; enhances the creep resistance of low-alloy steels

Relative Effect On Steel

	Cr	Mn	Mo	Ni	Ti	W	V
Hardenability	++	++	++	+	++	++	+++
High temperature strength	+		++	++	+	++	++
Ductility & Toughness		+		++			
Wear resistance	+		+		+	++	+
Promote fine grain size			+		++	+	+++
Corrosion resistance	++		+	+			

Stainless steel

•Stainless steels - A group of steels that contain at least 11% Cr. Exhibits extraordinary corrosion resistance due to formation of a very thin layer of Cr_2O_3 on the surface.

❑ Categories of stainless steels:

- Ferritic Stainless Steels – Composed of α ferrite (BCC)
- Martensitic Stainless Steels – Can be heat treated.
- Austenitic Stainless Steels – Austenite (γ) phase field is extended to room temperature. Most corrosion resistant.
- Precipitation-Hardening (PH) Stainless Steels – Ultra high-strength due to precipitation hardening.
- Duplex Stainless Steels – Ferrite + Austenite

Composition and Properties of some stainless steels are given in the next slide

Stainless Steel and its uses

Back

The pinnacle of New York's Chrysler Building is clad with stainless steel

Cutlery

Stainless Steel is a mixture of Steel, and Chromium

Advantages:

Does not rust

Disadvantages:

More difficult to Join tan ordinary Mild Steel

Surgical Instruments

Cast Irons

- Carbon 2.1- 4.5 wt% and Si (normally 1-3 wt%).
- Lower melting point (about 300 °C lower than pure iron) due to presence of eutectic point at 1153 °C and 4.2 wt% C.
- Low shrinkage and good fluidity and casting ability.
- Types of cast iron: grey, white, nodular, malleable and compacted graphite.

Applications of Cast Iron

- Cast iron is used in a wide variety of structural and decorative applications, because it is relatively , **inexpensive, durable & easily cast** into a variety of shapes.
- Construction of machines and structures **(High Tensile Strength)**
- As Columns , balusters & Arches **(High Compressive Strength)**
- Machine and car parts like
- Cylinder heads blocks
- gearbox cases
- cookware
- pipes etc.

Swing Machine

Arches in bridge

Columns

Applications of Cast Iron

- Stoves and fire backs , Vehicles engine(**High thermal conductivity and specific heat capacity)**
- for Decorative purposes: **(Good fluidity)**

Design made on column

Gate design

Stoves

Applications of Cast iron

- Cast irons are used in wide variety of application owing to the properties like good fluidity, ease of casting, low shrinkage, excellent machinability, wear resistance and damping capacity.
- Applications –
  - Car parts – cylinder heads, blocks and gearbox cases.
  - Pipes, lids (manhole lids)
  - Foundation for big machines (good damping property)
  - Bridges, buildings
  - Cook wares – Excellent heat retention

Nonferrous Metals

Nonferrous

• Cu Alloys

Brass: Cu-Zn alloy. Corrosion resistant. Used in costume jewelry, coins

Bronze : Cu – with Sn, Al, Si, Ni

Cu-Be: precipitation hardened (bushings, landing gear)

• Al Alloys

-low ρ: 2.7 g/cm^3

-Cu, Mg, Si, Mn, Zn additions

-solid solution or precipitation strengthened (structural aircraft parts & packaging)

• Mg Alloys

-very low ρ: 1.7g/cm^3

-ignites easily

-aircraft, missiles

• Ti Alloys

relatively low ρ: 4.5 g/cc reactive at high *T's* space and biomedical application

Noble metals

- Ag, Au, Pt

oxidation/corrosion resistant

• Refractory metals

-high melting *T's*

-Nb, Mo, W, Ta

Copper

- Copper is one of the earliest metals discovered by man.
- The boilers on early steamboats were made from copper.
- The copper tubing used in water plumbing in Pyramids was found in serviceable condition after more than 5,000 years.
- Cu is a ductile metal. Pure Cu is soft and malleable, difficult to machine.
- Very high electrical conductivity – second only to silver.
- Copper is refined to high purity for many electrical applications.
- Excellent thermal conductivity – Copper cookware most highly regarded – fast and uniform heating.
- Electrical and construction industries are the largest users of Cu.

Copper

- The second largest use of Cu is probably in coins.
- The U.S. nickel is actually 75% copper. The dime, quarter, and half dollar coins contain 91.67% copper and the Susan B Anthony dollar is 87.5% copper.
- The various Euro coins are made of Cu-Ni, Cu-Zn-Ni or Cu-Al-Zn-Sn alloys.

Introduction – Applications of copper

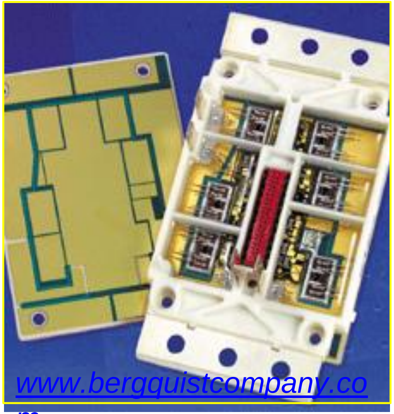
Properties:

- High electrical conductivity
- High thermal conductivity
- High corrosion resistance
- Good ductility and malleability
- Reasonable tensile strength

Applications:

Only second to silver for electrical conductance

Copper trolley wires



Electronic products

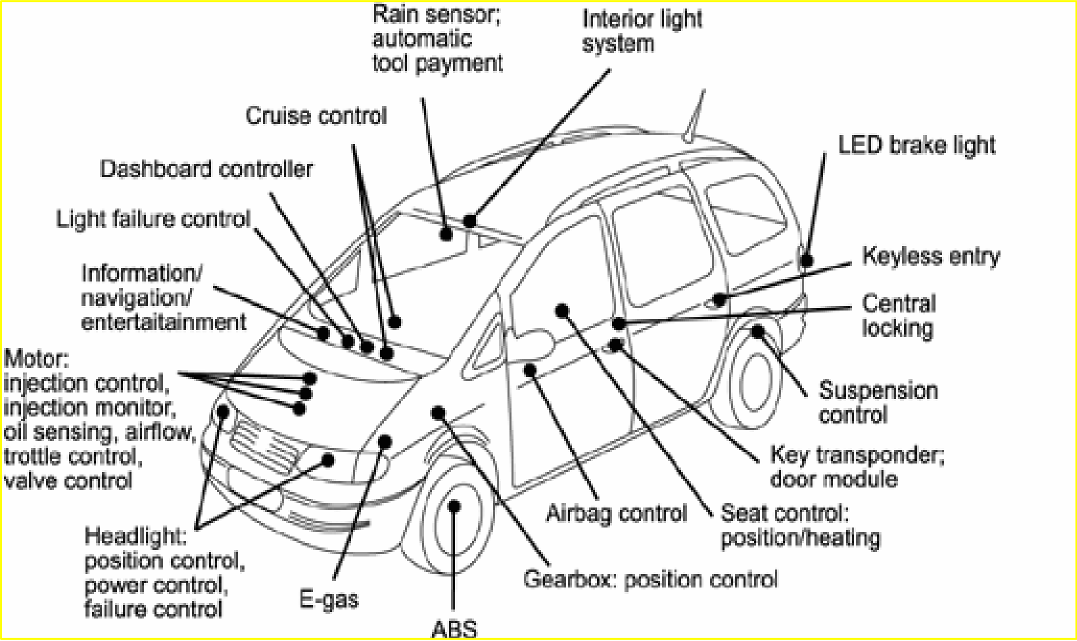
Copper finish parts

Copper plating

Application of copper in automotives

Copper: working behind the scenes in automotive applications.

- Increasing use of electronic parts in cars raise the amount of copper used per vehicle.



Copper Alloys

- Brasses and Bronzes are most commonly used alloys of Cu. Brass is an alloy with Zn. Bronzes contain tin, aluminum, silicon or beryllium.
- Other copper alloy families include copper-nickels and nickel silvers. More than 400 copper-base alloys are recognized.

Family of Cu Alloys		
Alloy	**Alloying element**	**UNS numbers**
Brass	Zinc (Zn)	C1xxxx–C4xxxx,C66400–C69800
Phosphor bronze	Tin (Sn)	C5xxxx
Aluminium bronzes	Aluminium (Al)	C60600–C64200
Silicon bronzes	Silicon (Si)	C64700–C66100
Copper nickel, nickel silvers	Nickel (Ni)	C7xxxx

Copper Alloys - Brass

❖ Brass is the most common alloy of Cu – It's an alloy with Zn

❖ Brass has higher ductility than copper or zinc.

❖ Easy to cast - Relatively low melting point and high fluidity

❖ Properties can be tailored by varying Zn content.

❖ Some of the common brasses are yellow, naval and cartridge.

❖ Brass is frequently used to make musical instruments (good ductility and acoustic properties).

Bronze

- Copper alloys containing tin, lead, aluminum, silicon and nickel are classified as bronzes.
- Cu-Sn Bronze is one of the earliest alloy to be discovered as Cu ores invariably contain Sn.
- Stronger than brasses with good corrosion and tensile properties; can be cast, hot worked and cold worked.
- Wide range of applications: ancient Chinese cast artifacts, skateboard ball bearings, surgical and dental instruments.

Bronze bearing

Beryllium copper

- Cu-Be alloys are heat treatable. Max solubility of Be in Cu is 2.7% at 866 °C. Decreasing solubility at lower temp. imparts precipitation hardening ability.
- Cast alloys - higher Be. Wrought alloys – lower Be and some Co
- Cu-Be is ductile, weldable and machinable. Also resistant to non-oxidizing acids (HCl or H_2CO_3), abrasive wear and galling.
- Thermal conductivity is between steels and aluminum.

Applications

- Used in springs, load cells and other parts subjected to repeated loading. Low-current contacts for batteries and electrical connectors. Cast alloys are used in injection molds. Other applications include jet aircraft landing gear bearings and bushings and percussion instruments.

Aluminum

□Aluminum is a light metal (ρ = 2.7 g/cc); is easily machinable; has wide variety of surface finishes; good electrical and thermal conductivities; highly reflective to heat and light.

□Versatile metal - can be cast, rolled, stamped, drawn, spun, roll-formed, hammered, extruded and forged into many shapes.

□Aluminum can be riveted, welded, brazed, or resin bonded.

□Corrosion resistant - no protective coating needed, however it is often anodized to improve surface finish, appearance.

□Al and its alloys - **high strength-to-weight ratio** (high specific strength) owing to low density.

□Such materials are widely used in aerospace and automotive applications where weight savings are needed for better fuel efficiency and performance.

□Al-Li alloys are lightest among all Al alloys and find wide applications in the aerospace industry.

Aluminum Alloys

- ❖ Aluminum alloys are classified into two categories – Cast and Wrought alloys.
- ❖ Wrought alloys can be either heat-treatable or non-heat treatable.
- ❖ Alloys are designated by a 4 digit number. Wrought – the 1st digit indicates the major alloying element. Cast – The last digit after the decimal indicates product from(casting - 0 or ingot - 1)

Wrought

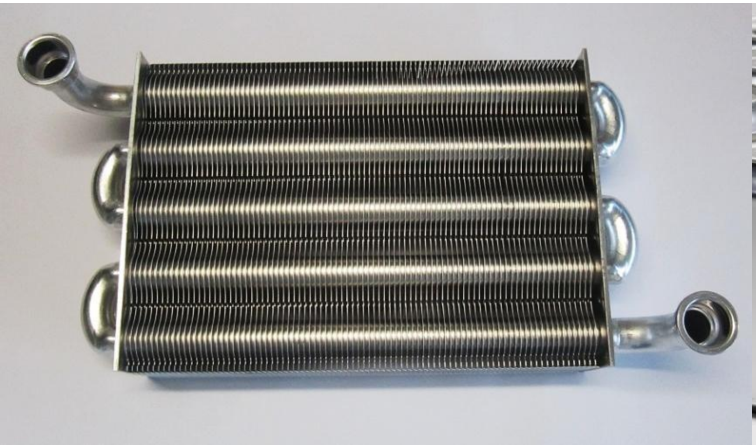
Alloy Series	***Principal Alloying Element***
1xxx	99.00% Aluminum Minimum
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and Silicon
7xxx	Zinc
8xxx	Other Elements

As Cast

Alloy Series	***Principal Alloying Element***
1xx.x	Aluminum, 99.00% or greater
2xx.x	Copper
3xx.x	Silicon with Copper and/or Magnesium
4xx.x	Silicon
5xx.x	Magnesium
6xx.x	Unused Series
7xx.x	Zinc
8xx.x	Tin
9xx.x	Other Elements

Applications

Al –Cu alloys



Al –Mn alloys

Applications



Al –Mg alloys


Al –Zn alloys

Titanium

- Pure titanium melts at 1670 ^{o}C and has a low density of 4.51 g/cc (40% lighter than steel and 60% heavier than aluminum).
- Titanium has high affinity to oxygen – strong deoxidiser. Can catch fire and cause severe damage
- Ti is stronger than Al - high strength and low weight makes titanium very useful as a structural metal.
- Excellent corrosion resistance due to a presence of a protective thin oxide surface film. Can be used as biomaterial.
- Can be used in elevated temperature components.
- Limitation of pure Ti is its lower strength. Alloying is done to improve strength.

Titanium

- ❖Oxygen, nitrogen, and hydrogen can cause titanium to become more brittle. Care should be taken during processing.
- ❖Titanium can also be cast using a vacuum furnace.
- ❖Because of its high strength to weight ratio and excellent corrosion resistance, titanium is used in a variety of applications:
- ❖Aircraft – Body structure, Engine parts
- ❖sporting equipment, chemical processing, desalination, turbine engine parts, valve and pump parts, marine hardware
- ❖Medical implants - prosthetic devices.
- ❖Recently use of Ti in bikes and automotives is increasing

Applications of titanium alloys

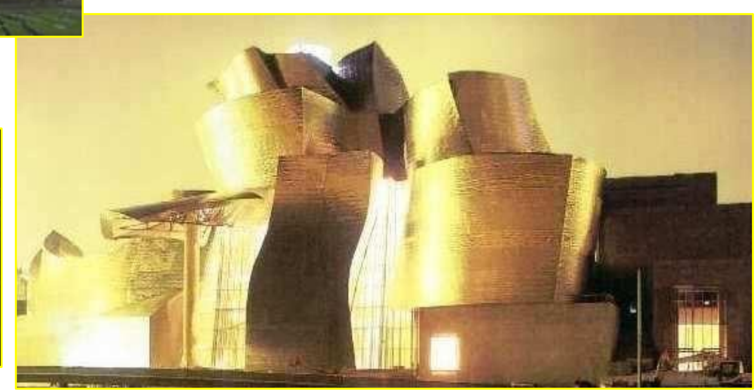
- Used mainly in aerospace, marine, chemical, biomedical applications and sports.


Turbine blades


National science centre, Scotland


Hip-joint component


Shape memory alloy


Titanium cladded Guggenheim Bilbao museum, Spain at sunset.

Titanium alloys

❖Pure Ti exhibits two phases – Hexagonal α-phase at room temperature and BCC β-phase above 882 °C.

❖Strength of Titanium is improved by alloying. Alloying elements are either α or β stabilizer.

❖Elements with electron/atoms ratio < 4 – α stabilizer (Al, O, Ga), = 4 – neutral (Sn, Zr) and > 4 – β stabilizer (V, Mo,Ta, W).

❖(α + β) two-phase alloys can be obtained with right proportions of alloying elements.

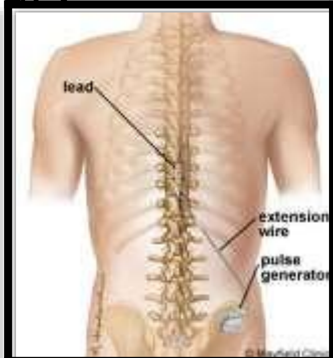
❖α alloys have low density, moderate strength, reasonable ductility and good creep resistance.

❖Metastable β alloys are heavier, stronger and less ductile than α alloys. Creep strength reduces with increasing β content

❖ (α + β) alloys show a good strength-ductility combination

Applications of Ti and Ti alloys

Metallic biomaterials have essentially three fields of use; these are the artificial hip joints, wires , screw, plates and nails for internal fixation of fractures, and dental implants. Any of these devices must support high mechanical load and resistance of material against breakage is essential. High mechanical properties are needed for structural efficiency of surgical and dental implants. But their volume is restricted by anatomic realities what require good yield and fatigue strengths of metal .



The use of titanium alloys is due to:

1 their excellent corrosion resistance.

2 high strength to weight ratio and low elastic modulus.

** Titanium continues to be widely used in biomedical applications.

Ti-6Al-4V alloy is the most frequently used these days .

Nickel

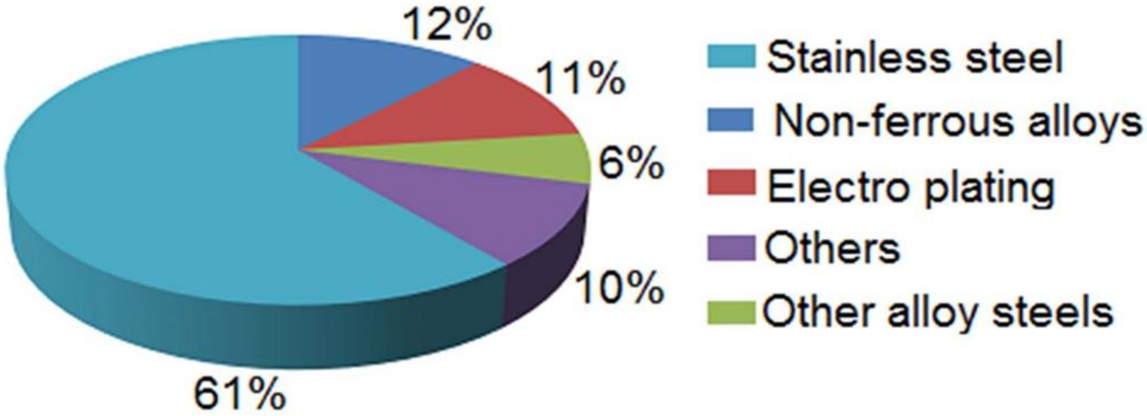
- Nickel is a high-density, high-strength metal with good ductility and excellent corrosion resistance and high temperature properties.
- Ni has may unique properties including its excellent catalytic property. Nickel Catalyst for Fuel Cells: Nickel-cobalt is seen as a low-cost substitute for platinum catalysts.
- Two-thirds of all nickel produced goes into stainless steel production. Also used extensively in electroplating various parts in variety of applications.
- Ni-base super alloys are a unique class of materials having exceptionally good high temperature strength, creep and oxidation resistance. Used in many high temperature applications like turbine engines.

Nickel

- Shape Memory Alloys: Ni base (Ni-Ti) and Ni containing (Cu-Al-Ni) shape memory alloys that can go back to original form, are an important class of engineering materials finding widespread use in many applications.

- Nickel-containing materials are used in buildings and infrastructure, chemical production, communications, energy (batteries: Ni-Cd, Ni-metal hydrides), environmental protection, food preparation, water treatment and transportation.

Applications of Nickel



Turbine engine

Electroplating

Batteries

Magnesium

- Magnesium - Lightest among commonly used metals (ρ 1.7 g/cm^3). Melting point is 650 °C and it has HCP structure.
- Is very reactive and readily combustible in air. Can be used as igniter or firestarter.
- Thermal conductivity is less than Al while their CTE is almost same.
- Pure Mg has adequate atmospheric resistance and moderate strength.
- Properties of Mg can be improved substantially by alloying.
- Favorable atomic size - Can be alloyed with many elements. Most widely used alloying elements are Al, Zn, Mn and Zr.
- Mg Alloys – Cast, Wrought
- Wrought alloys are available in rod, bar, sheet, plate, forgings and extrusions.

Magnesium Alloys

- Mg alloys: Impact and dent resistant, have good damping capacity - effective for high-speed applications.
- Due to its light weight, superior machinability and ease of casting, Mg and its alloys are used in many applications:– Auto parts, sporting goods, power tools, aerospace equipment, fixtures, electronic gadgets, and material handling equipment.
- Automotive applications include gearboxes, valve covers, alloy wheels, clutch housings, and brake pedal brackets.



Ceramics Materials

- Ceramics
  - Refractory Materials
  - Abrasives
  - Glass
  - Advanced Ceramics

Refractory Materials

- **Refractory** - retains its strength at high temperatures > 500°C.
- Must be chemically and physically stable at high temperatures. Need to be resistant to thermal shock, should be chemically inert, and have specific ranges of thermal conductivity and thermal expansion.
- Are used in linings for furnaces, kilns, incinerators, crucibles and reactors.
- Aluminium oxide (alumina), silicon oxide (silica), calcium oxide (lime) magnesium oxide (magnesia) and fireclays are used to manufacture refractory materials.
- Zirconia - extremely high temperatures.
- SiC and Carbon – also used in some very severe temperature conditions, but cannot be used in oxygen environment, as they will oxidize and burn.

