Nature and Properties of Materials: Classification

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Introduction: Big questions

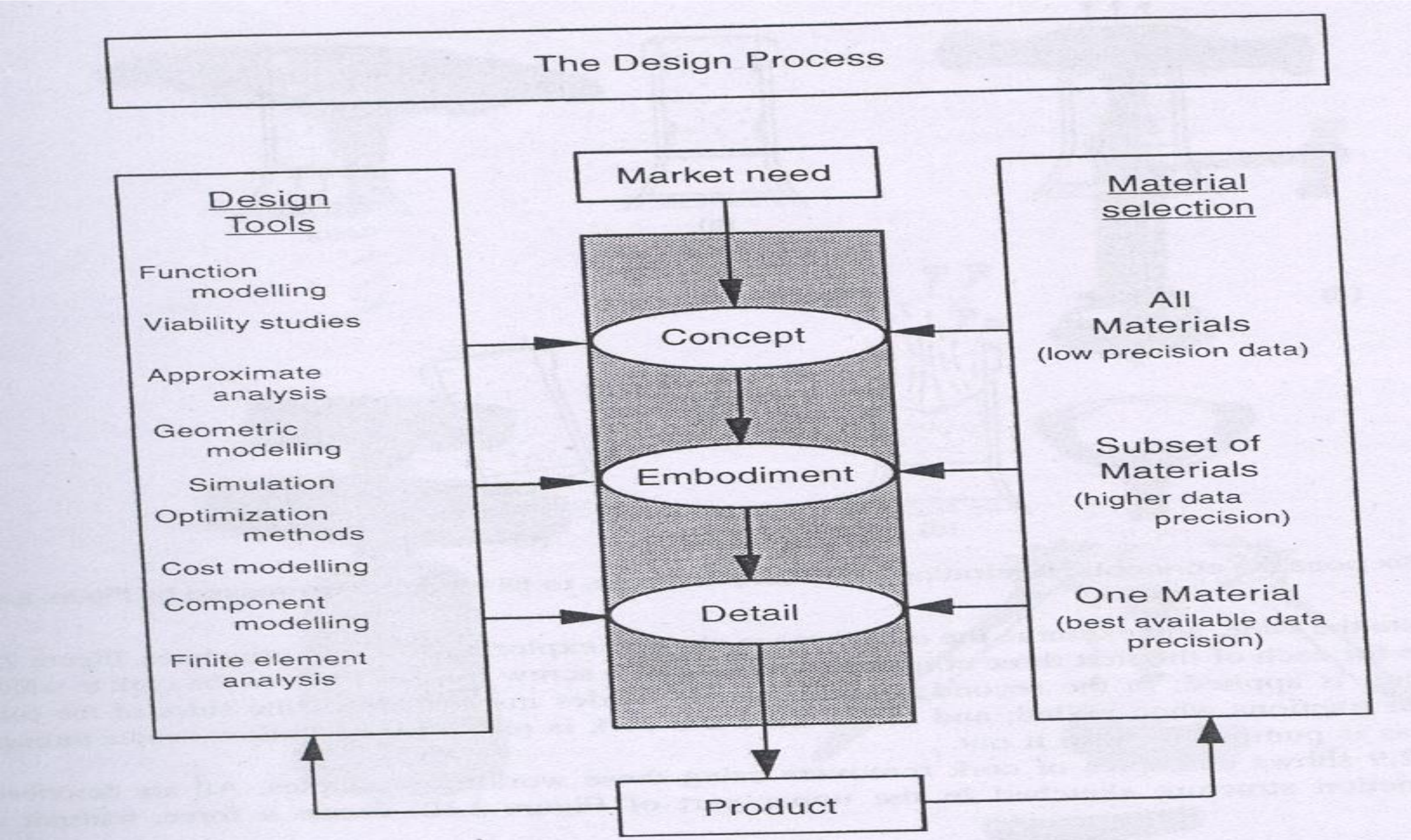
- There are more than 50,000 materials available for the engineers today! While designing a structure or device how is he going to select one suitable material?
- A living species is uniquely identifiable by its Genome is there an equivalence in the material world?
- When we think of a device design what comes first? The material – form or function?