Advanced Ceramics: Automobile Engine parts

Advantages:

Operate at high temperatures – high efficiencies; Low frictional losses; Operate without a cooling system; Lower weights than current engines

Disadvantages:

Ceramic materials are brittle; Difficult to remove internal voids (that weaken structures); Ceramic parts are difficult to form and machine

Potential materials: Si_3N_4 (engine valves, ball bearings), SiC (MESFETS), & ZrO_2 (sensors),

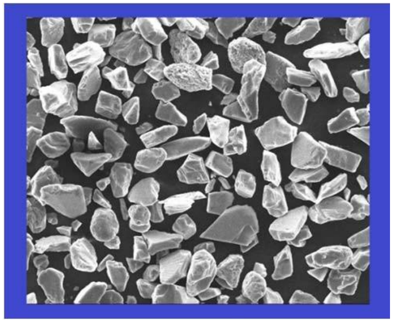
Possible engine parts: engine block & piston coatings

Microelectromechanical systems (MEMS)

- MEMS – These micron-sized structures such as beams, cantilevers, diaphragms, valves, plates and switches that can function as tiny sensors and actuators.
- Fabricated by integrated circuit (IC) manufacturing processes: bulk and surface micromachining.
- Thousands of micromachines can be fabricated on a single silicon wafer with supporting circuits integrated on the chip. Can be mass-produced in the millions at low prices.
- Low-cost, commercial MEMS devices developed for: Corrosion detectors and monitors; Instrumentation for automotive and aerospace; Biological and medical devices; Chemical and environmental sensors; Manufacturing and process control devices ;Virtual reality systems

Abrasive Ceramics

- Abrasives are used in cutting and grinding tools.
- Diamonds - natural and synthetic, are used as abrasives, though relatively expensive. Industrial diamonds are hard and thermally conductive. Diamonds unsuitable as gemstone are used as industrial diamond
- Common abrasives – SiC, WC, Al_2O_3 (corundum) and silica sand.
- Either bonded to a grinding wheel or made into a powder and used with a cloth or paper.



Silicon carbide

Glass

- Glass - inorganic, non-crystalline (amorphous) material.
- Range - soda-lime silicate glass for soda bottles to the extremely high purity silica glass for optical fibers.
- Widely used for windows, bottles, glasses for drinking, transfer piping and receptacles for highly corrosive liquids, optical glasses, windows for nuclear applications.
- The main constituent of glass is silica (SiO_2). The most common form of silica used in glass is sand.
- Sand fusion temp to produce glass - 1700 °C. Adding other chemicals to sand can considerably reduce the fusion temperature.
- Sodium carbonate (Na_2CO_3) or soda ash, (75% SiO_2 + 25% Na_2O) will reduce the fusion temperature to 800 °C.

Key Properties of Glass

- Glass-ceramic materials should have:
  - Relatively high mechanical strengths
  - Low coefficients of thermal expansion
  - Relatively high temperature capabilities
  - Good dielectric properties
  - Good biological compatibility
  - Thermal shock resistance

Polymers

- **Polymers** – Chain of H-C molecules. Each repeat unit of H-C is a monomer e.g. ethylene (C_2H_4), Polyethylene – $(–CH_2–CH_2)_n$
- Polymers: Thermosets – Soften when heated and harden on cooling – totally reversible. Thermoplasts – Do not soften on heating
- **Plastics** – moldable into many shape and have sufficient structural rigidity. Are one of the most commonly used class of materials.
- Are used in clothing, housing, automobiles, aircraft, packaging, electronics, signs, recreation items, and medical implants.
- Natural plastics – hellac, rubber, asphalt, and cellulose.

Characteristics and Applications of some common Thermoplastics

Material	Characteristics	Applications
Polyethylene	Chemically resistant, tough, low friction coeff., low strength	Flexible bottles, toys, battery parts, ice trays, film wrapping materials
Polyamide (Nylon)	Good strength and toughness, abrasion resistant, liquid absorber, low friction coeff.	Bearings, gears, cams, bushings and jacketing for wires and cables
Fluorocarbon (Teflon)	Chemically inert, excellent electrical properties, relatively weak	Anticorrosive seals, chemical pipes and valves, bearings, anti-adhesive coatings, high temp electronic parts
Polyester (PET)	Tough plastic film, excellent fatigue and tear strength, corrosion resistant	Recording tapes, clothing, automotive tyre cords, beverage containers
Vinyl	Low-cost general purpose material, rigid, can be made flexible	Floor coverings, pipe, electric al wire insulation, garden hose, phonograph records
Polystyrene	Excellent electrical prop and optical clarity, good thermal and dimensional stability	Wall tile, battery cases, toys, lighting panels, housing appliances

Characteristics and Applications of some common Thermosetting Polymers

Material	Characteristics	Applications
Epoxy (Araldite)	Excellent mechanical properties and corrosion resistance, good electrical prop., good adhesion and dimensional stability	Electrical moldings, sinks, adhesives, protective coatings, fiber reinforced plastic (FRP), laminates
Phenolic (Bakelite)	Excellent thermal stability (>150°C), inexpensive, can be compounded with many resins	Motor housings, telephones, auto distributors, electrical fixtures
Polyester (Aropol)	Excellent electrical properties, low cost, can be formulated for room or high temperature, often fiber reinforced	Helmets, fiberglass boats, auto body components, chair fans

Elastomers

- ❖ **Elastomer** – a polymer with rubber-like elasticity.
- ❖ Each of the monomers that link to form the polymer is usually made of carbon, hydrogen, oxygen and/or silicon.
- ❖ Cross-linking in the monomers provides the flexibility.
- ❖ Glass transition temperature, T_g, is the temperature at which transition from rubbery to rigid state takes place in polymers.
- ❖ Elastomers are amorphous polymers existing above their T_g. Hence, considerable segmental motion exists in them.
- ❖ Their primary uses are in seals, adhesives and molded flexible parts.

Characteristics and Applications of some commercial Elastomers

Material	Characteristics	Applications
Natural rubber (NR)	Useful temp. range : - 60 – 120°Cgood resistance to cutting abrasion, resistant to oil, ozone, elng. 500- 700%	Pneumatic tyres and tubes, heels and soles, gaskets
Styrene-butadiene copolymer (SBR))	Temp. range: - 60 – 120° C, Good physical properties, elongation 450 – 500%	Same as natural rubber
Acrylonitrile-butadiene copolymer (NBR)	Temp. range: - 50 – 150° C. Excellent resistance to oils, elongation 400 – 600%	Gasoline, chemicals and oil hose, seals and O-rings, soles and heels
Chloroprene (CR)	Temp. range: - 50 – 105° C. Excellent resistance to high and low temp. excellent electrical prop. Elng. 100 – 800%	High and low temp. insulation, seals, diaphragm, tubing for food and medical uses

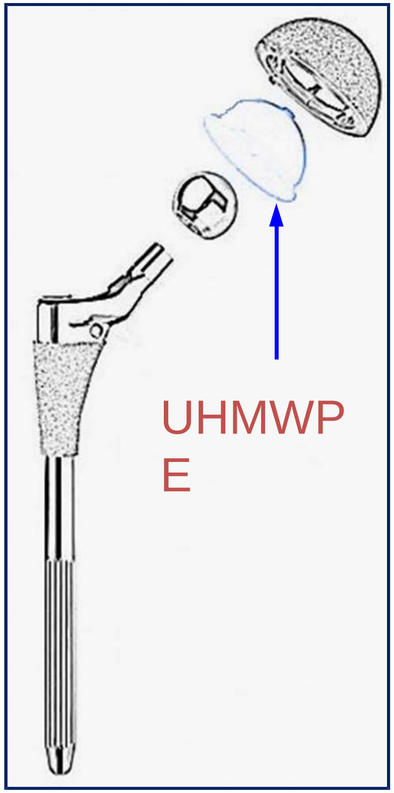
Liquid Crystal Polymers (LCP)

- LCPs are a group of chemically complex structure having unique properties. Primarily used in LCDs (liquid crystal displays) on watches, flat panel computer monitors, televisions and clocks.
- Advantages - LCDs are thinner and lighter and consume much less power than cathode ray tubes (CRTs).
- The name "liquid crystal" arises out of their characteristics. It takes a fair amount of heat to change a suitable substance from a solid into a liquid crystal, and it only takes a little more heat to turn the liquid crystal into a real liquid.
- LCDs use these liquid crystals because they react predictably to electric current in such a way as to control light passage.
- A particular sort of nematic liquid crystal, called twisted nematics (TN), is naturally twisted. Applying an electric current to these liquid crystals will untwist them to varying degrees, depending on the applied electrical potential.

Advanced Polymers

Ultrahigh Molecular Weight Polyethylene (UHMWPE)

- **Molecular weight ca. 4 x 10^6 g/mol**
- **Outstanding properties**
  - **high impact strength**
  - **resistance to wear/abrasion**
  - **low coefficient of friction**
  - **self-lubricating surface**
- **Important applications**
  - **bullet-proof vests**
  - **golf ball covers**
  - **hip implants (acetabular cup)**



Metals

- Composed of one or more metallic elements (*Iron, Copper, Aluminum*)
- Metallic element may combine with nonmetallic elements (*carbon, nitrogen, oxygen*) in relatively small amount.

Mechanical Properties:

- Stiff & strong
- Ductile (large amount of deformation without fracture)
- Resistant to fracture.
- Metallic materials have large numbers of nonlocalized electron.
- Good conductors of electricity & heat
- Not transparent

Example:

The Golden Gate Bridge north of San Francisco, California, is one of the most famous and most beautiful examples of a steel bridge. (Courtesy of Dr. Michael Meier.)

Polymers

- Consist of organic (carbon-containing) long molecular chains or network
- Plastic & rubber materials (*Poly vinyl Chloride (PVC), Polyester*)
- Organic compound – carbon, hydrogen & other nonmetallic elements (O, N, Si)

<u>Mechanical Properties:</u>

- Stiffness & strength per mass are comparable to metal&ceramic
- Ductile & pliable (easily formed into complex shape)
- Inert chemically & unreactive in large number of environment
- Tendency to soften and/or decomposed at modest temperature
- Low electrical conductivity & nonmagnetic

Example:

Since its development during World War II, nylon fabric remains the most popular material of choice for parachute designs.
(Courtesy of Stringer/Agence France Presse/Getty Images.)

Ceramics

- Compounds between metallic and nonmetallic elements.

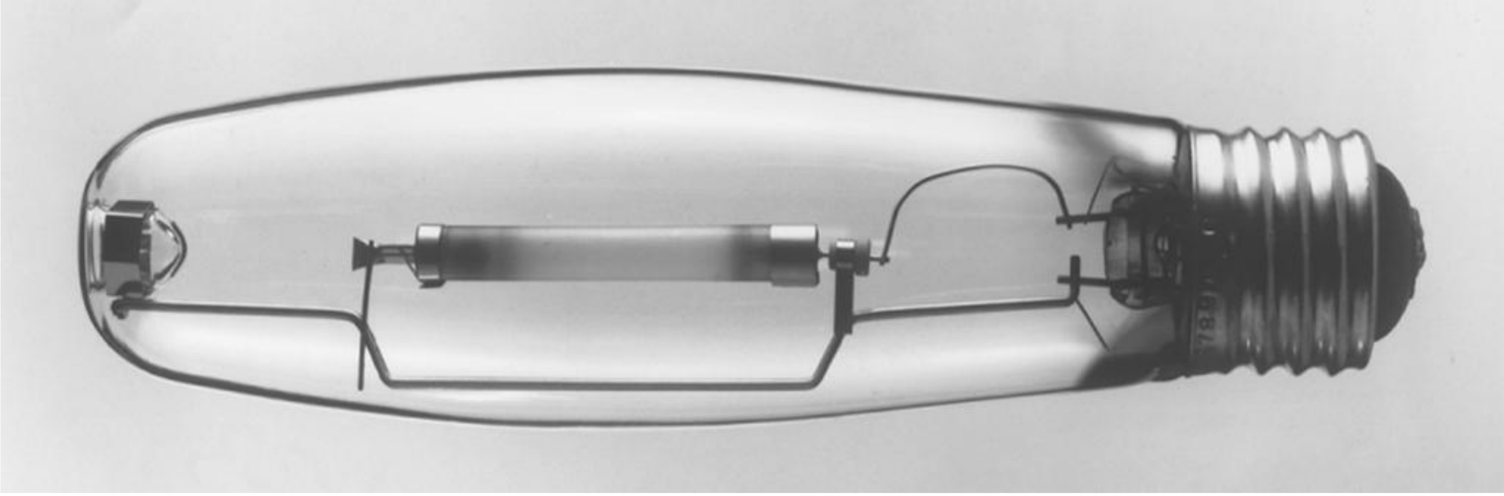
  They are most frequently oxides, nitrides and carbides
- Example: aluminum oxide, silicon dioxide, silicon nitride
- Traditional ceramics: clay minerals, cement, glass

Mechanical Properties:

- Stiff & strong
- Very hard
- Brittle (lack ductility)
- Highly susceptible to fracture.
- Insulative to passage of heat & harsh environment
- Optical characteristic – transparent, translucent, opaque
- Oxide ceramic – exhibit magnetic behavior

Example:

High-temperature sodium vapor lamp made possible by use of a translucent Al_2O_3 cylinder for containing the sodium vapor.
(Note that the Al_2O_3 cylinder is inside the exterior glass envelope.) (Courtesy of General Electric Company.)

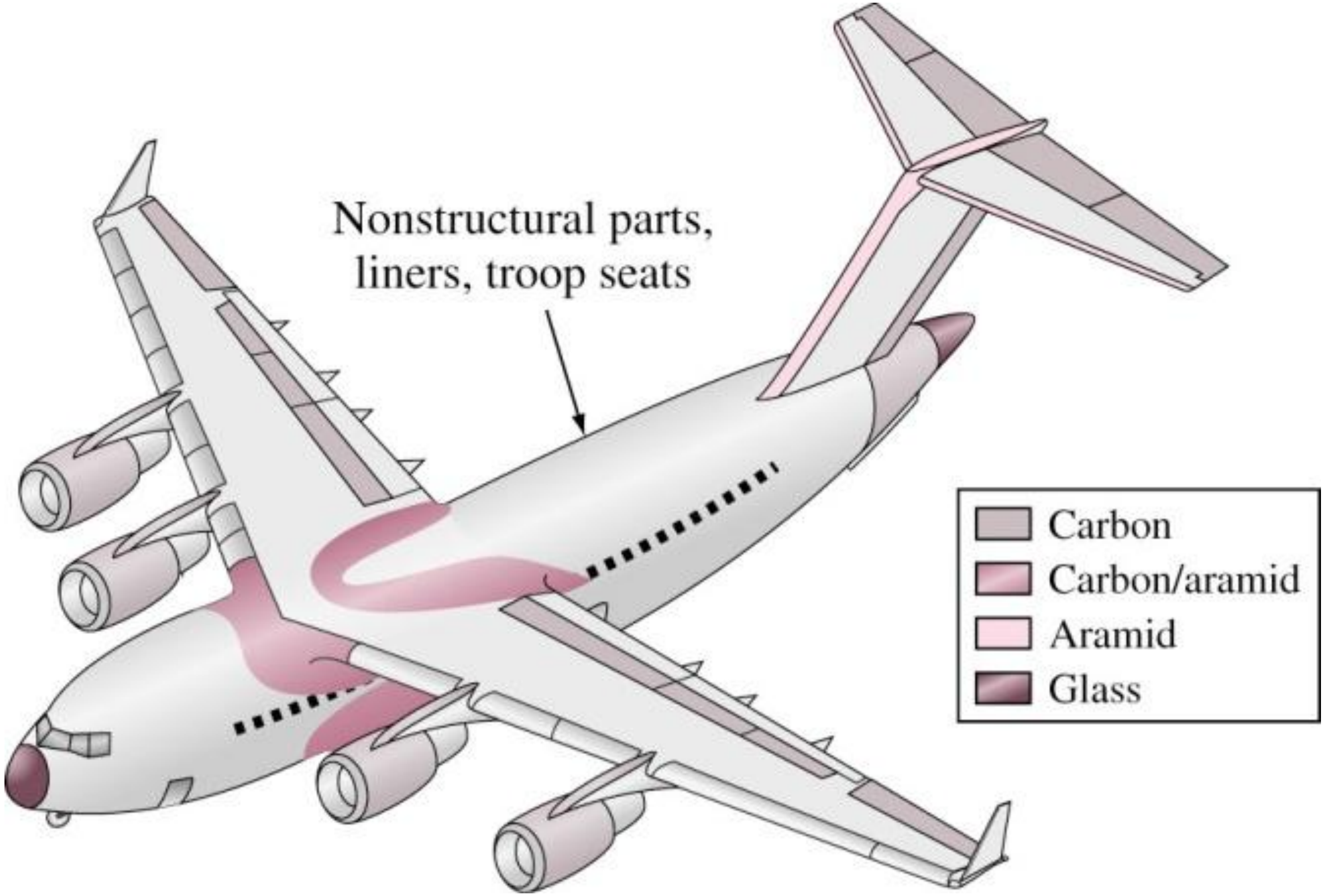


Composites

- Compose of two (or more) individual materials
  Eg: (metal, ceramic, polymer)
- Design goal: to achieve a combination of properties that is not display by any single material & also to incorporate the best characteristic of each of the component.
- Example: fiberglass – small glass fiber embedded within polymeric material (epoxy/polyester)
- Mechanical properties of glass fiber: strong, stiff, brittle
- Mechanical properties of polymer: ductile, weak, flexible
- Mechanical properties of fiberglass: strong, stiff, flexible, ductile, low density

Example:

Overview of the wide variety of composite parts used in the Air Force's C- 17 transport
(From Advance Composites, May/June 1988, p.53.)



Advanced Materials

Electronic Materials

- Semiconductor
- Superconductor

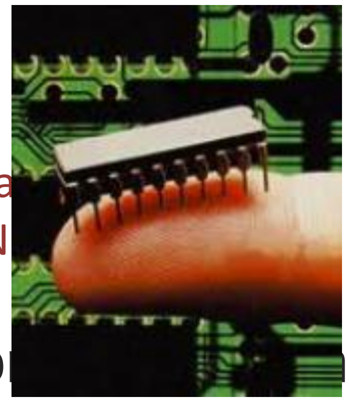
Smart / Future Materials

- Ferroelectric
- Piezoelectric
- Pyroelectric
- Shape memory alloy
- Bio-degradable
- Nanomaterials
  - Smaller than 100nm

Electronic

i. Semiconductor

- The bonding is covalent (electrons are shared between atoms). The electrical properties depend strongly on minute proportions of contaminants.
  - Silicon, Si
  - Germanium, Ge
  - Gallium Arsenide, Ga
  - Gallium Nitride, GaN
  - Silicon Carbide, SiC



- Silicon is an impo ic riggered computer development revolution. Over the years, integrated circuits have been made with a greater density of transistors located on a single silicon chip with a corresponding decrease in transistor width. These chips play a vital role in computerized manufacturing.

Electronic Materials

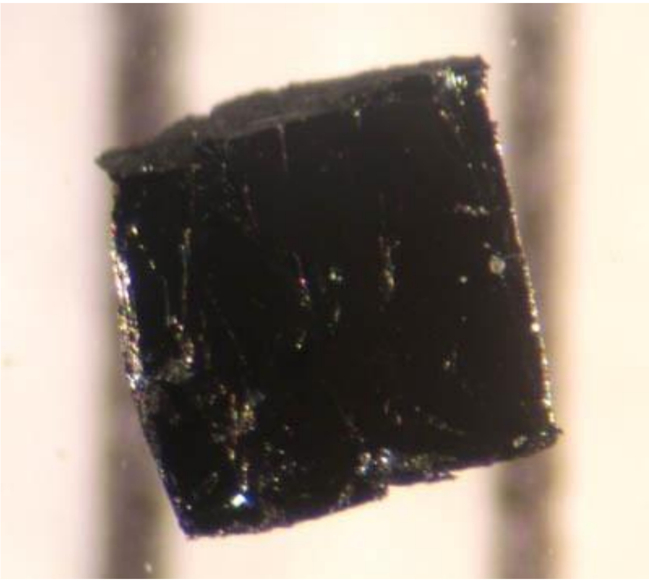
Not a major type of material, but are extremely important for advanced engineering technology: communication satellites, advanced computers, digital watches, robots, etc.
Silicon is the most important electronic material, it is modified in various ways to change its electrical properties.

ii. Superconductor

Superconductivity is a phenomenon of exactly zero electrical resistance

Superconducting magnets
MRI/NMR machines, mass spectrometers, and the beam-steering magnets used in particle accelerators

Superconductor



- High Curie Temperature, T_c , oxide ceramic superconductors – BSCCO (bisko) – Bismuth Strontium Calcium Copper Oxide: *good, functionally; bad, structurally (brittle)*
- Image courtesy: wiki

Future Trends Materials

- **Smart Materials : Change their properties by sensing external stimulus.**

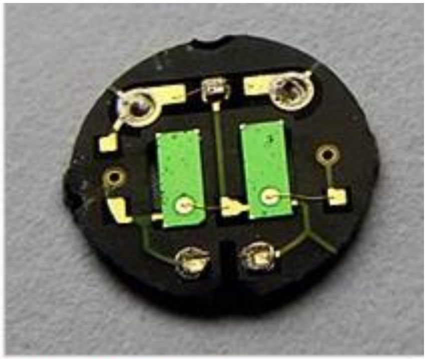
  - **Ferroelectric : Ferroelectricity** is a property of certain materials that have a spontaneous electric polarization that can be reversed by the application of an external electric field.
    - **Used as Ferroelectric Random Access Memory (FRAM)**
    - **Capacitor / Multilayer Ceramic Capacitor.**

  - **Piezoelectric materials: Produce electric field when exposed to force and vice versa.**
    - **Used in actuators and vibration reducers.**
    - piezoelectric sensor
    - piezoelectric ultrasound – known as piezosurgery

Future Trends Materials

- **Smart Materials : Change their properties by sensing external stimulus.**

  - **Pyroelectric : Produce electric field when exposed to heat or cool and vice versa.**
    - **pyroelectric sensor**
    - **passive infrared sensor**



Pyroelectric sensor

Future Trends Materials

- **Future Materials**

  - **Shape memory alloys: Strained material reverts back to its original shape above a critical temperature.**
    - **Used in heart valves and to expand arteries.**

  - **Bio-degradable materials**: return to compounds found in nature. *Degradation* caused by enzymatic process resulting from the action of cells
    - **Example:bio-plastic**
    - Biodegradable electronics
    - Biodegradable polythene film

Introduction to SMA

- Smart or intelligent materials are materials that have to respond to stimuli and environmental changes and to activate their functions to these changes.
- The stimuli like temperature, pressure, electric flow, magnetic flow, mechanical, etc can originate internally or externally.
- Shape memory alloys are smart materials.
- Shape-memory alloys (SMAs) are a unique family of metals exhibiting an ability to recover macroscopic deformation introduced at low temperature simply by heating the material through a transformation temperature.
- Shape-memory effect (SME) is therefore the ability of a material to return to a pre-set shape upon finishing the transformation.
- The same alloys exhibiting SME also to some extent exhibit superelasticity.