Boeing 787-Dreamliner: Expression of Form, Function or Material?

Basics of Design

- Mechanical Design refers to the detailing of mechanical components that have mass, carry loads and other functionalities like thermal/electromagnetic/surface finish requirements and must be manufactured
- The process of Design includes the selection of engineering materials based on a set of defined properties

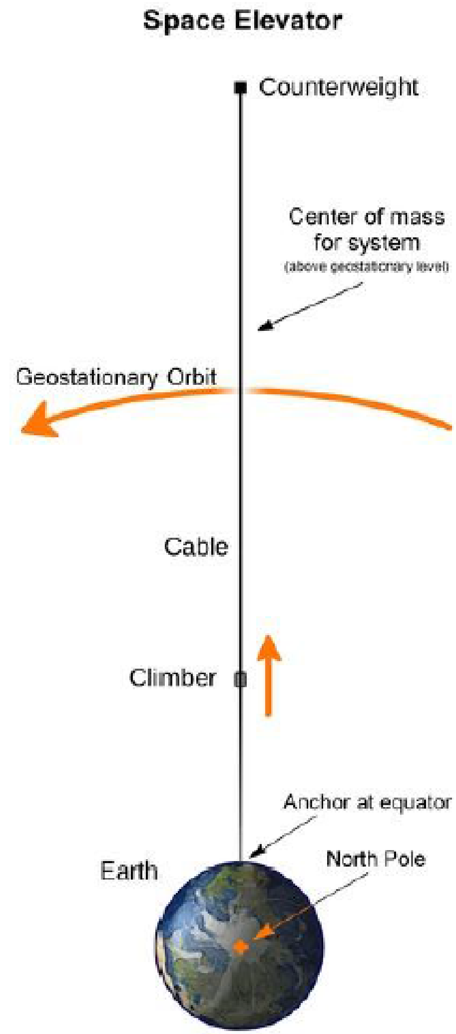
The Design Process



What is the significance of Materials in Design?

- Starting from the embodiment process, an initial choice of set of materials are to be made. After all, no designer wants his design to remain as ‘Conceptual’!
- Of course, often scientists go for futuristic design. Best example towards this direction is the **Tsiolkovsky Tower**’.
- In 1895 a Russian scientist named Konstantin Tsiolkovsky took inspiration from the Eiffel Tower in Paris and wanted to put a "celestial castle" at the end of a spindle shaped cable, with the "castle" orbiting the earth in a geosynchronous orbit (i.e. the castle would remain over the same spot on the earth). The tower would be built from the ground to an altitude of 35,800 kilometers.

What is the significance of Materials in Design?



Needless to say even the strongest material of 19^{th} and 20^{th} century would not be able to sustain the forces. With the advent of nano-materials and a change of concept, however, today we can 'in principle' implement such concepts.

Apparent Gravitational Field & G. E.:

$$g = -\left(\frac{G}{M} r^2\right) + \omega^2 \mathrm{r}$$

$$\sigma . ds = g . \rho . s . dr$$

S – CS Area of the Cable

What are the Governing Parameters for Materials Selection in Design?

From the challenge of product realization, materials are chosen in general based on the following characteristics:

(a) Performance Characteristics (material properties that satisfy the functional requirements).

(b) Processing Characteristics (involves issues like manufacturability, joining and finishing).