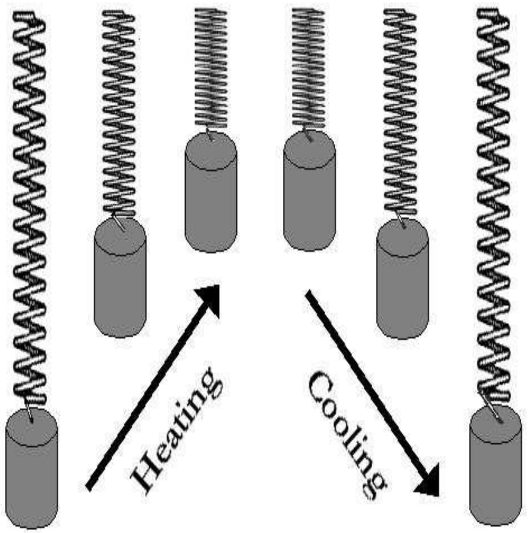
SMA

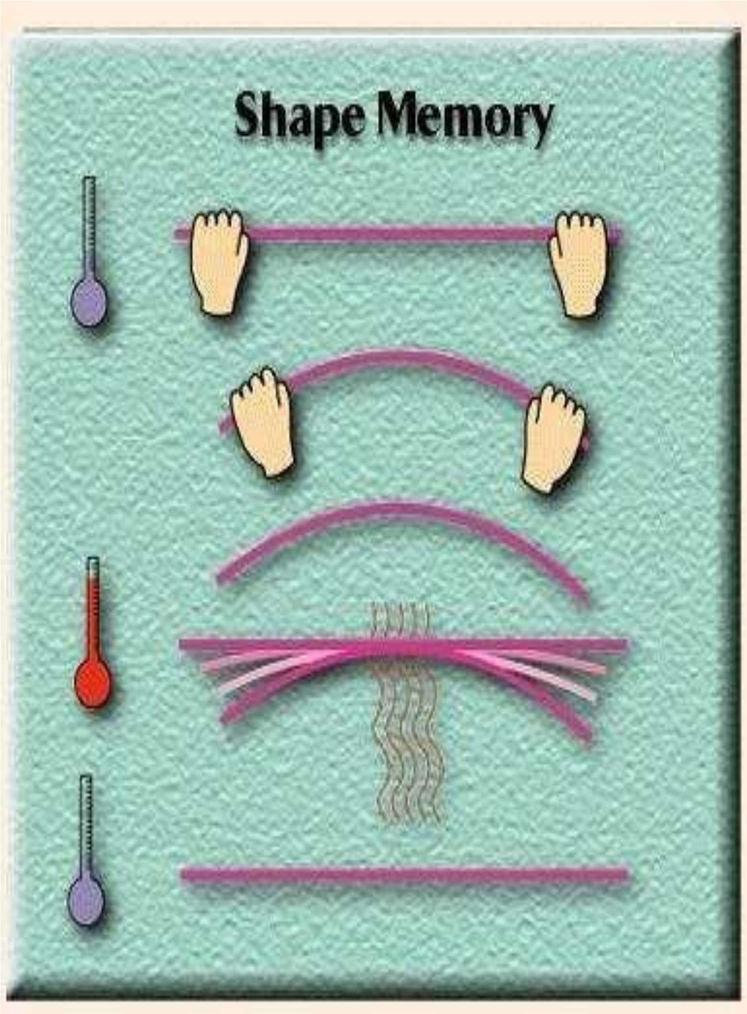
- Example: Copper-Aluminum-Nickel, Copper-Zinc-Aluminum, and Iron-Manganese-Silicon

  Nickel-Titanium alloys

  Ni-Ti-Pd

  Ni-Ti-Hf





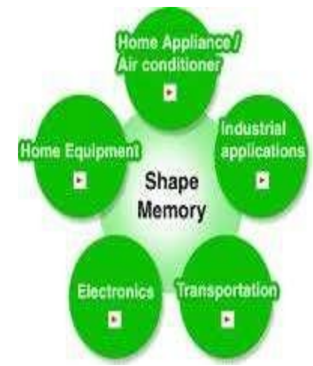
 MARTENSITE
DEFORMING MARTENSITE
DEFORMED MARTENSITE
 AUSTENSITE

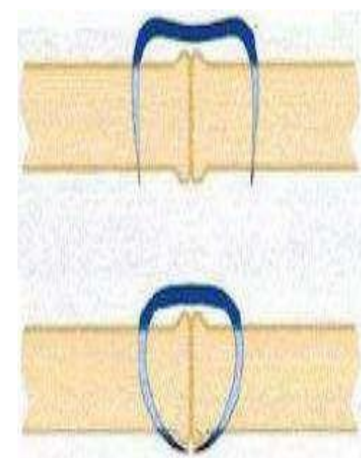
 MARTENSITE

APPLICATIONS

- Medicine
- Optometry
- Engines
- Aerospace
- Robotics
- Automotive
- Pipings
- Civil stuctures
- Water spinkers
- Textile






Biodegradable Materials

Product	Time to Biodegrade
Apple core	1–2 months
General paper	1–3 months
Paper towel	2–4 weeks
Cardboard box	2 months
Cotton cloth	5 months
Plastic coated milk carton	5 years
Wax coated milk carton	3 months
Tin cans	50–100 years
Aluminium cans	150–200 years
Glass bottles	Undetermined (forever)
Plastic bags	10–20 years
Soft plastic (bottle)	100 years
Hard plastic (bottle cap)	400 years

Future Trends Materials

- **MEMS: Microelectromechanical systems.**
  - **Miniature devices**
  - **Micro-pumps, sensors**

- **Nanomaterials: Characteristic length < 100 nm**
  - **Examples: ceramics powder and grain size < 100 nm**
  - **Nanomaterials are harder and stronger than bulk materials.**
  - **Have biocompatible characteristics (as in Zirconia)**
  - **Transistors and diodes are developed on a nanowire.**

Classification and application of material's engineering

Materials Engineering	Examples
1) Metals	Vehicle casis, engine jet component, structures (bridge, building, etc)
2) Polymers	Liquid Crystal Display (LCD), gasket, computer casing, rubber glove
3) Ceramics	Capasitor, varistor, bearing, glass, clay
4) Electronic materials	Transistor, diode, light emitting diode (LED), solar sel
5) Biomaterials	Replace natural body tissues
6) Composites	Fiberglass, aerospace material, golf club shafts, tennis rackets

Variety in materials

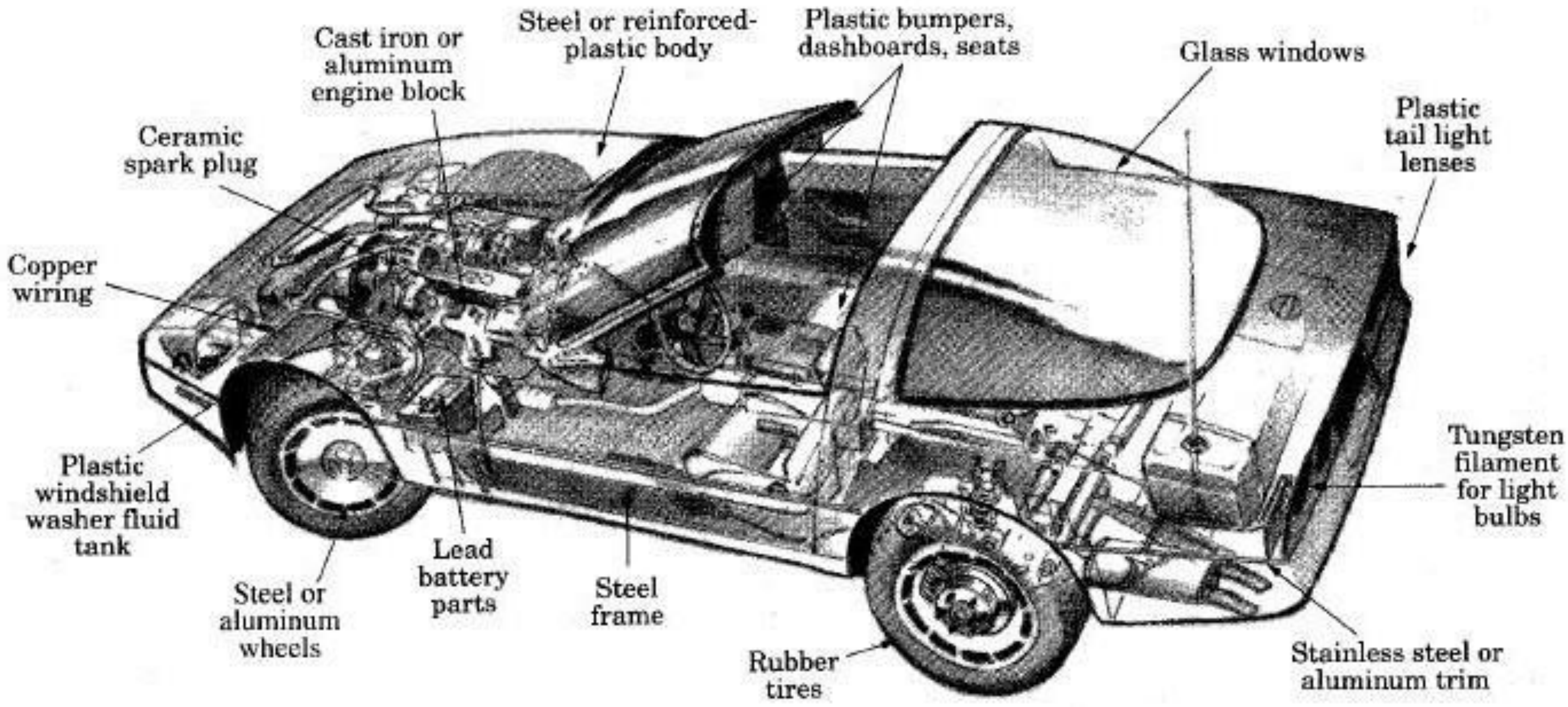


Image courtesy: Caltech Engineering Design lab handout

PROPERTIES COMPARISON

Properties / Material	Metals	Ceramics	Polymers
Tensile strength	High	Low	High
Compression strength	Low	High	Medium
Ductility	High	Low	High
Electric and thermal conductivity	High	Low	Low
Hardness	High	High	Medium
Density	High	Medium	Low
Elasticity	Medium	Low	High
Toughness	Medium	Low	High

Quiz

1. Classify materials. Classify metals.
2. What are the typical grades of steel? What is the effect of different alloying elements in steel?
3. Why are tool steels hard? What is HSLA steel?
4. What are the major alloying elements in stainless steels? Why are stainless steels resistant to corrosion?
5. What is 17-7PH steel? What is the source of high strength in these steels?
6. What should be minimum carbon content in a cast iron?
7. Why is grey cast iron so brittle? Why is it resistant to wear?
8. How can the ductility of cast irons be increased?
9. What is the shape of graphite in malleable cast iron?
10. What are the useful properties of cast iron?
11. Why is copper used extensively in electrical and thermal applications?

Quiz

12. What is Brass? What are typical alloying elements in bronze?
13. Which is the heat treatable alloy of copper?
14. How are Alumium alloys classified and designated?
15. What are the different temper designation of aluminum alloys?
16. Why is titanium resistant to corrosion?
17. What are the typical phases in Ti alloys? What is α and β stabilizer?
18. Why Ti alloys are preferred for high temperature applications?
19. What are the different categories of ceramic materials?
20. What are the main constituents in refractory ceramics? What are the main constituents of glass?
21. What are the key properties of glass-ceramics?

Quiz

22. What are thermosets and thermoplasts?
23. Why do plastics find widespread applications?
24. What is elastomer? What are their typical characteristics and applications?
25. What is glass transition temperature?
26. What is UHMWPE polymer?
27. What is LCP?
28. Why are LCPs used in LCD displays?
29. What is twisted nematics?
30. Name some natural plastics.

Case studies on Material Selection

Case Study: Selection of material for Heat Sink

- A microchip may only consume milliwatts, but the power is dissipated in a tiny volume. The power is low but the high power density
- The Pentium chip of today's PCs already reaches 85C, requiring forced cooling.
- Multiple-chip modules (MCMs) pack as many as 130 chips on to a single substrate.
- Heating is kept under control by attaching the chip to a heat sink (Figure 5.4), taking pains to ensure good thermal contact between the chip and the sink.
- To prevent electrical coupling and stray capacitance between chip and heat sink, the heat sink must be a good electrical insulator, meaning a resistivity ρe > 10^{19}µΩcm.
- But to drain heat away from the chip as fast as possible, it must also have the highest possible thermal conductivity, .

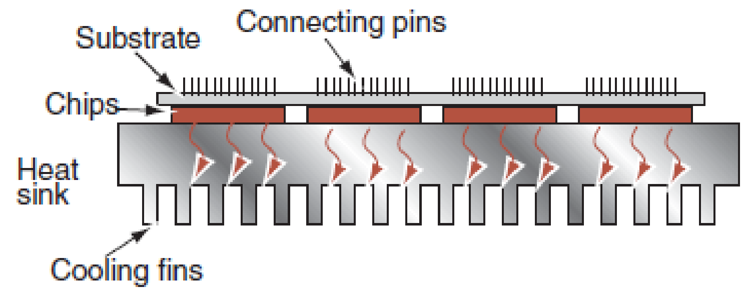


Fig. A heat sink for power micro-electronics

Function, constraints, objective, and free variables for the heat sink

Function	Heat sink
Constraints	• Material must be "good insulator", or $\rho_e > 10^{19}$ µΩ. cm • All dimensions are specified
Objective	Maximize thermal conductivity, λ
Free variables	Choice of material

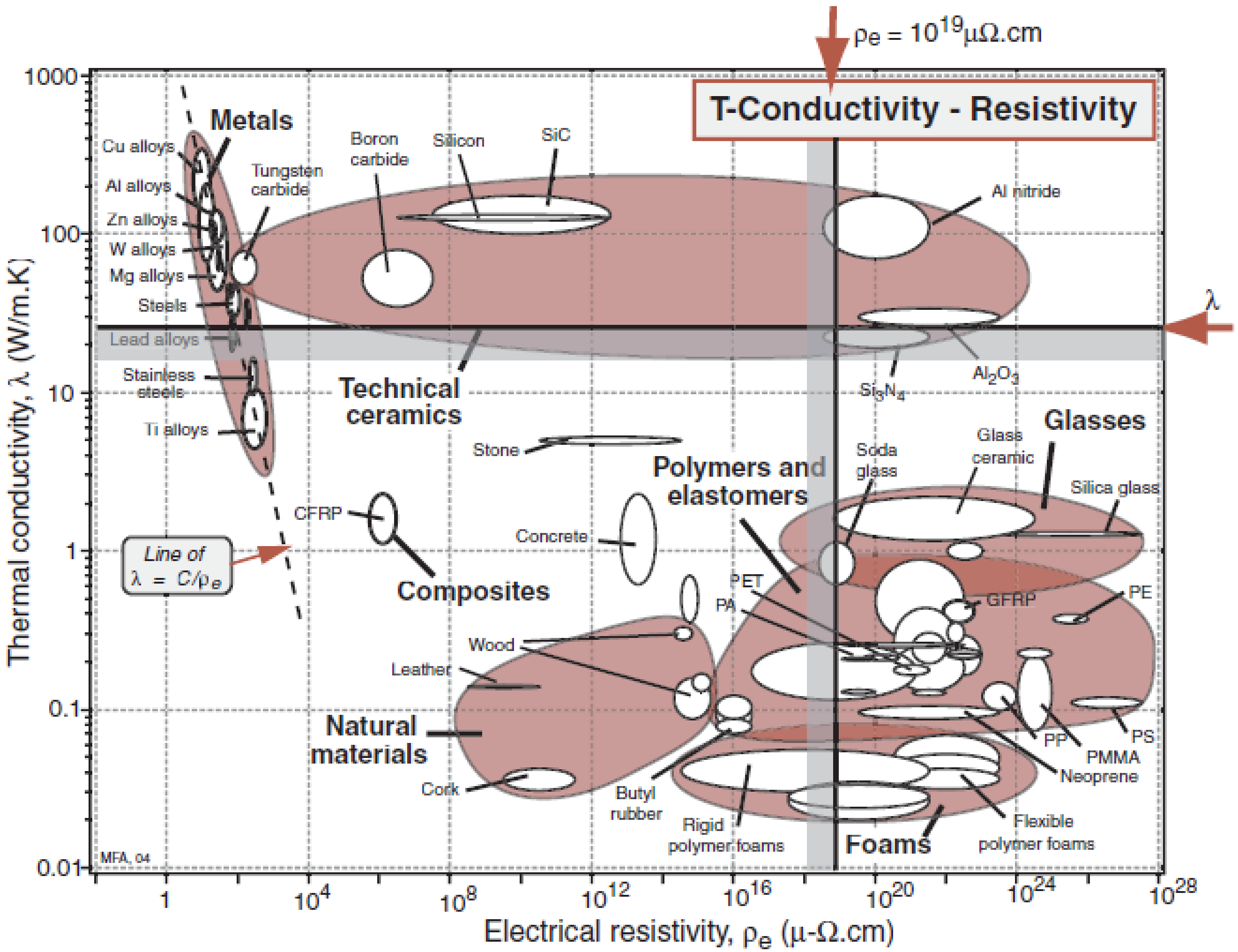


Fig: The λ - ρ_e chart

Case Study: Materials for overhead transmission lines

- Electrical power, today, is generated centrally and distributed by overhead or underground cables.
- Buried lines are costly so cheaper overhead transmission is widely used.
- A large span is desirable because the towers are expensive, but so too is a low electrical resistance to minimize power losses.
- The span of cable between two towers must support the tension needed to limit its sag and to tolerate wind loads.
- Consider the simple case in which the tower spacing L is fixed at a distance that requires a cable with a strength f of at least 80MPa (a constraint).
- The objective then becomes that of minimizing resistive losses, and that means seeking materials with the lowest possible resistivity.

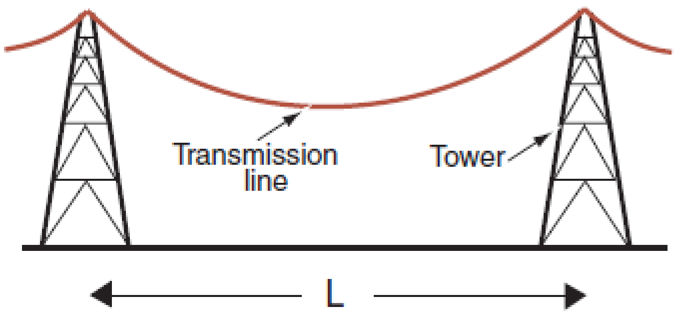
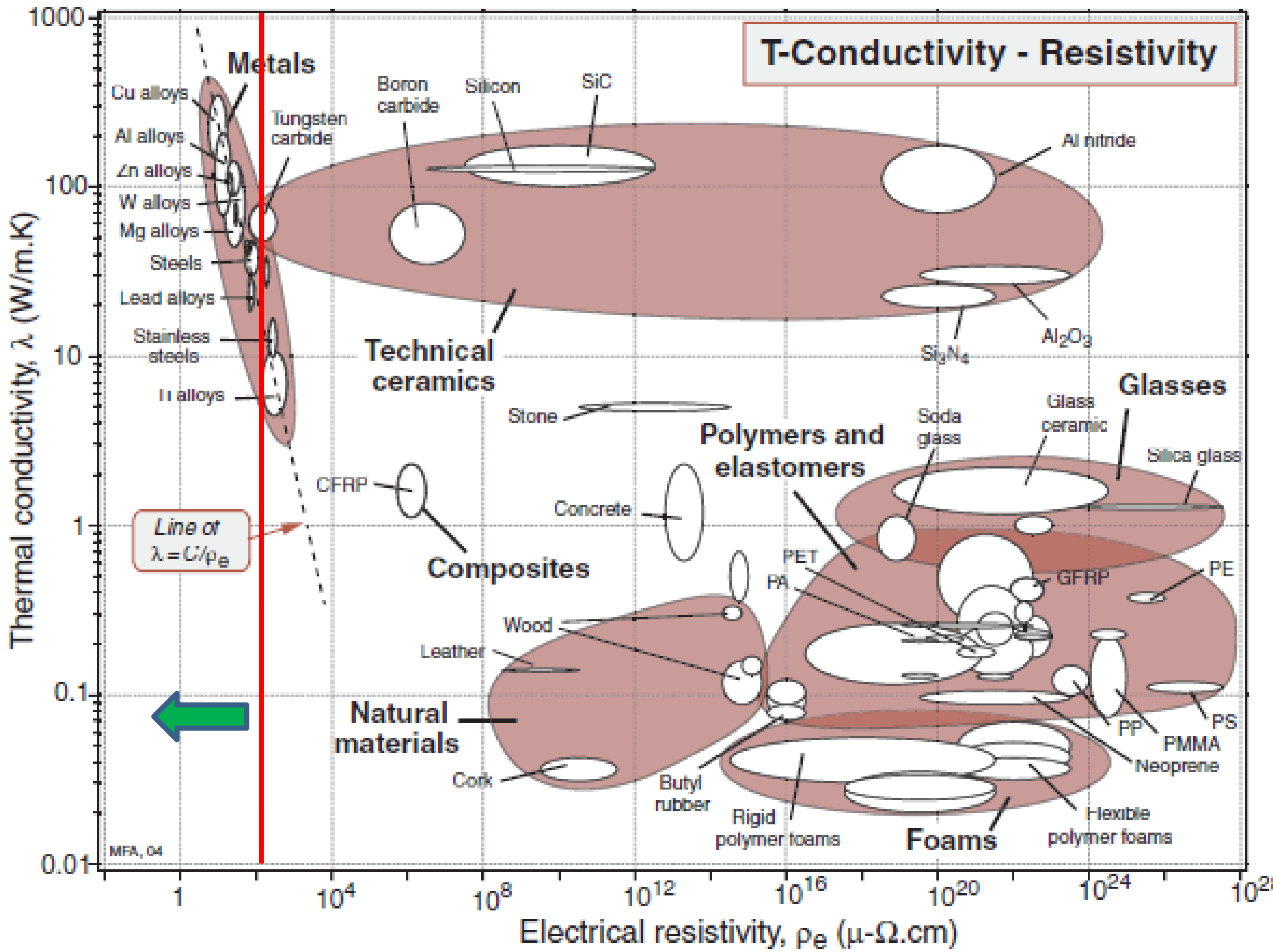
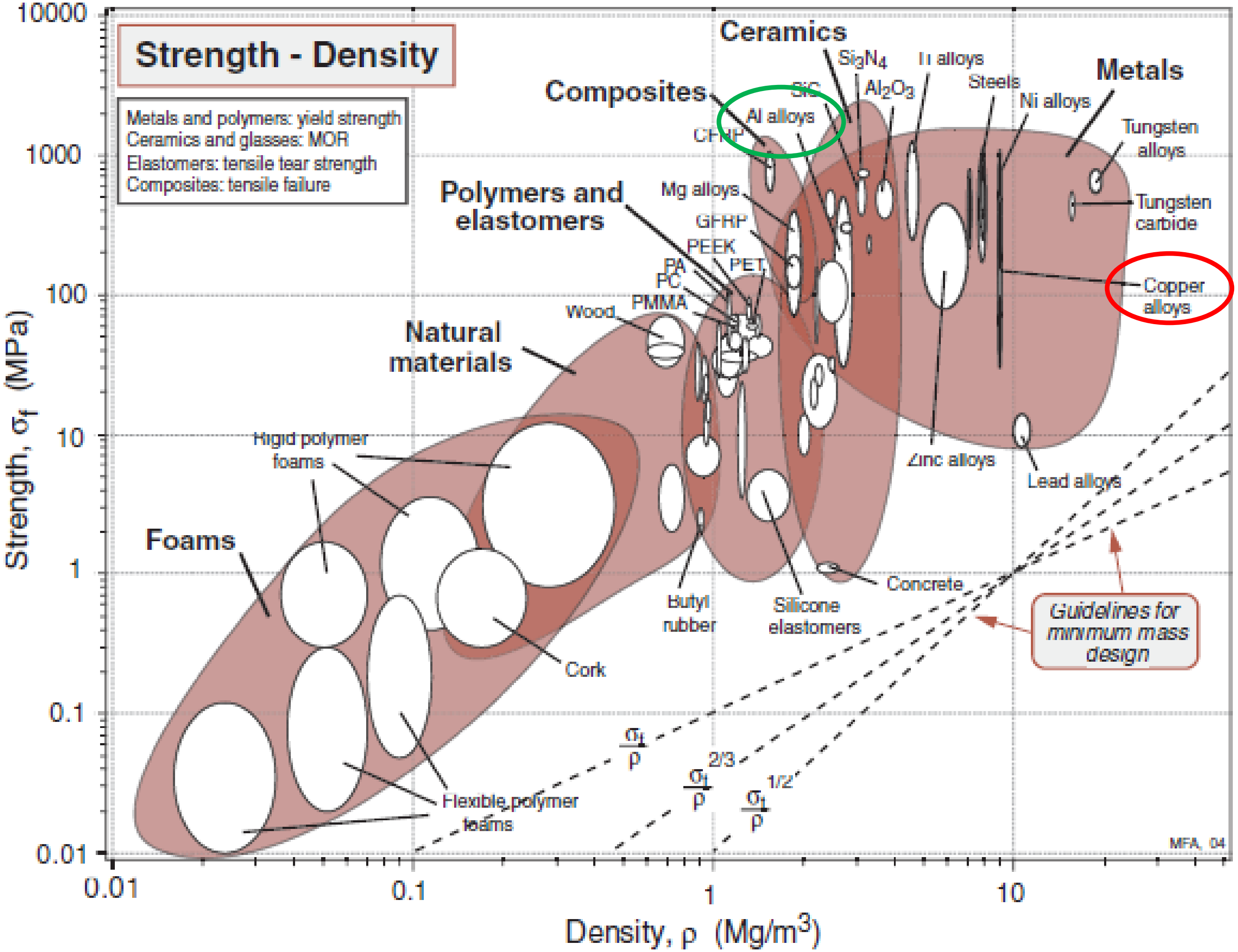


Fig: A transmission line

Function, constraints, objective, and free variables for the transmission line

Function	Long span transmission line
Constraints	• Span L is specified • Material must be strength $\sigma_f > 80$ MPa
Objective	Minimize electrical resistivity ρ_e
Free variables	Choice of material


T-Conductivity - Resistivity
Thermal conductivity, λ (W/m.K)
Electrical resistivity, ρe (μ-Ω.cm)
1000
100
10
1
0.1
0.01
1
10^4
10^8
10^12
10^16
10^20
10^24
10^28
Metals
Cu alloys
Al alloys
Zn alloys
W alloys
Mg alloys
Steels
Lead alloys
Stainless steels
Ti alloys
Tungsten carbide
Boron carbide
Silicon
SiC
Al nitride
Technical ceramics
Si3N4
Al2O3
Glasses
Glass ceramic
Soda glass
Silica glass
Stone
Polymers and elastomers
CFRP
Concrete
Line of λ = C/ρe
Composites
PET
PA
GFRP
PE
Wood
Leather
Natural materials
Cork
Butyl rubber
Rigid polymer foams
Foams
Flexible polymer foams
PP
PS
PMMA
Neoprene
MFA, 04



Strength - Density
Metals and polymers: yield strength
Ceramics and glasses: MOR
Elastomers: tensile tear strength
Composites: tensile failure
Ceramics
Composites
Metals
Polymers and elastomers
Natural materials
Foams
Si3N4
SiC
Al2O3
Ti alloys
Steels
Ni alloys
Al alloys
CFRP
Tungsten alloys
Tungsten carbide
Mg alloys
GFRP
PEEK
PET
PA
PC
PMMA
Wood
Copper alloys
Zinc alloys
Lead alloys
Rigid polymer foams
Butyl rubber
Silicone elastomers
Concrete
Cork
Flexible polymer foams
Guidelines for minimum mass design
MFA, 04
Strength, σf (MPa)
Density, ρ (Mg/m3)
10000
1000
100
10
1
0.1
0.01
0.01
0.1
1
10

Case Study: Lightest Tie rod

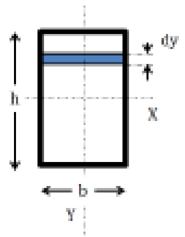
Case Study
Find the Lightest STIFF <u>Tie-Rod</u> →

Objective	• Minimize the mass
Constraints	• Stiffness specified • Length L
Free Variables	• Area (A) of the cross-section • Choice of the material

Tie-Rod =
TRACTION CONDITIONS

DATA
F =1000 N

Dimensions:
Length: 300 mm
Thickness = 1 mm
Width = 25 mm



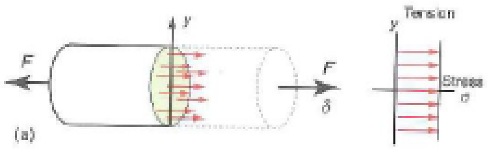
In Traction,
the shape of the cross-section is not important

$$\boxed{m = A \cdot L \cdot \rho} \longrightarrow A = \frac{m}{L \cdot \rho}$$

$$From\ material: \ \frac{\sigma}{\varepsilon} = E$$

$$From\ definition: \ \delta = \varepsilon \cdot L$$

$$F = \sigma \cdot A$$



$$\frac{F}{\delta} \geq S_{min} = S$$

Case Study: Lightest Tie rod

Case Study
Find the Lightest STIFF <u>Tie-Rod</u>

$$\frac{F}{\delta} \geq S_{min} = S$$

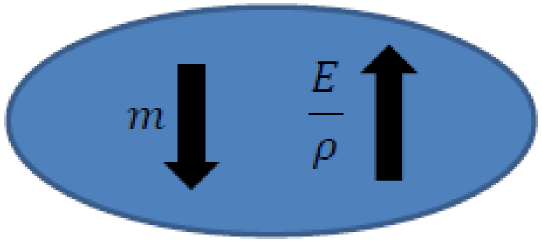
$$\frac{\sigma \cdot A}{\varepsilon \cdot L} \geq S_{min}$$

$$\left.\begin{array}{l} \dfrac{E \cdot A}{L} \geq S_{min} \\[2ex] A = \dfrac{m}{L \cdot \rho} \end{array}\right\} \quad m \geq S \cdot L^2 \cdot \frac{\rho}{E}$$

F = 1000 N
$\delta = 3{,}78 \cdot 10^{-3}$ mm
$S_{min} = 264{,}5 \cdot 10^6$ N/m
Dimensions:
Length: 300 mm
Thickness = 1 mm
Width = 25 mm

$$m \geq (264{,}5 \cdot 10^6) \cdot (300 \cdot 10^{-3})^2 \cdot \frac{\rho}{E}$$

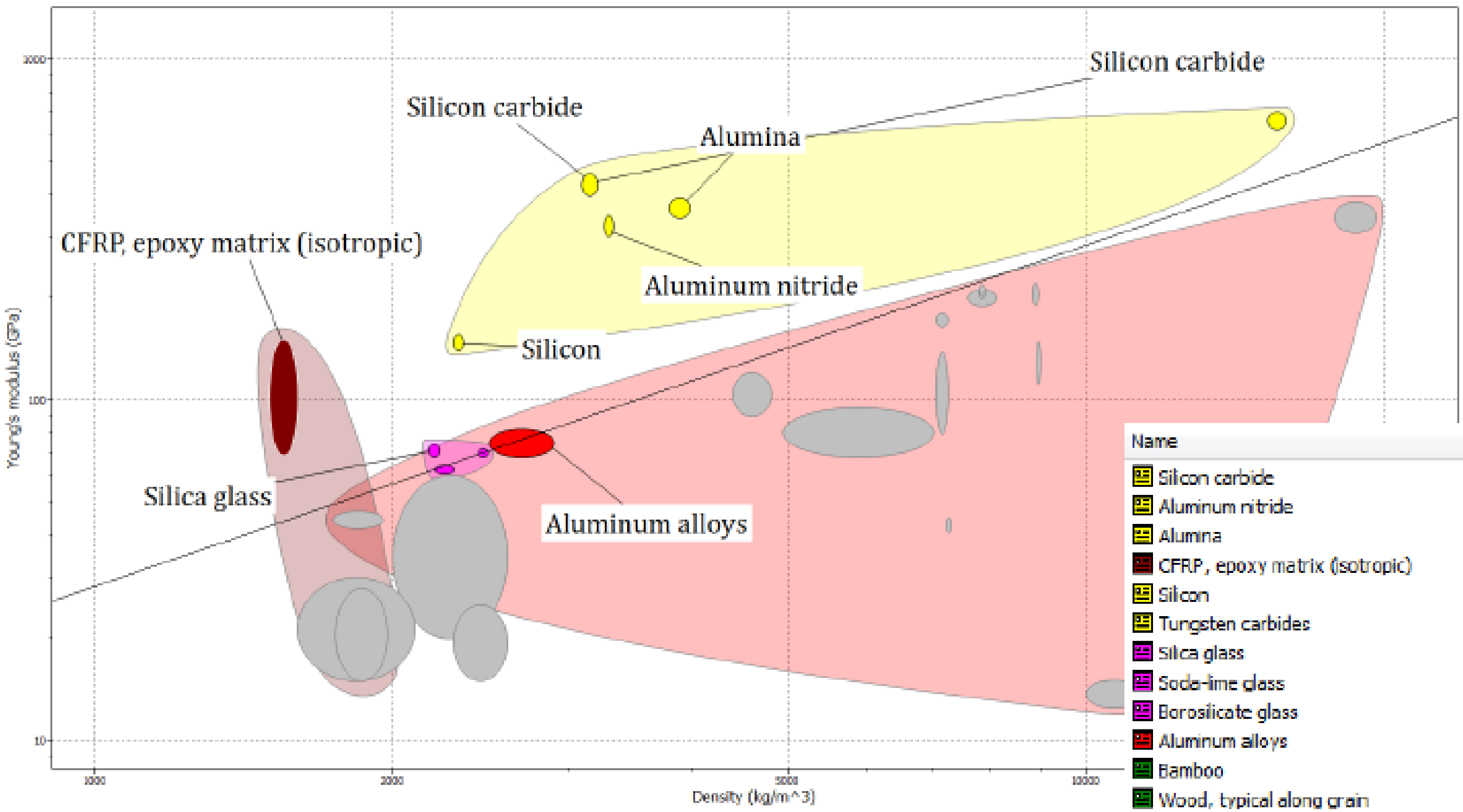
$$\geq \; \ldots \cdot \frac{\rho}{E}$$



Case Study: Lightest Tie rod

$m \downarrow \quad \frac{E}{\rho} \uparrow$

Case Study
Find the Lightest STIFF <u>Tie-Rod</u>

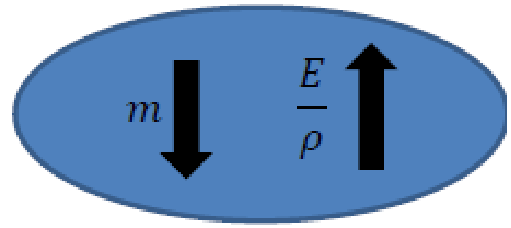


Name	Stage 1: Index
Silicon carbide	0.136
Aluminum nitride	0.0984
Alumina	0.094
CFRP, epoxy matrix (isotropic)	0.0657
Silicon	0.0634
Tungsten carbides	0.0425
Silica glass	0.0323
Soda-lime glass	0.0284
Borosilicate glass	0.0278
Aluminum alloys	0.0277
Bamboo	0.025
Wood, typical along grain	0.0158

Case Study: Lightest Tie rod

Case Study 2:
Find the Lightest STIFF <u>Tie-Rod</u>

$$\left.\begin{array}{l} \dfrac{E \cdot A}{L} \geq S_{min} \\[2ex] A = \dfrac{m}{L \cdot \rho} \end{array}\right\} \; m \geq S \cdot L^2 \cdot \frac{\rho}{E}$$



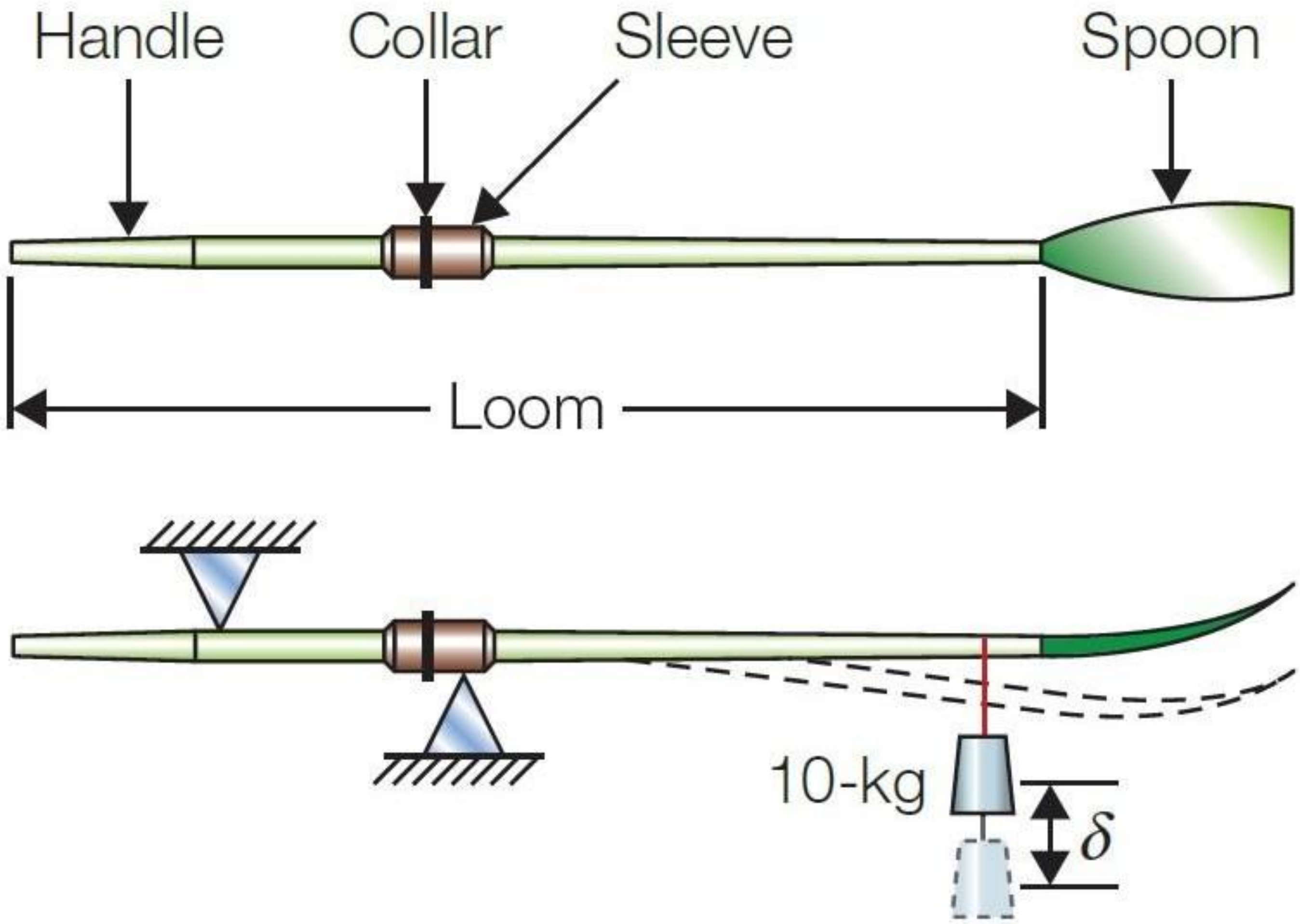
$F = 1000$ N
$\delta = 3{,}78 \cdot 10^{-3}$ mm
$S_{min} = 264{,}5 \cdot 10^{6}$ N/m

Dimensions:
Length: 300 mm
Thickness = 1 mm
Width = 25 mm

Stainless Steel ($E = 200$ GPa; $\rho = 7800$ kg/m^3)
Silicon carbide ($E = 430$ GPa; $\rho = 3150$ kg/m^3)
Al Alloys ($E = 75$ Gpa; $\rho = 2700$ kg/m^3)

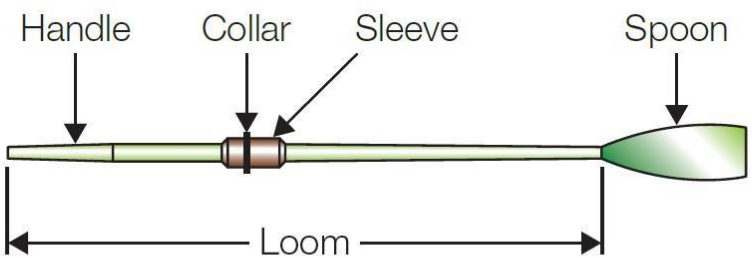
Material	Weight (kg)	A (mm^2)	Width and Thickness (mm)
Silicon Carbide	0,174	179,8	13,4
Al Alloys	0,856	1050	32,4