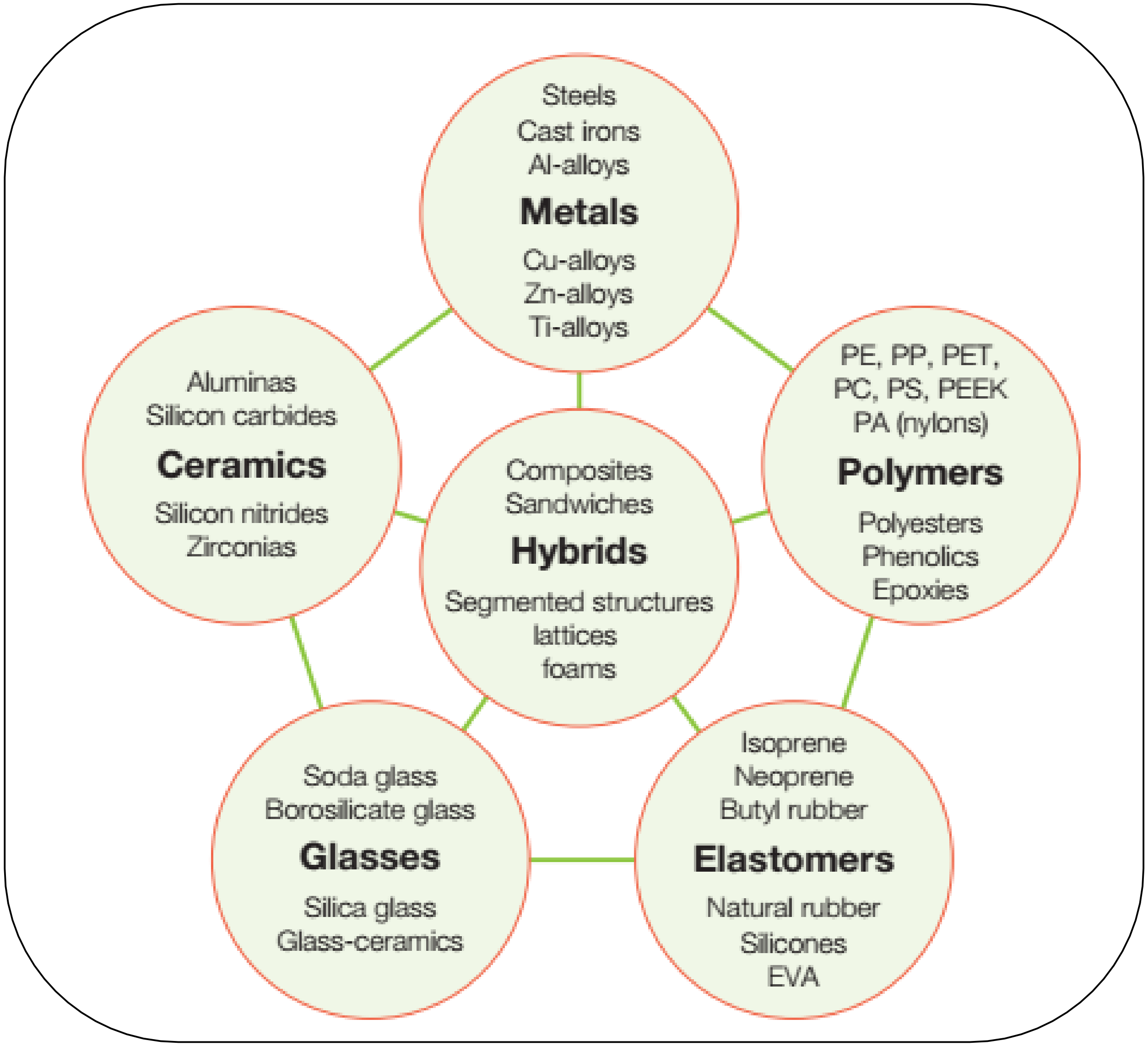
(c) Sustainability Characteristics (involves the estimation of environmental impact upon choosing the material)

(d) Business Considerations (to find out the profitability of choosing a material, availability of the materials etc.)