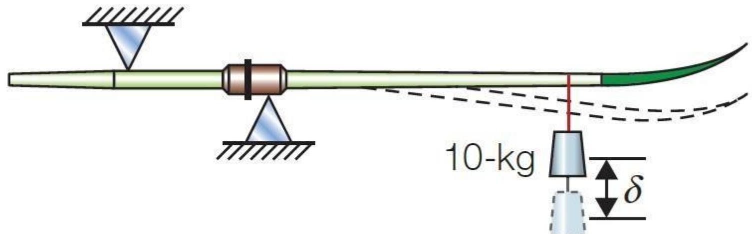
Case Study :
Materials for Oars

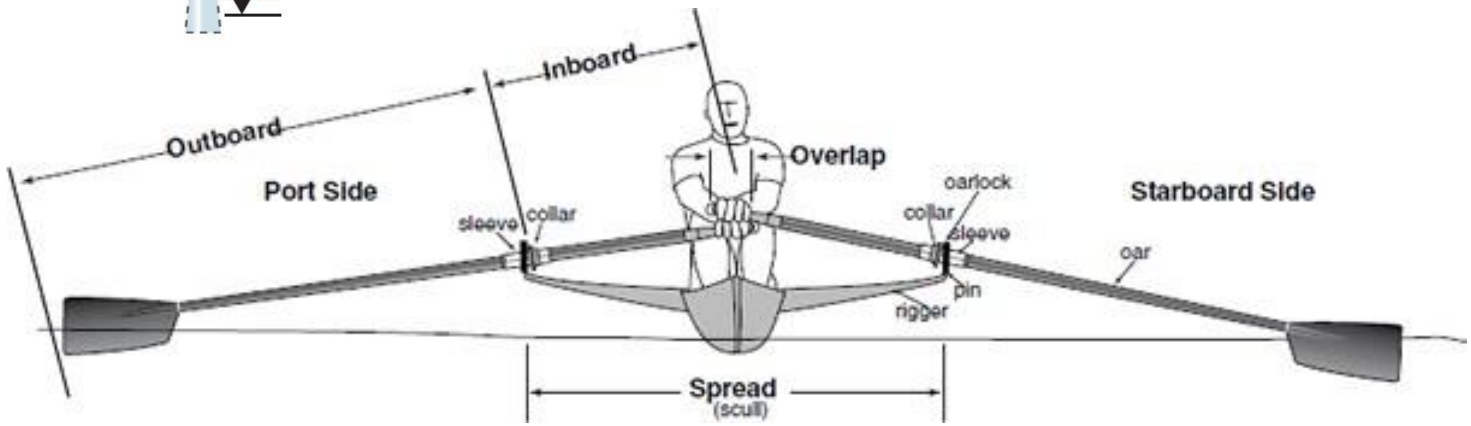


Case Study :
Materials for Oars

Objective	• Minimize the mass
Constraints	• Stiffness specified • Length L • Circular shape (beam)
Free Variables	• Area (A) of the cross-section • Choice of the material

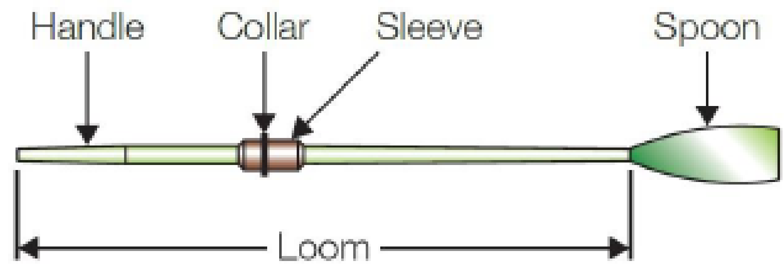






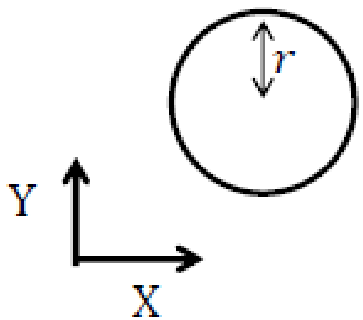
L (Outboard) = 2 m

Case Study
Materials for Light Oars

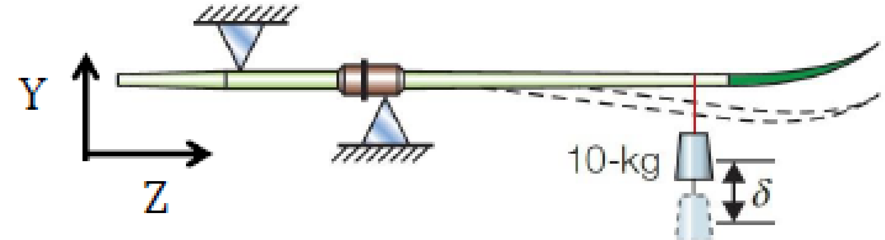


We assume solid section

$$A = \pi \cdot r^2$$

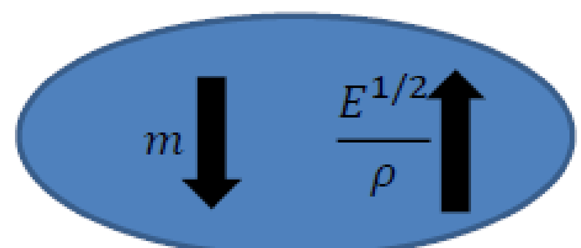


$$I = \frac{\pi r^4}{4} = \frac{A^2}{4\pi}$$



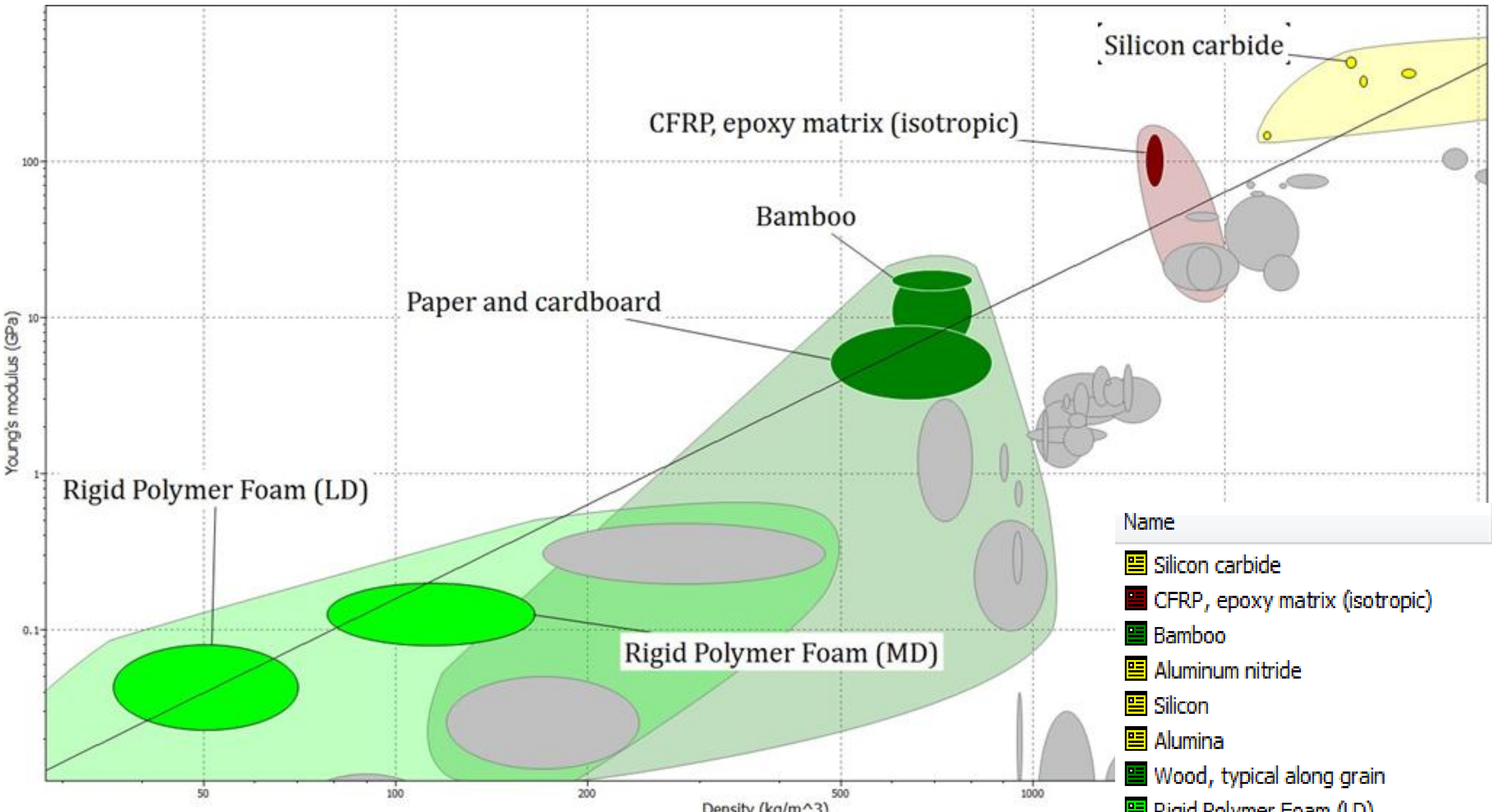
$$\left\{ \begin{array}{l} \dfrac{F}{\delta} \geq S_{min} = \dfrac{C_1 E I}{L^3} \\ A = \dfrac{m}{L \cdot \rho} \end{array} \right.$$

$$\left\{ \begin{array}{l} A = \dfrac{m}{L \cdot \rho} \\ m \geq \left(\dfrac{4 \cdot \pi \cdot S \cdot L^5}{3} \right)^{1/2} \cdot \dfrac{\rho}{E^{1/2}} \end{array} \right.$$



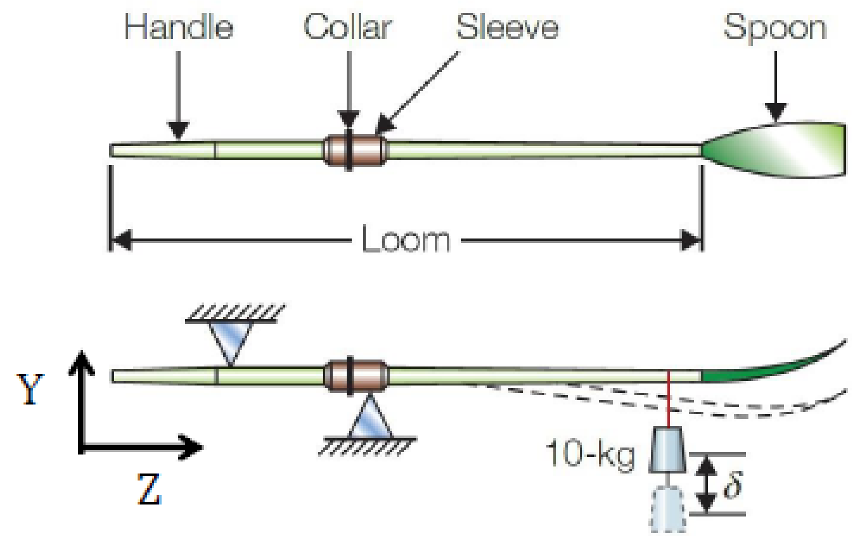
Case Study :
Materials for Light Oars

$m \downarrow \qquad \frac{E^{1/2}}{\rho} \uparrow$



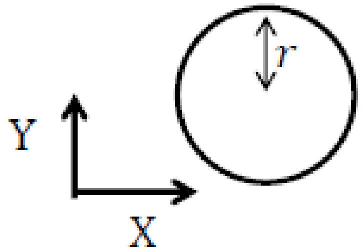
Name	Stage 1: Index
Silicon carbide	0.00657
CFRP, epoxy matrix (isotropic)	0.00651
Bamboo	0.00601
Aluminum nitride	0.00546
Silicon	0.00522
Alumina	0.00492
Wood, typical along grain	0.00478
Rigid Polymer Foam (LD)	0.00413
Paper and cardboard	0.00354
Rigid Polymer Foam (MD)	0.00314

Case Study
Materials for Light and Slender Oars



We assume solid section

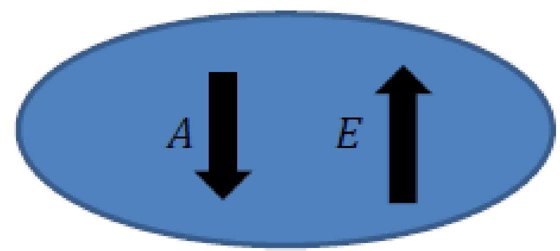
$$A = \pi \cdot r^2$$



$$I = \frac{\pi r^4}{4} = \frac{A^2}{4\pi}$$

$$\begin{cases} \dfrac{F}{\delta} \geq S_{min} = \dfrac{C_1 E I}{L^3} \\ I = \dfrac{\pi r^4}{4} = \dfrac{A^2}{4\pi} \end{cases}$$

$$A \leq \left(\frac{4 \cdot \pi \cdot S \cdot L^3}{3}\right)^{1/2} \cdot \frac{1}{E^{1/2}}$$



Place LIMITS to a single Property
Evaluating the Properties Chart ➡ 10 Gpa < E < 200 GPa

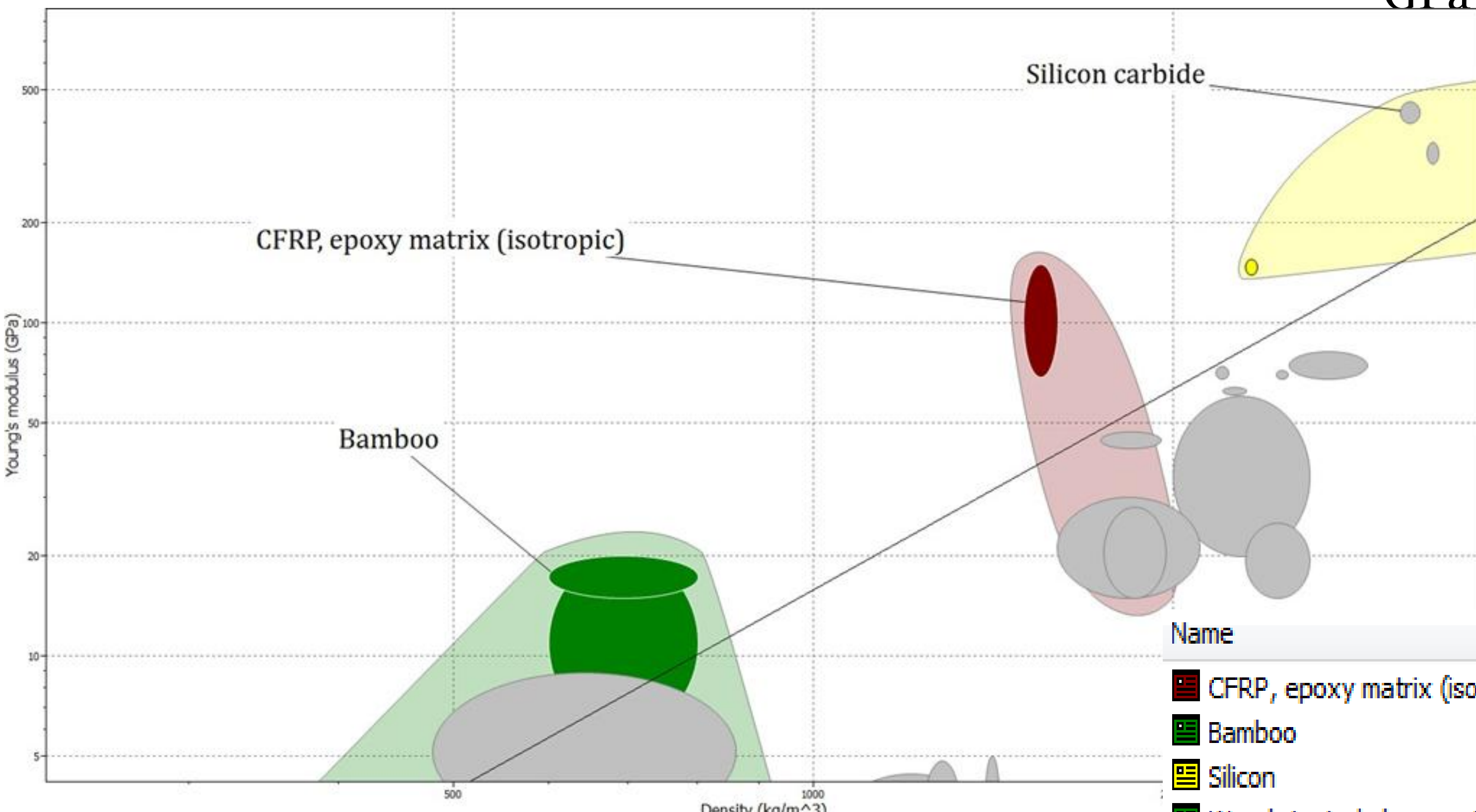
Case Study :
Materials for Light and Slender Oars

$$m \downarrow \qquad \frac{E^{1/2}}{\rho} \uparrow$$

+

10 Gpa < E < 200 GPa

CFRP - best material with more control of the properties
Bamboo – Traditional material for oars for canoes
Woods – Traditional, but with natural variabilities
Ceramics – Low toughness and high cost



Name	Stage 1: Index
CFRP, epoxy matrix (isotropic)	0.00651
Bamboo	0.00601
Silicon	0.00522
Wood, typical along grain	0.00478

Case Study :
Materials for Light and Slender Oars

$$Solid\ I = \frac{\pi r^4}{4} \quad \frac{A^2}{}$$

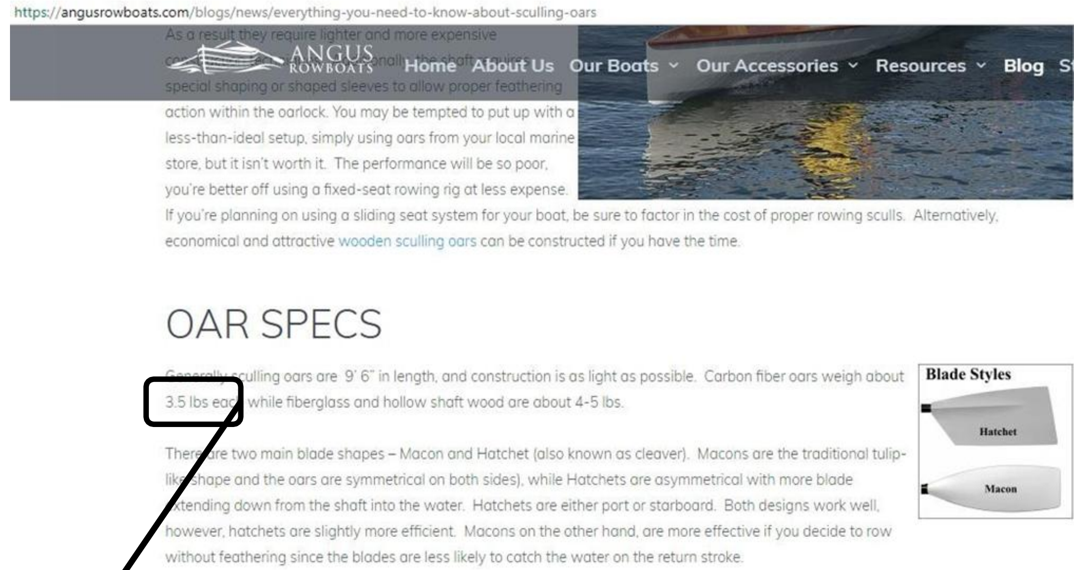
$$Tube\ I = \pi r^3 t \quad \frac{}{4\pi}$$

$$S \geq \frac{\frac{3 \cdot m^2}{E}}{4 \cdot \pi \cdot L^5} \cdot \frac{}{\rho^2}$$

$m \Downarrow$ *At fixed* S_{min}

$S_{min} \Uparrow$

$\delta_{max} \Downarrow$ *At fixed* m


https://angusrowboats.com/blogs/news/everything-you-need-to-know-about-sculling-oars

As a result they require lighter and more expensive ... special shaping or shaped sleeves to allow proper feathering action within the oarlock. You may be tempted to put up with a less-than-ideal setup, simply using oars from your local marine store, but it isn't worth it. The performance will be so poor, you're better off using a fixed-seat rowing rig at less expense.

If you're planning on using a sliding seat system for your boat, be sure to factor in the cost of proper rowing sculls. Alternatively, economical and attractive wooden sculling oars can be constructed if you have the time.

OAR SPECS

Generally sculling oars are 9' 6" in length, and construction is as light as possible. Carbon fiber oars weigh about 3.5 lbs each while fiberglass and hollow shaft wood are about 4-5 lbs.

There are two main blade shapes – Macon and Hatchet (also known as cleaver). Macons are the traditional tulip-like shape and the oars are symmetrical on both sides), while Hatchets are asymmetrical with more blade extending down from the shaft into the water. Hatchets are either port or starboard. Both designs work well, however, hatchets are slightly more efficient. Macons on the other hand, are more effective if you decide to row without feathering since the blades are less likely to catch the water on the return stroke.