Material → Processing → Design

- Cost Effectiveness
- High Performance
- Service Conditions
- Total Energy Consumption
- Environment
- Government Regulations

Menu of Engineering materials



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

Metals

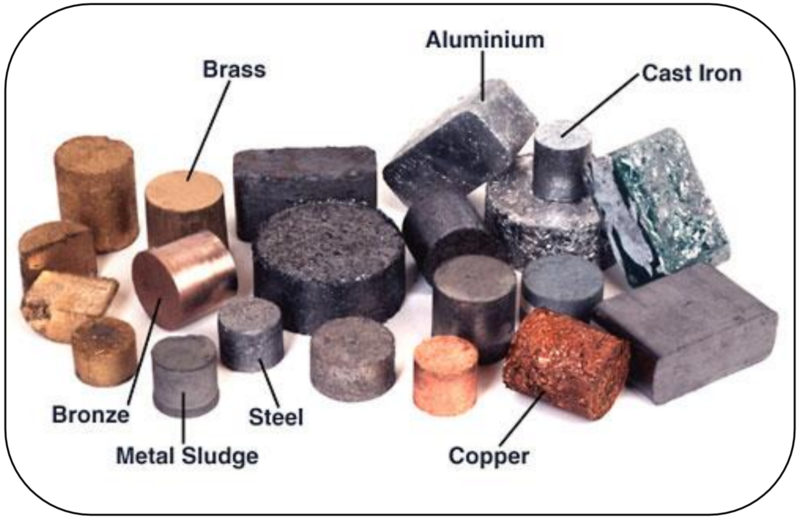
Metals are characterized by following properties: -

Physical Properties

- ✓ High **strength** and **stiffness**
- ✓ Good **electrical** and **heat conductors**.
- ✓ **Malleable** - can be beaten into thin sheets.
- ✓ **Ductile** - can be stretched into wire.
- ✓ Possess **metallic luster**.

Chemical Properties

- ✓ Usually have 1-3 electrons in their outer shell.
- ✓ **Lose** their **valence electrons** easily.
- ✓ Form oxides that are basic.
- ✓ Are **good reducing agents** (loses electrons).
- ✓ Have **lower electronegativity** (tendency to attract electrons).



Metals

Image: http://byjus.com/

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- The aluminum for beverage cans consists mostly of aluminum, but it contains small amounts of other metals as well. These are typically 1% magnesium, 1% manganese, 0.4% iron, 0.2% silicon, and 0.15% copper.

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- Manganese – Corrosion Resistance (5+), improves workability at high temperature
- Magnesium – light weight, Corrosion resistance (2+)
- Copper – Strength, Anti-microbial and antibiofouling element
- Silicon – Improve Performance in casting thin sections

Types of Al - alloys

- 1000 series: Pure Al >99%, Ductile Elect Conductor, Foil
- 2000 series: Al+Cu(4%), Strong – Aircraft Skin, Rivet
- 3000 series: Al+Mn(1%), Corrosion Resistant - Roofing Sheet, Cooking Pan
- 5000 series: Al+Mg(3%) , Strong - Pressure Vessels
- 6000 series Al+Mg(.5%)+Si(.5%): Age hardening, window frame
- 7000 series: Al+Zn(6%), strong, age-hardening, Spars
- Al-Li (3%) alloys: Strong, very light, Aircraft Skin

O – annealed, H-strain hardened

Material Attributes

King-dom	Family	Class	Sub Class	Mem	Attribute
			1000	5005-O	Density
	Ceramics	Steels	2000	5005-H4	Modulus
	Glasses	Cu-alloys	3000	5005-H6	Strength
	Metals	Al-alloys	4000	5083-O	Tough-ness
Material	Polymers	Ti-alloys	5000	5083-H2	Condu-ctivity
	Elastomer	Ni-alloys	6000	5083-H4	Exp. Coeff
	Composite	Zn-alloys	7000	5154-O	Resistivity
			8000	5154-H2	Cost
					Corrosion
					Oxidation

A Case Study of Vehicle Material Selection

For many years the biggest end-use market for aluminium has been the **Transportation Sector**. More than a quarter of all aluminium is used in the transport sector.

Originally indispensable for its lightweight for the aerospace industry, aluminium is now widely used in cars, buses, coaches, lorries, trains, ships, ferries, and bicycles.

The Success Story of Aluminium

Reduced Fuel Consumption
Lower energy consumption and gas emissions through reduced weight: extensive use of aluminium can result in up to 300 kg weight reduction in a medium size vehicle (1400kg).

For every 100 kg reduction in the automotive sector, there is a cut of 20% lower exhaust gas emissions and proportionally reduced operating costs.

Strength to Weight Ratio

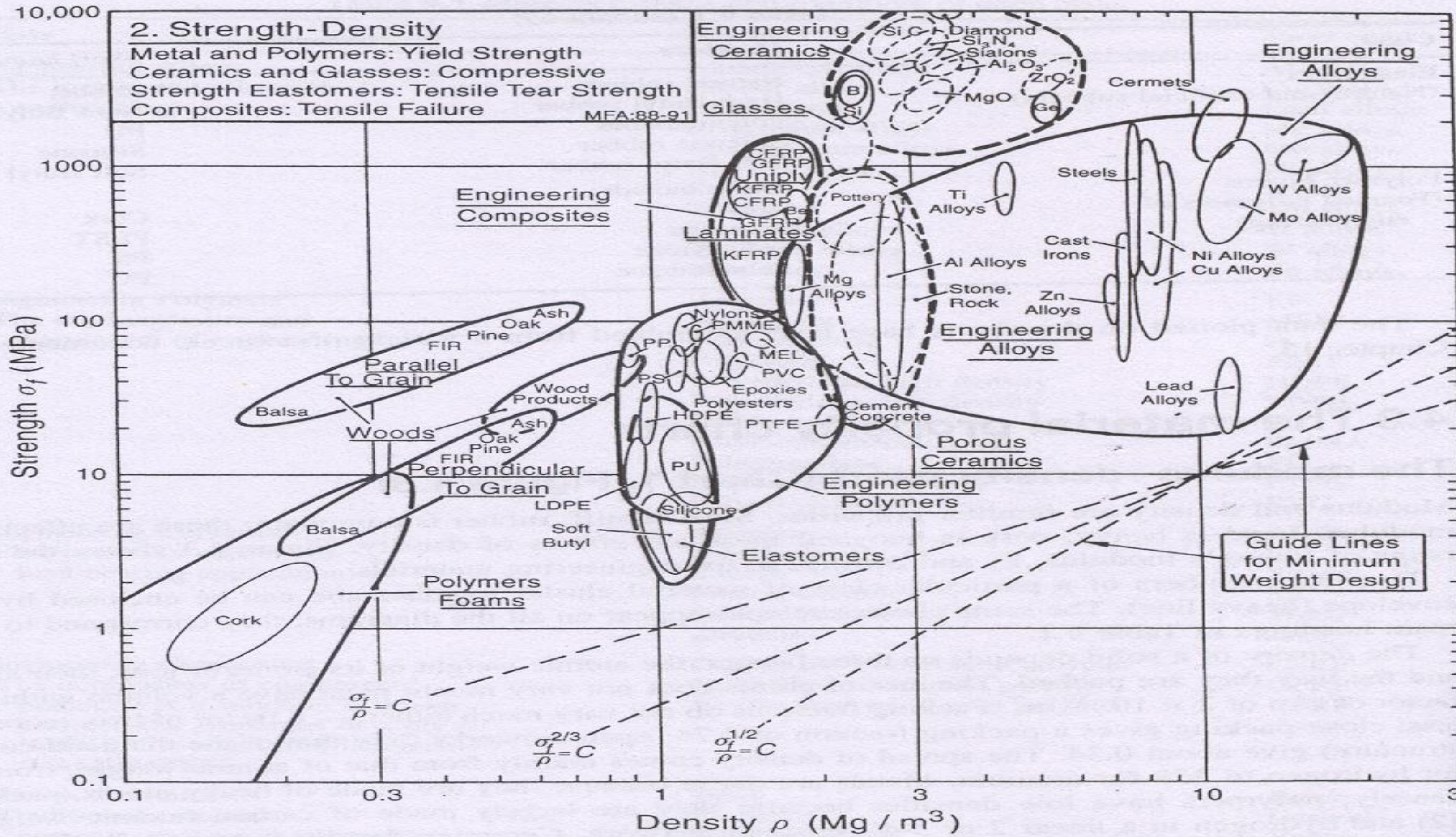

Fig. 4.4 Chart 2: Strength, σ_f, plotted against density, ρ (yield strength for metals and polymers, compressive strength for ceramics, tear strength for elastomers and tensile strength for composites). The guide lines of constant σ_f/ρ, $\sigma_f^{2/3}/\rho$ and $\sigma_f^{1/2}/\rho$ are used in minimum weight, yield-limited, design.

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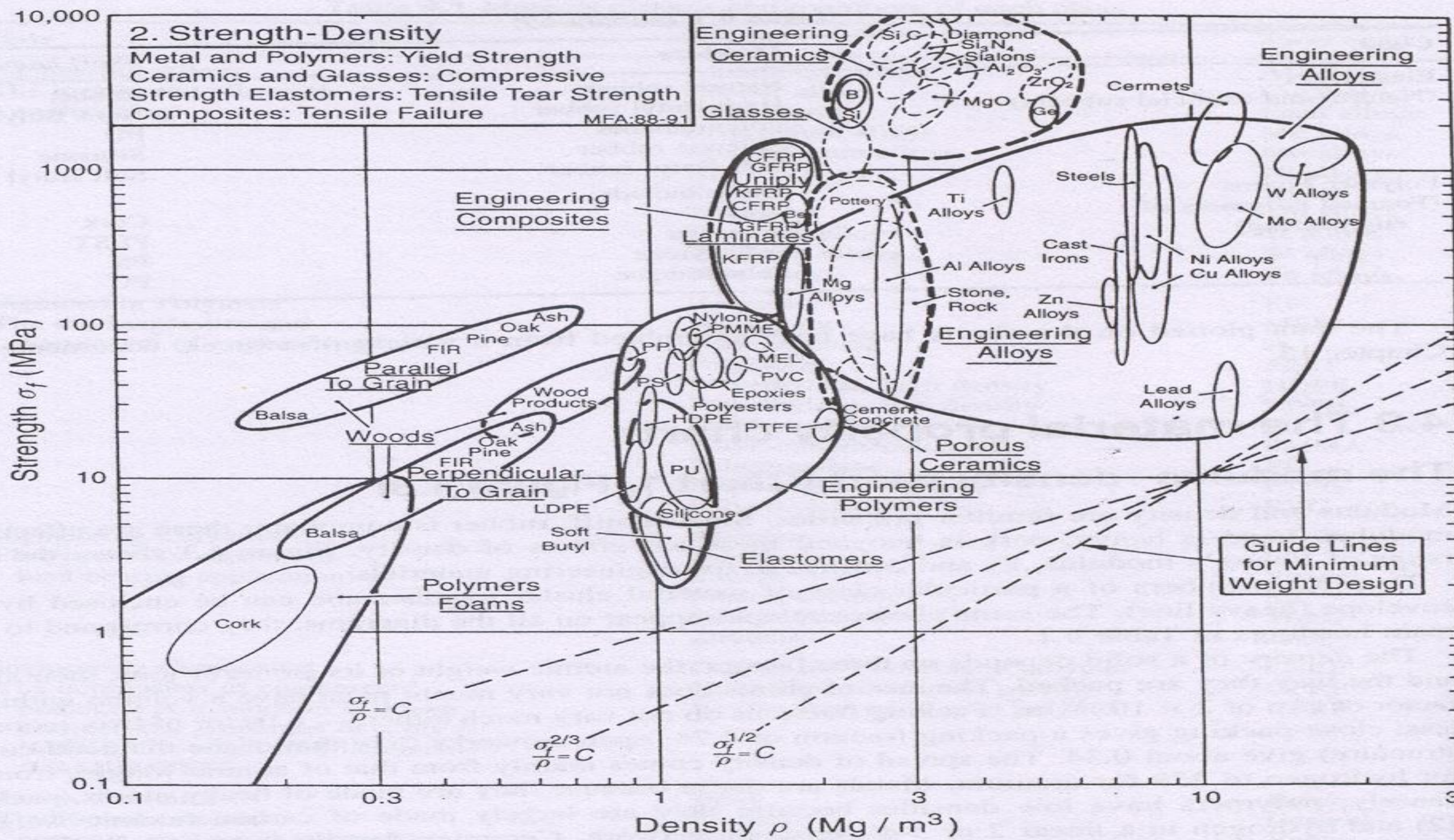