1,58 kg

Probably Tube shape

Assume 2,5 kg for a Solid Oar

CFRP (E = 110 GPa; ρ = 1550 kg/m³)

Bamboo (E = 17,5 GPa; ρ = 700 kg/m³)

S_{CFRP} = 853,94 N/m

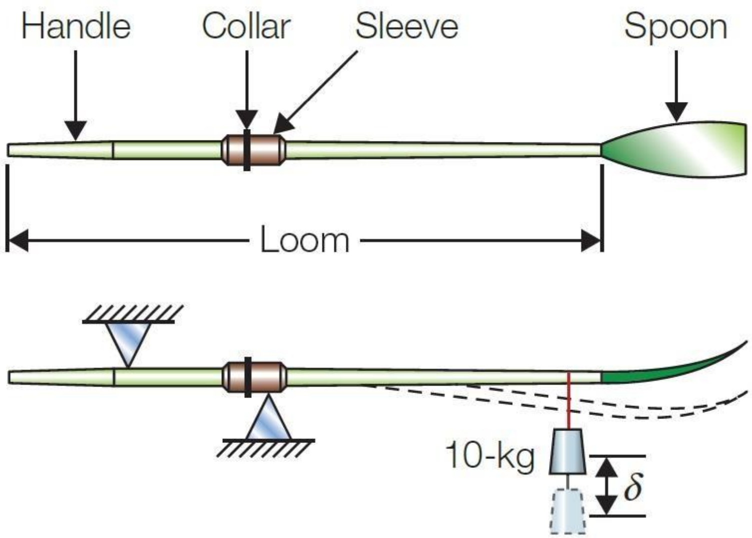
S_{Bamboo} = 666,1 N/m

CFRP good for Competition Oar

Case Study :
Materials for CHEAP and Slender Oars

→

Objective	• Minimize the cost
Constraints	• Stiffness specified • Length L • Circular shape (beam)
Free Variables	• Area (A) of the cross-section • Choice of the material



L (Outboard) = 2 m

Case Study :
Materials for CHEAP and Slender Oars

$$\begin{cases} m \geq \left(\dfrac{4 \cdot \pi \cdot S \cdot L^5}{3}\right)^{1/2} \cdot \dfrac{\rho}{E^{1/2}} \\ C = m \cdot C_m \end{cases} \longrightarrow \quad m = \frac{C}{C_m}$$

$$C \geq \left(\frac{4 \cdot \pi \cdot S \cdot L^5}{3}\right)^{1/2} \cdot \frac{\rho \cdot C_m}{E^{1/2}}$$

$$C \downarrow \quad \frac{E^{1/2}}{\rho \cdot C_m} \uparrow$$

$\boldsymbol{C}$ Cost

$\boldsymbol{C_m}$ Cost per unit of mass

$\downarrow$

Better to consider cost always as a function of mass

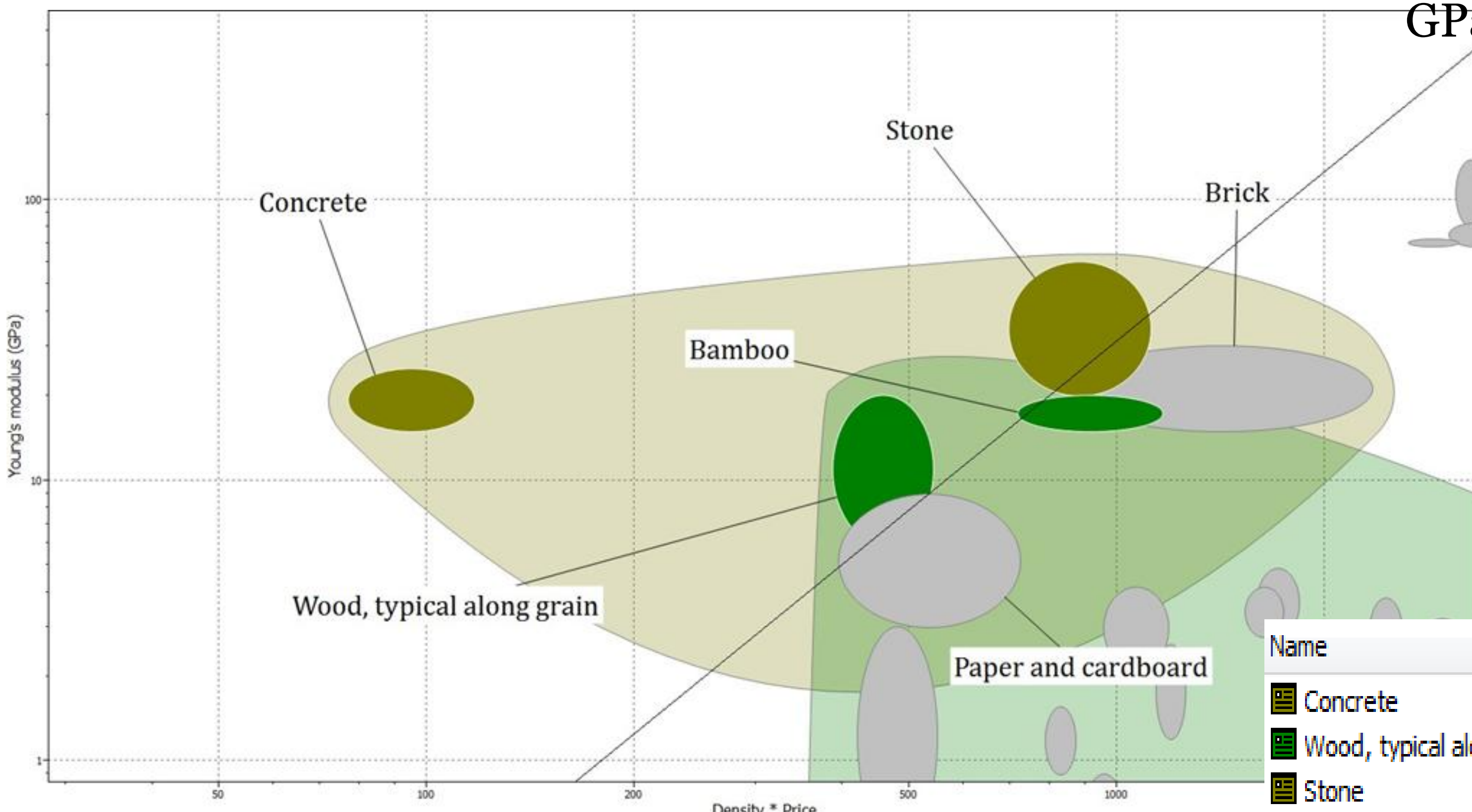
Case Study :
Materials for CHEAP and Slender Oars

$$C \downarrow \qquad \frac{E^{1/2}}{\rho \cdot C_m} \uparrow$$

+

10 Gpa < E < 200 GPa

Bamboo – Traditional material for oars for canoes
Woods – Traditional, but with natural variabilities
Stone and Concrete – Low toughness and difficult to manufacture



Name	Stage 1: Index
Concrete	0.0464
Wood, typical along grain	0.00722
Stone	0.00665
Bamboo	0.00455

Case Study :
Materials for CHEAP and Slender Oars

$$\begin{cases} m \geq \left(\dfrac{4 \cdot \pi \cdot S \cdot L^5}{3}\right)^{1/2} \cdot \dfrac{\rho}{E^{1/2}} \\ C = m \cdot C_m \end{cases} \longrightarrow \quad m = \frac{C}{C_m}$$

$$C \geq \left(\frac{4 \cdot \pi \cdot S \cdot L^5}{3}\right)^{1/2} \cdot \frac{\rho \cdot C_m}{E^{1/2}}$$

$$C \downarrow \qquad \frac{E^{1/2}}{\rho \cdot C_m} \uparrow$$

$\boldsymbol{C}$ Cost

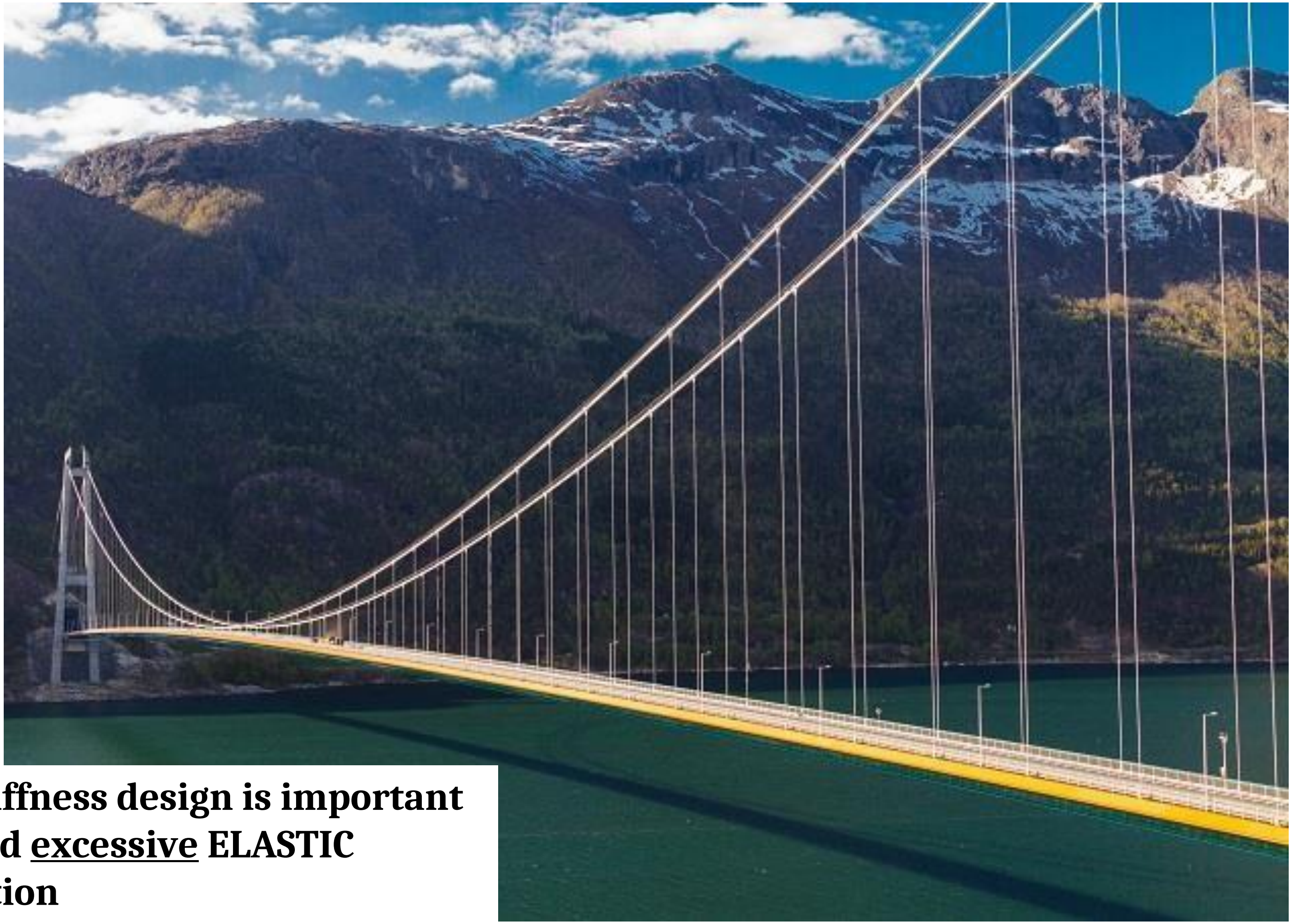
$\boldsymbol{C_m}$ Cost per unit of mass

$\downarrow$

Better to consider cost always as a function of mass

Woods good for Commercial Oar

The Stiffness design

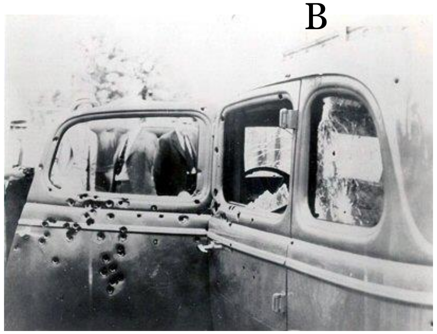


The Stiffness design is important to avoid <u>excessive</u> ELASTIC deflection

Case Study :
Materials for Car Body

Some context → Car Evolution

1932 Ford Model B



1934 Bonnie and Clyde car

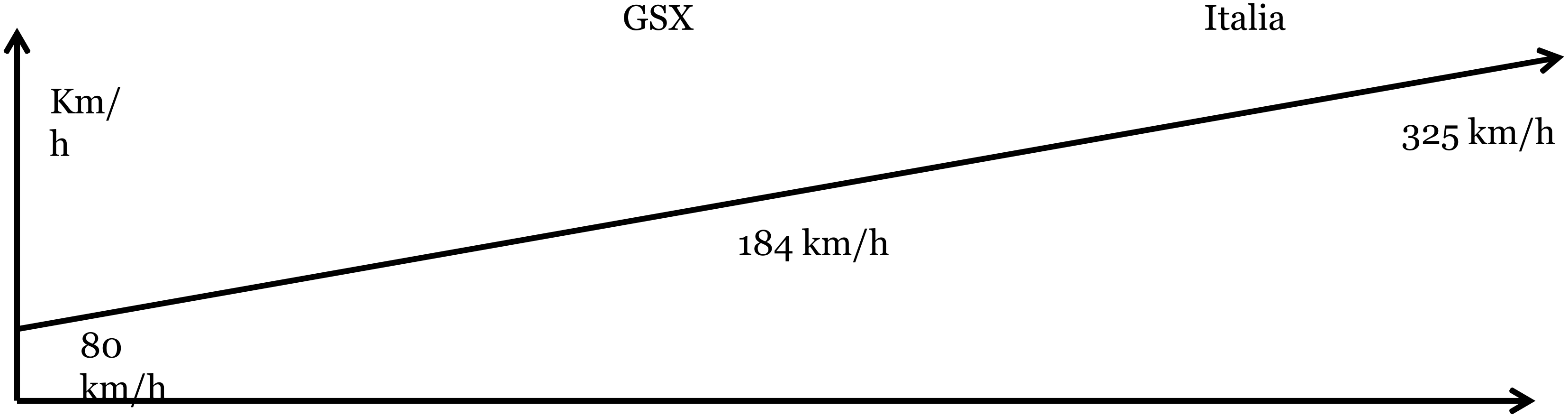
Case Study : Materials for Car Body

Some context → Car Evolution

1932 Ford Model B

1970 Buick GSX

2010 Ferrari 458 Italia



Case Study :
Materials for Car Body

$Deformation?? \rightarrow ENERGY\ CONSUMPTION$

At first, automotive industry move to too deformable cars and then move to have a mix FOR PEOPLE SAFETY

Rover 100 (1997)   Rover 100 (2017)

Sometimes exaggerate

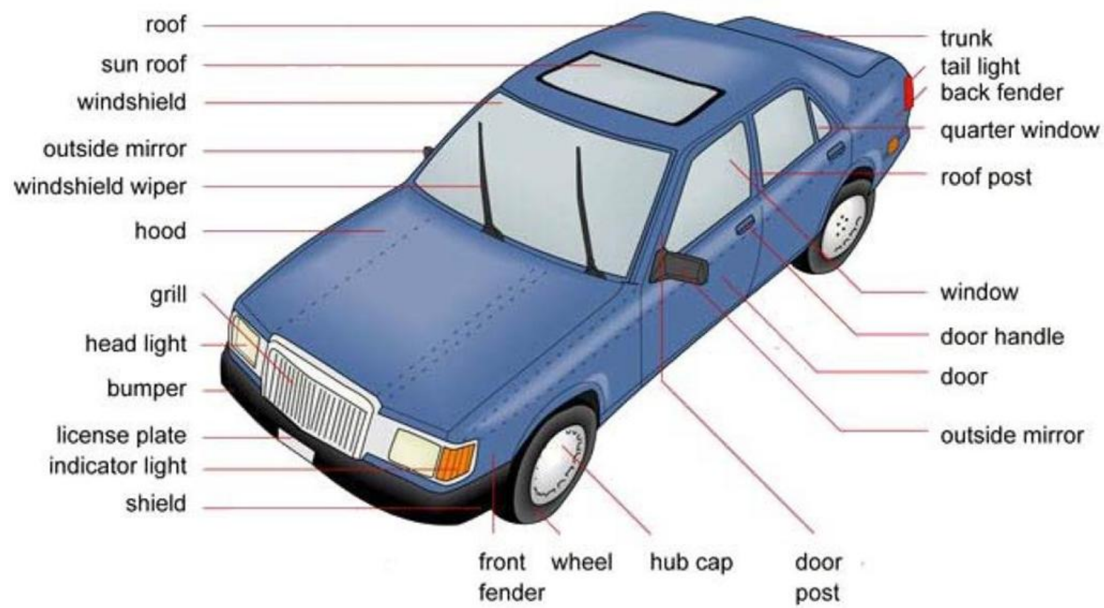
Case Study : Materials for Car Body (Car Hood or Car Door)

Objective	• Maximize plastic deformation at high load
Constraints	• Geometry • $High\ \sigma_y$ • Division for price • Consider manufacture
Free Variables	• Choice of the material

$LIGHT??\rightarrow m$

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

Total strain energy PER UNIT OF MASS



Case Study : Materials for Car Body (Car Hood or Car Door)

Objective	• Maximize plastic deformation at high load
Constraints	• Geometry • $High\ \sigma_y$ • Division for price • Consider manufacture
Free Variables	• Choice of the material

$LIGHT??\to m$

$LIGHT??\to m$

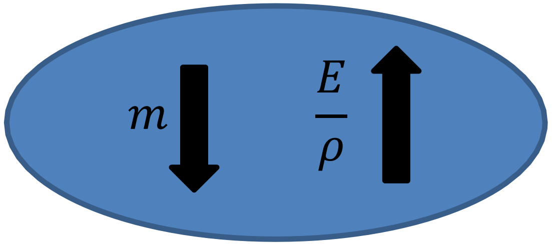
$$\frac{W_{el}}{\rho}=\frac{{\sigma_f}^2}{2\cdot E\cdot \rho}=M_2$$

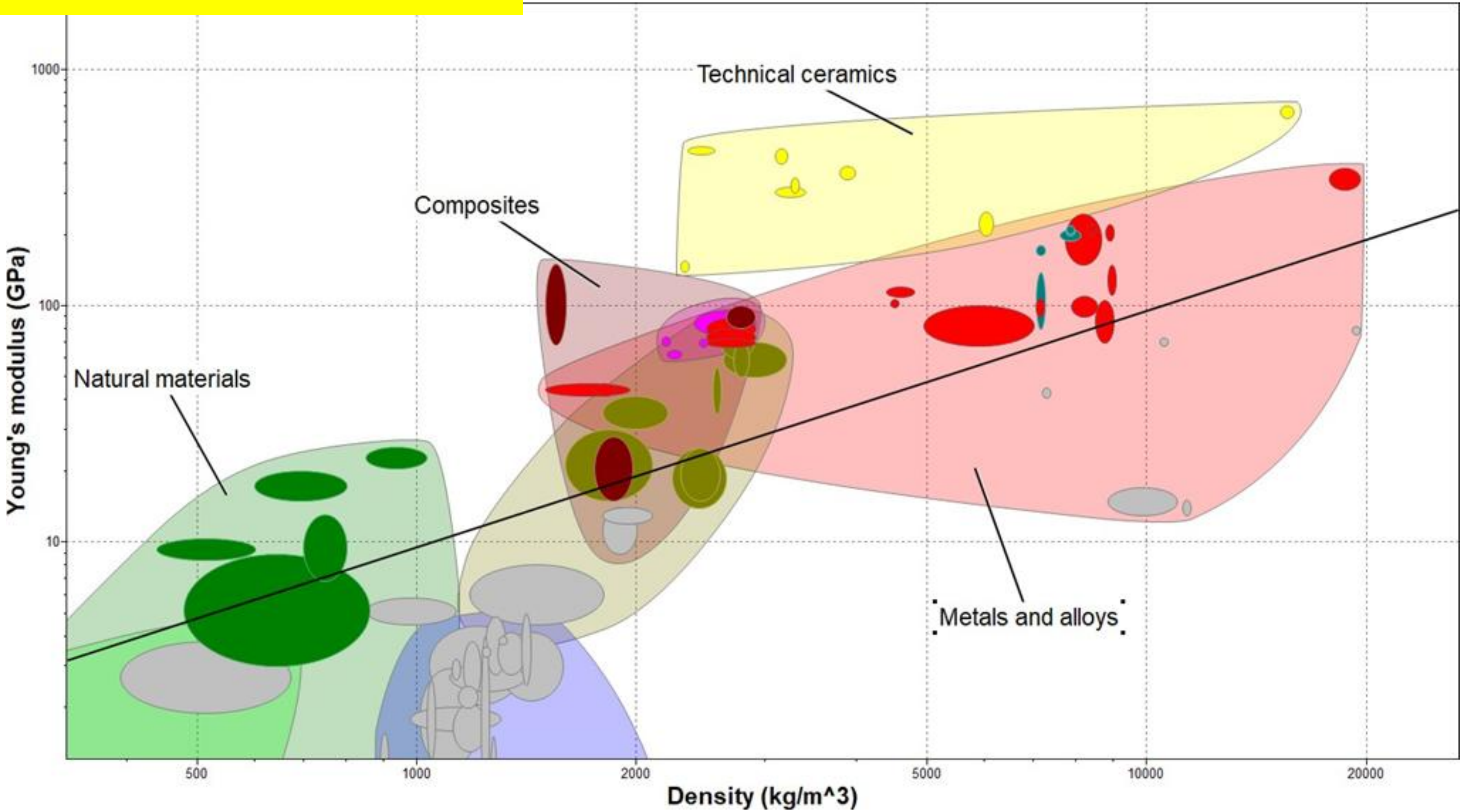
Total strain energy PER UNIT OF MASS

Steps:

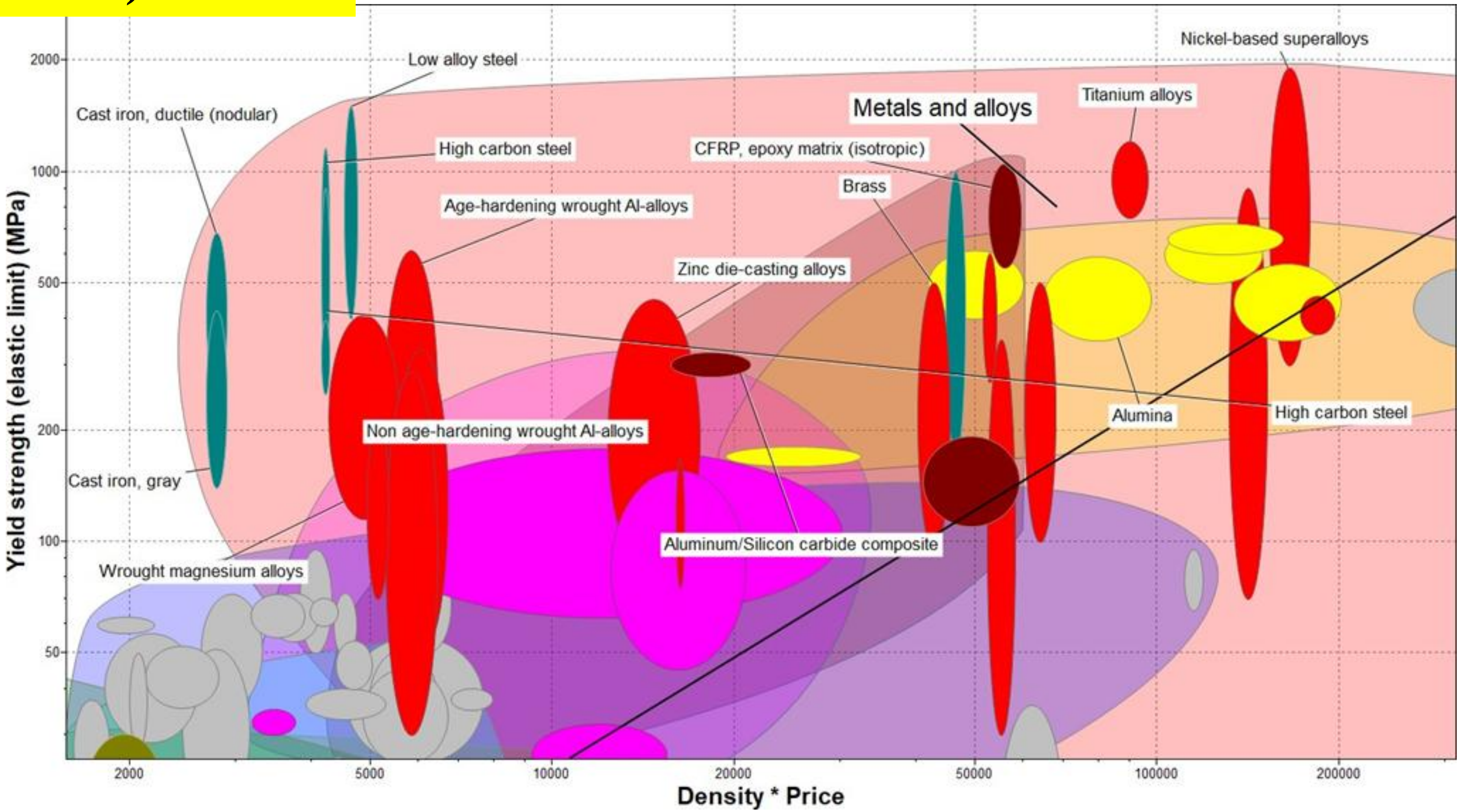
- *Stiffness selection (Take off flexible materials)*
- *Yield strength selection to minimize the costs (Automotive)*
- *Minimum Yield Strength*
- *Maximization of stored energy*

Case Study : Materials for Car Body (Car Hood or Car Door)



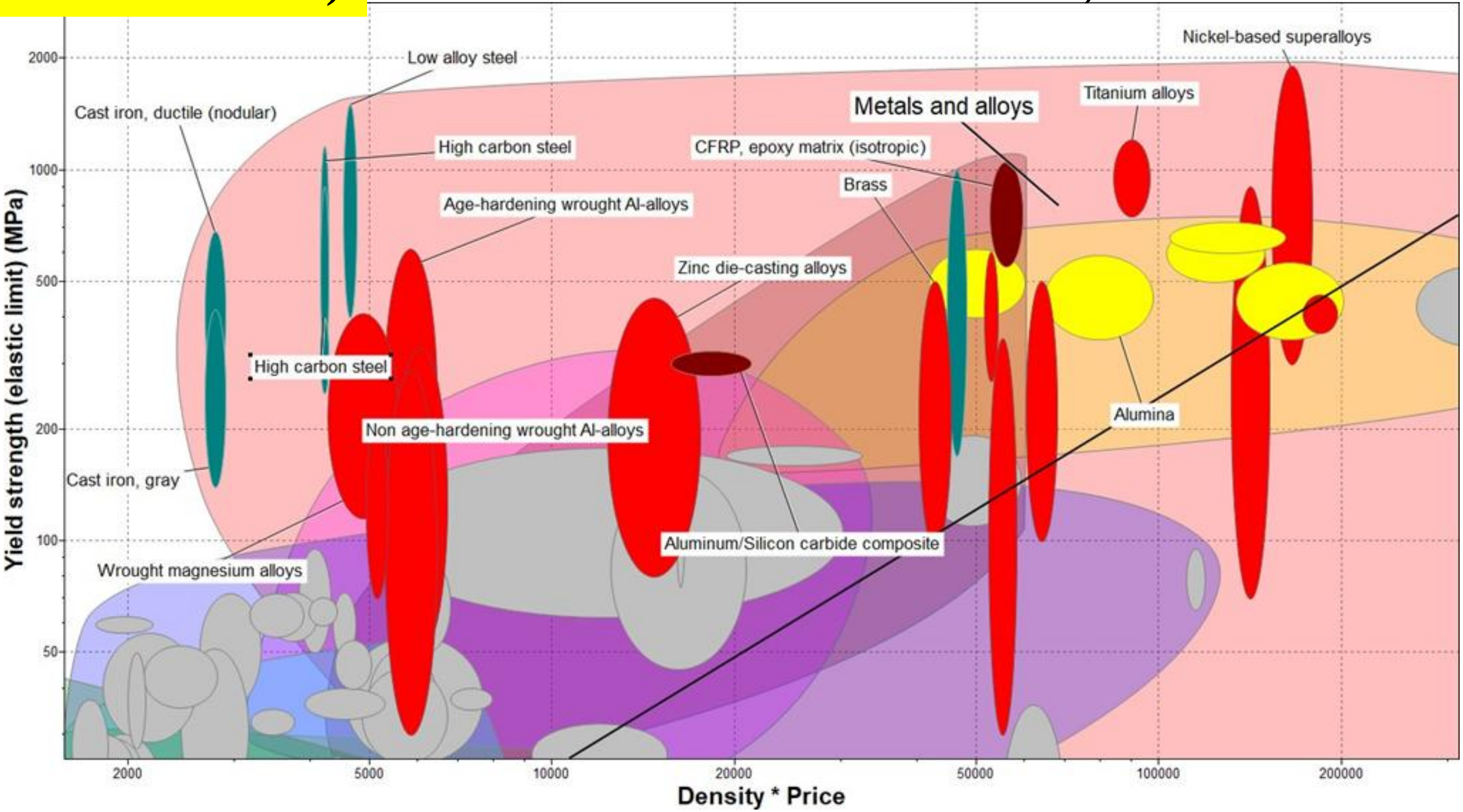


Case Study : Materials for Car Body (Car Hood or Car Door)



Case Study 12: Materials for Car Body (Car Hood or Car Door)

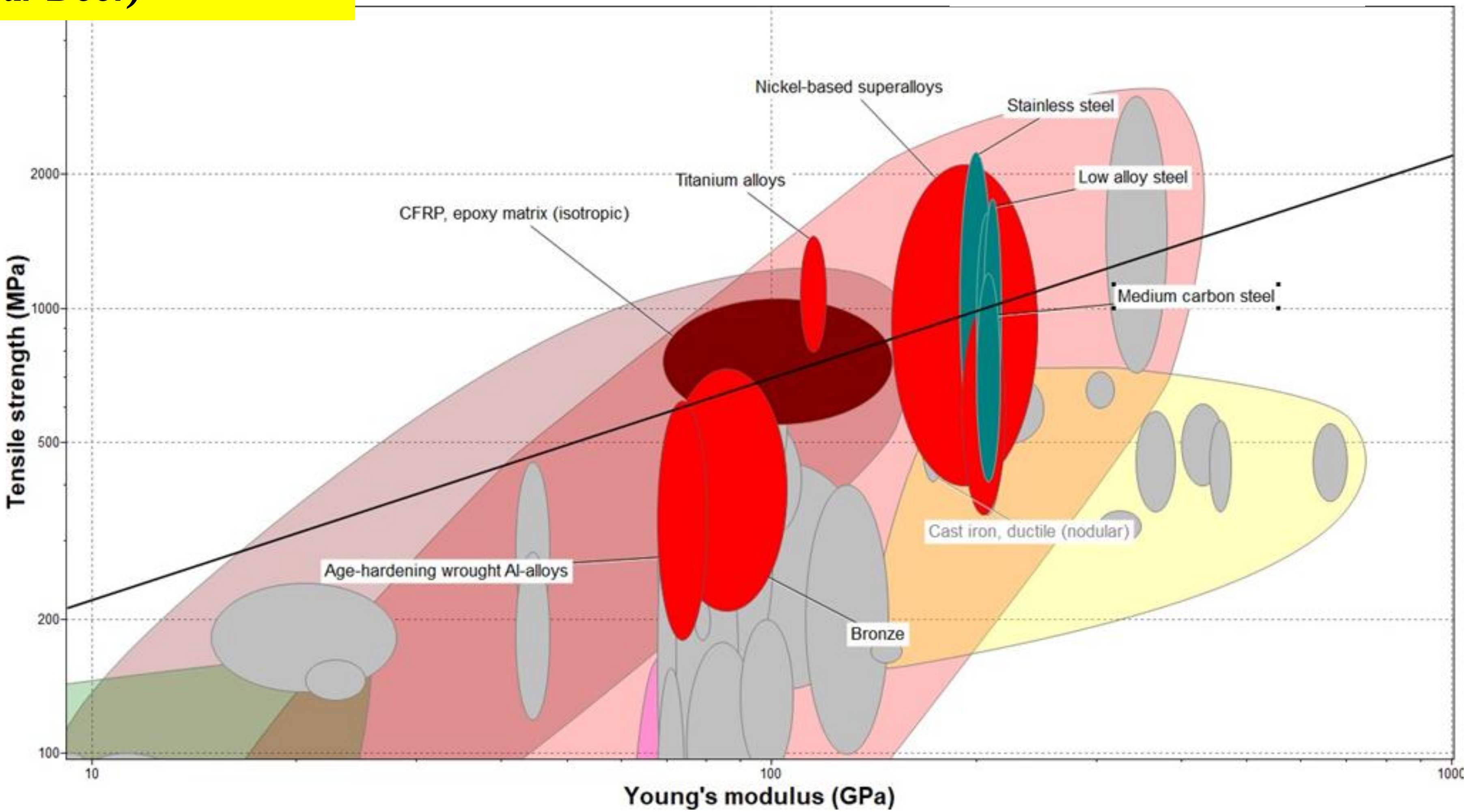
+ $minimum\ \sigma_y$ (200 MPa)



Case Study : Materials for Car Body (Car Hood or Car Door)

$$W_{el} = \frac{\sigma_f^{\,2}}{2E} = M_1$$

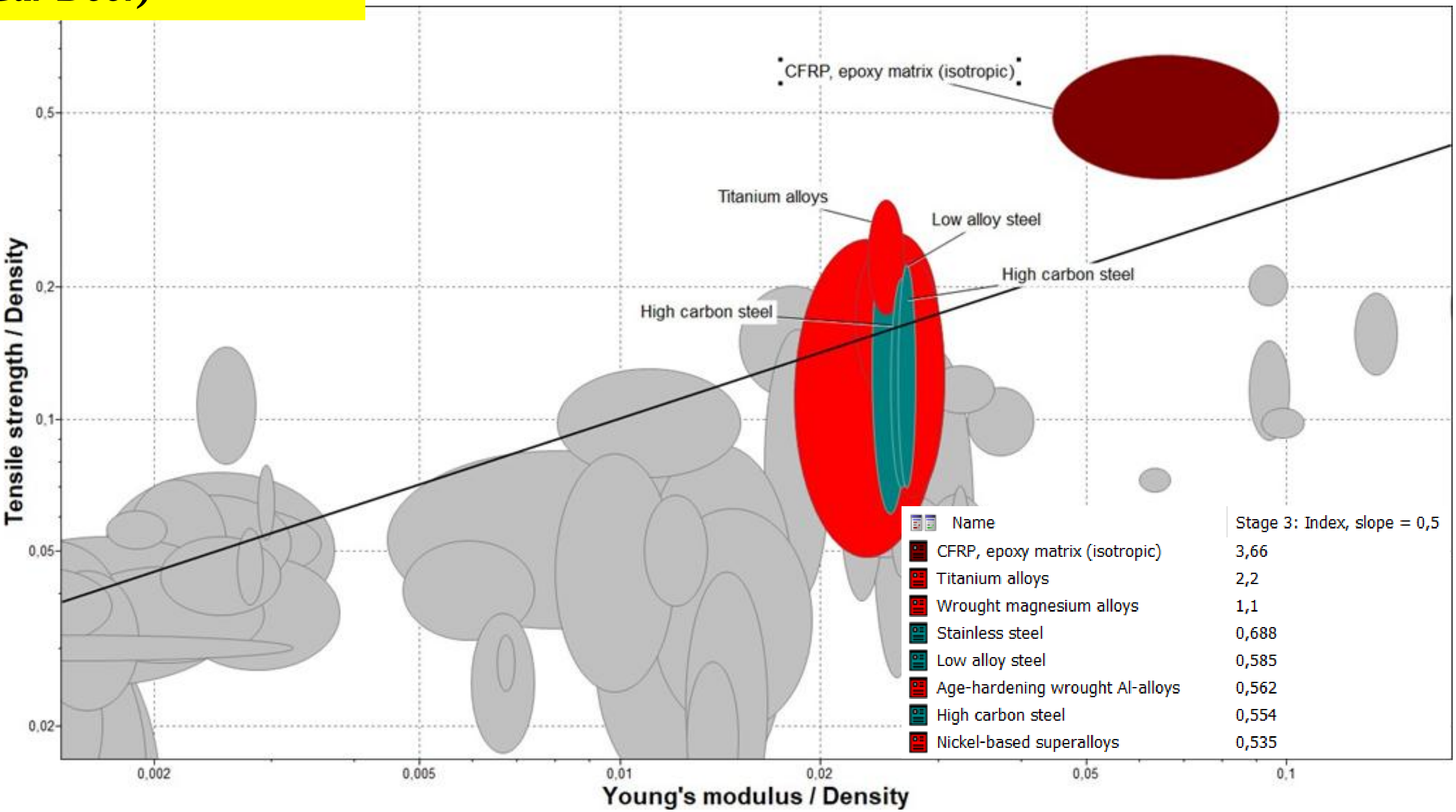
Total strain energy PER UNIT OF VOLUME



Case Study : Materials for Car Body (Car Hood or Car Door)

$$\frac{W_{el}}{\rho} = \frac{\sigma_f^{\,2}}{2 \cdot E \cdot \rho} = M_2$$

Total strain energy PER UNIT OF MASS



Case Study : Materials for Car Body (Car Hood or Car Door)

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

Total strain energy PER UNIT OF MASS

Lamborghini Huracan 2015

Name	Stage 3: Index, slope = 0,5
CFRP, epoxy matrix (isotropic)	3,66
Titanium alloys	2,2
Wrought magnesium alloys	1,1
Stainless steel	0,688
Low alloy steel	0,585
Age-hardening wrought Al-alloys	0,562
High carbon steel	0,554
Nickel-based superalloys	0,535

Case Study : Materials for Car Body (Car Hood or Car Door)

Manufacturing Consideration

Changing the carbon fiber manufacturing process

Lamborghini's innovation is a product and a process called Forged Composite. This material starts off as a sheet of uncured plastic that is mixed with short lengths of randomly placed carbon fiber strands. Unlike traditional pre-preg carbon fiber cloth, you don't have to carefully cut this material and lay it out precisely in a mold. You just have to cut off the right mass and put the chunk into a hot press mold. You squeeze it, heat it and you're done. The part that comes out of the mold is as light (or lighter) and as stiff (or stiffer) than a conventionally laid-up carbon fiber part, and you can produce it in minutes rather than hours.

You can now treat carbon fiber the way the automobile industry has treated steel, aluminum, and unreinforced plastic for decades.

This changes the rules of manufacturing because you can now treat carbon fiber the way the automobile industry (and every other manufacturing industry) has treated steel, aluminum, and unreinforced plastic for decades: You just stamp out the parts you need. As automakers look to the future of increased CAFE standards and lighter-weight vehicles, making parts out of carbon fiber without the extra labor expense is a killer app.

"By continuing to develop our patented forged composite materials, we are able to create a product that can enhance Lamborghini super sports cars in both their performance and their appearance," said Maurizio Reggiani, Director of R&D for Lamborghini. "The ability to leverage this kind of lightweight material gives Lamborghini an advantage that will benefit our cars – as well as production process – in the future."

[www.digitaltrends.com/cars/lamborghini-forged-carbon-fiber-manufacturing-process]

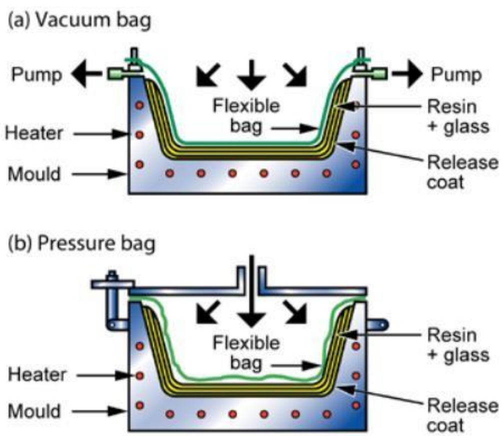
Vacuum and pressure bag molding

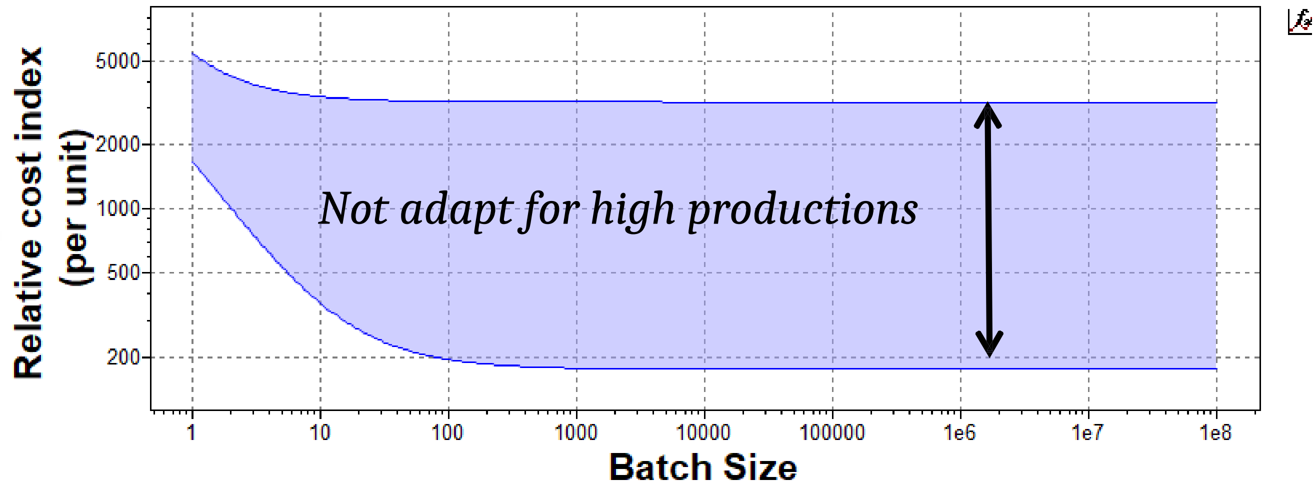
Case Study : Materials for Car Body (Car Hood or Car Door)

Cost model and defaults

Relative cost index (per unit)	178	-	3,2e3	

Parameters: Material Cost = 7,33EUR/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 137EUR/hr, Discount Rate = 5%, Capital Write-off Time = 5yrs, Load Factor = 0,5





Material Cost=7,33EUR/kg, Component Mass=1kg, Overhead Rate=137EUR/hr, Capital Write-off Time=5yrs, Load Factor=0,5, Discount Rate=5%

Capital cost	3,01e4	-	7,52e5	EUR
Material utilization fraction	0,85	-	0,95	
Production rate (units)	0,05	-	1	/hr
Tooling cost	752	-	3,01e3	EUR
Tool life (units)	100	-	1e3	

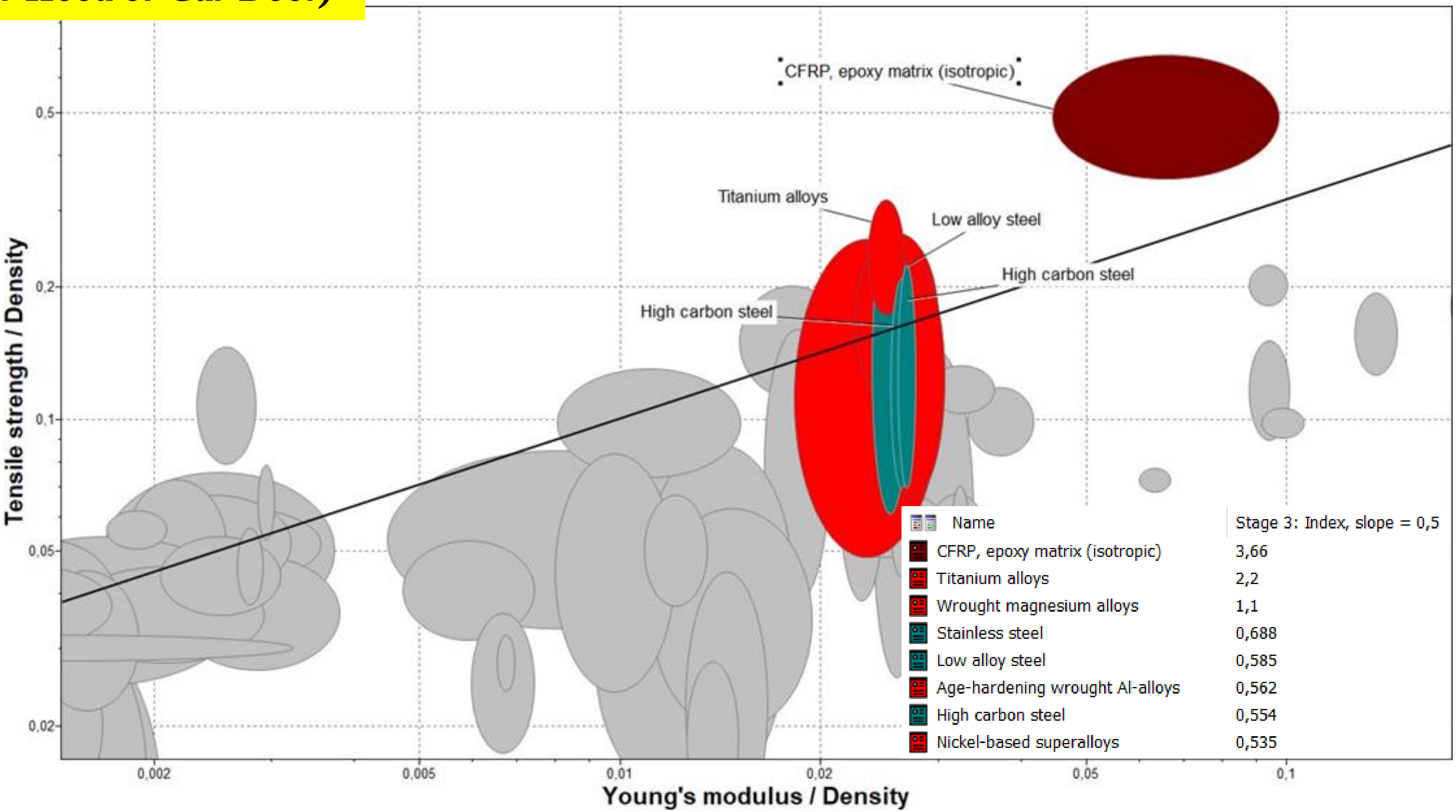
No way for a commercial car

Case Study 12:
Materials for Car Body
(Car Hood or Car Door)

And which Metal?

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

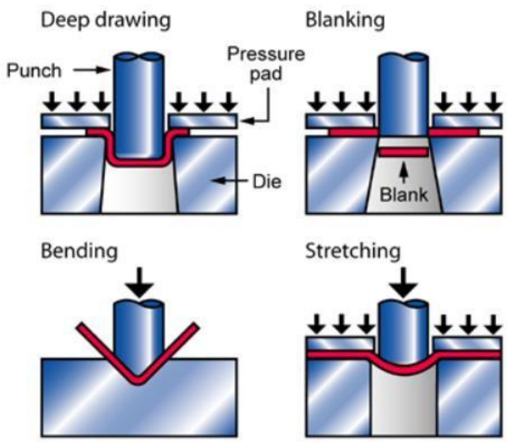
Total strain energy
PER UNIT OF MASS



Name	Stage 3: Index, slope = 0,5
CFRP, epoxy matrix (isotropic)	3,66
Titanium alloys	2,2
Wrought magnesium alloys	1,1
Stainless steel	0,688
Low alloy steel	0,585
Age-hardening wrought Al-alloys	0,562
High carbon steel	0,554
Nickel-based superalloys	0,535

Stamping

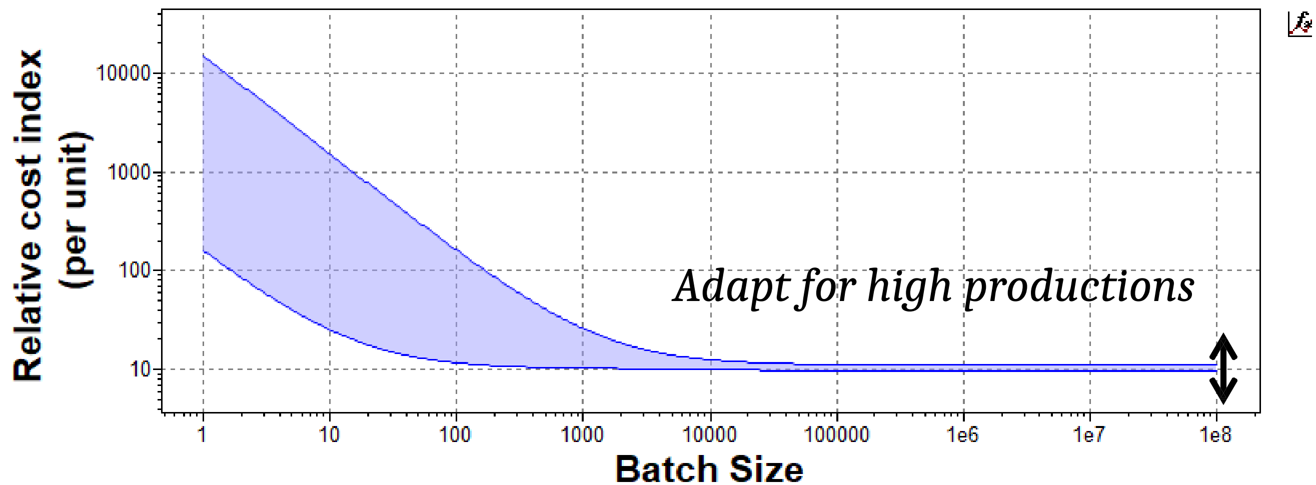
Case Study : Materials for Car Body (Car Hood or Car Door)



Cost model and defaults

Relative cost index (per unit)	10,3	-	26	

Parameters: Material Cost = 7,33EUR/kg, Component Mass = 1kg, Batch Size = 1e3, Overhead Rate = 137EUR/hr, Discount Rate = 5%, Capital Write-off Time = 5yrs, Load Factor = 0,5



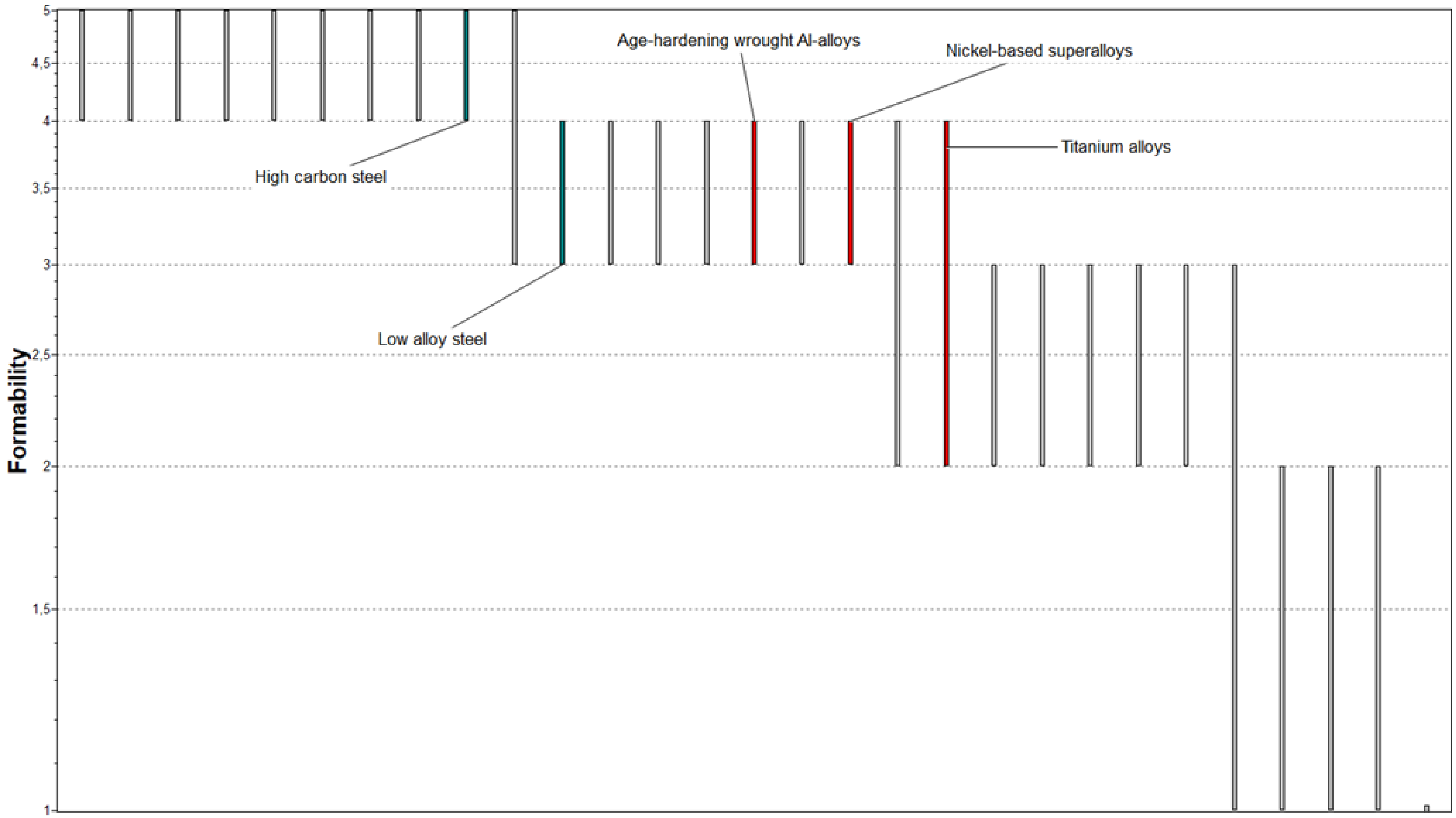
Material Cost=7,33EUR/kg, Component Mass=1kg, Overhead Rate=137EUR/hr, Capital Write-off Time=5yrs, Load Factor=0,5, Discount Rate=5%

Capital cost	7,52e3	-	7,52e4	EUR
Material utilization fraction	0,7	-	0,8	
Production rate (units)	200	-	5e3	/hr
Tooling cost	150	-	1,5e4	EUR
Tool life (units)	1e4	-	1e6	

PROCESSABILITY

Case Study : Materials for Car Body (Car Hood or Car Door)

Metals easy to stamp

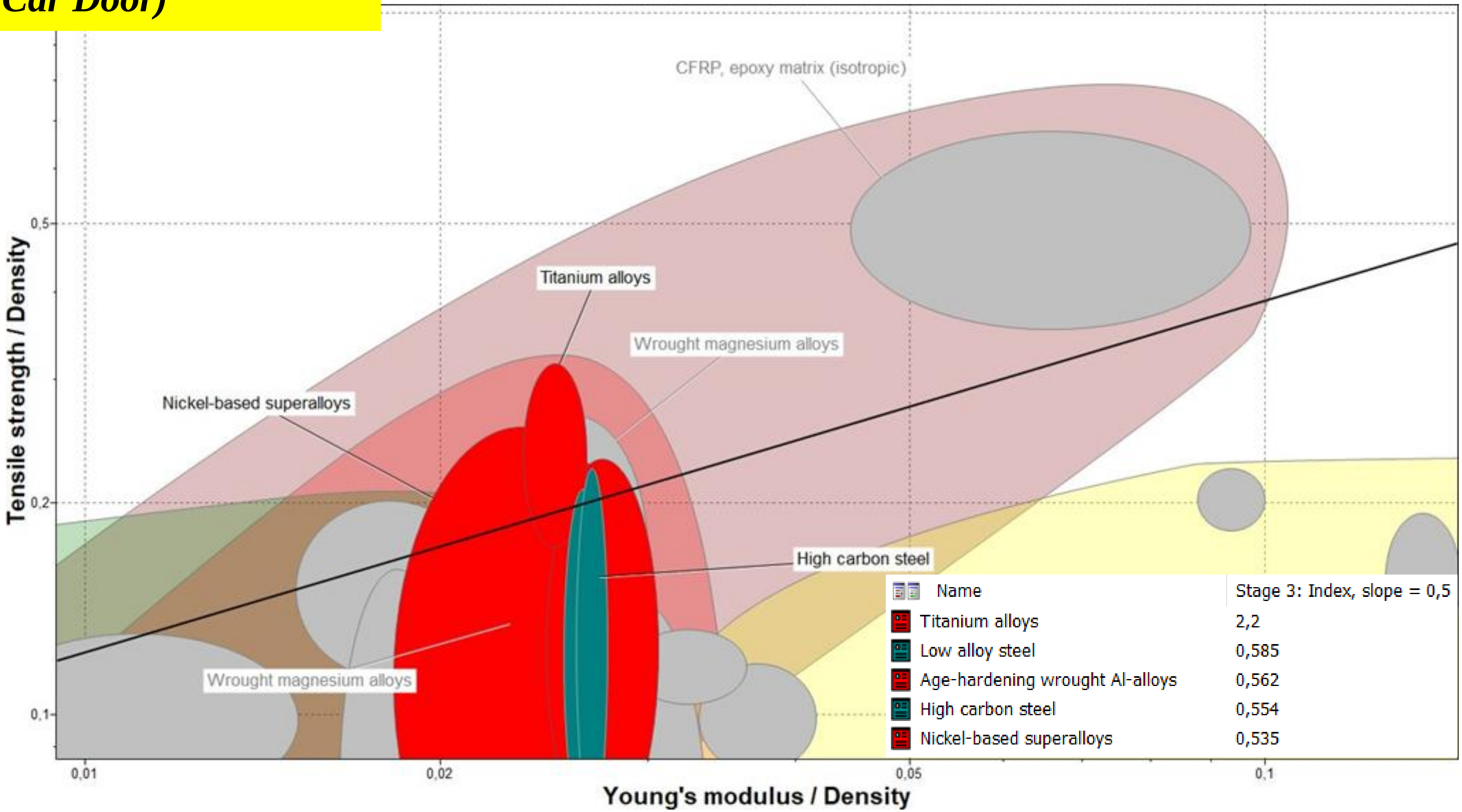


Case Study : Materials for Car Body (Car Hood or Car Door)

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

+ Minimum Formability (4)

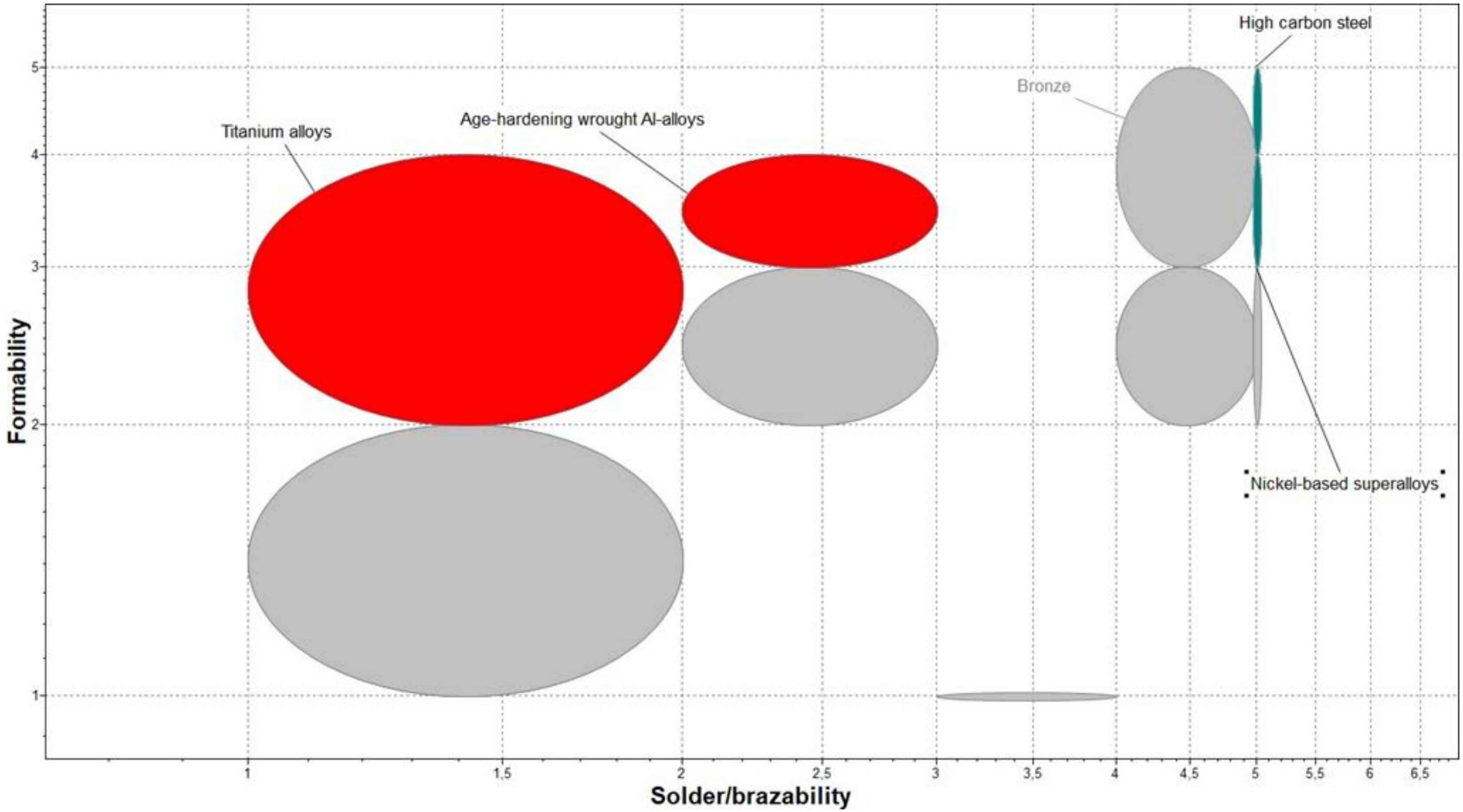
Total strain energy PER UNIT OF MASS



PROCESSABILITY

Case Study : Materials for Car Body (Car Hood or Car Door)

Metals easy to stamp



Case Study 12:
Materials for Car Body
(Car Hood or Car Door)

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

Total strain energy
PER UNIT OF MASS

+ Minimum Formability (4)
+ Minimum Brazability (3)

Case Study : Materials for Car Body (Car Hood or Car Door)

Name	Stage 3: Index, slope = 0,5
Low alloy steel	0,585
Age-hardening wrought Al-alloys	0,562
High carbon steel	0,554
Nickel-based superalloys	0,535

Deeper selection?

⬇

LEVEL 3

[https://www.cartalk.com/blogs/jim-motavalli/steel-vs-aluminum-lightweight-wars-heat]

Materials Selection Steps

Decide Design Requirements

Get rid of Candidates that don't fit constraints e.g. max service temperature isn't high enough

Optimize on Objectives e.g. low mass, low cost, high strength

Scrutinize candidate shortlist – do I have valid properties

- Materials Selection is about trade-offs, not one right answer
- Environmental legislation, processability and the security of the supply chain are important factors, along side mechanical and thermal performance

Optional:

Decide on strategy to fill knowledge gaps

THANK YOU