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Non-Metals

Non-metals are characterized by the following properties: -

Physical Properties

- ✓ **Poor conductors** of heat and electricity.
- ✓ **Brittle** - if a solid.
- ✓ Non - ductile.
- ✓ Do not possess metallic luster.
- ✓ Transparent as a thin sheet.
- ✓ Solids, liquids or gases at room temperature.

Chemical Properties

- ✓ Usually have 4-8 electrons in their outer shell.
- ✓ Gain or share valence electrons easily.
- ✓ Form **oxides** that are **acidic**.
- ✓ Are **good oxidizing** agents.
- ✓ Have **higher electronegativity**.

Non-metals

Image: http://byjus.com/

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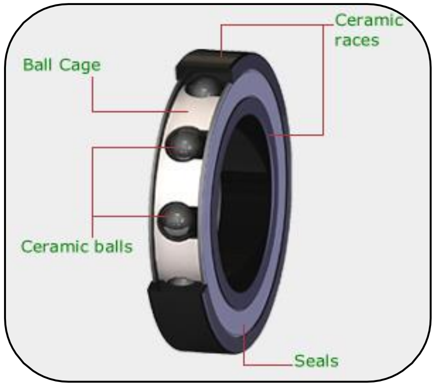
Ceramics

- Ceramics are inorganic materials developed from compounds of metal and non-metal.
- They are formed by the action of heat and subsequent cooling.
- Brittle in nature and good insulator of heat and electricity.
- Excellent compressive strength.

Roof tiles

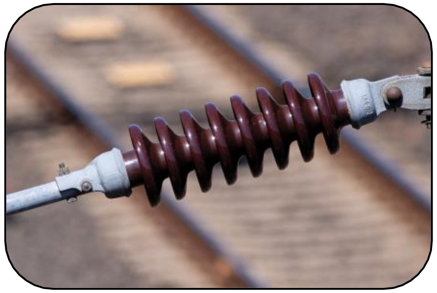


Bearings

Bricks

Ceramic coated turbine blades

Pottery



Electric insulators

Polymers

A polymer is a **large molecule** composed of many **repeated subunits**.

Natural Polymers – Shellac (bio-adhesive), amber, wool, silk and natural rubber, etc.

Synthetic polymers - Synthetic rubber, Bakelite, neoprene, nylon, polystyrene, polyethylene, polyvinyl chloride

Natural rubber

Shellac

Synthetic polymers

Image: Callister, 7th Ed.

Composites

- Two or more constituent materials with significantly different properties which after combination produce a material with characteristics different from the individual components.
- The individual **components** remain **separate** and **distinct** within the finished structure.

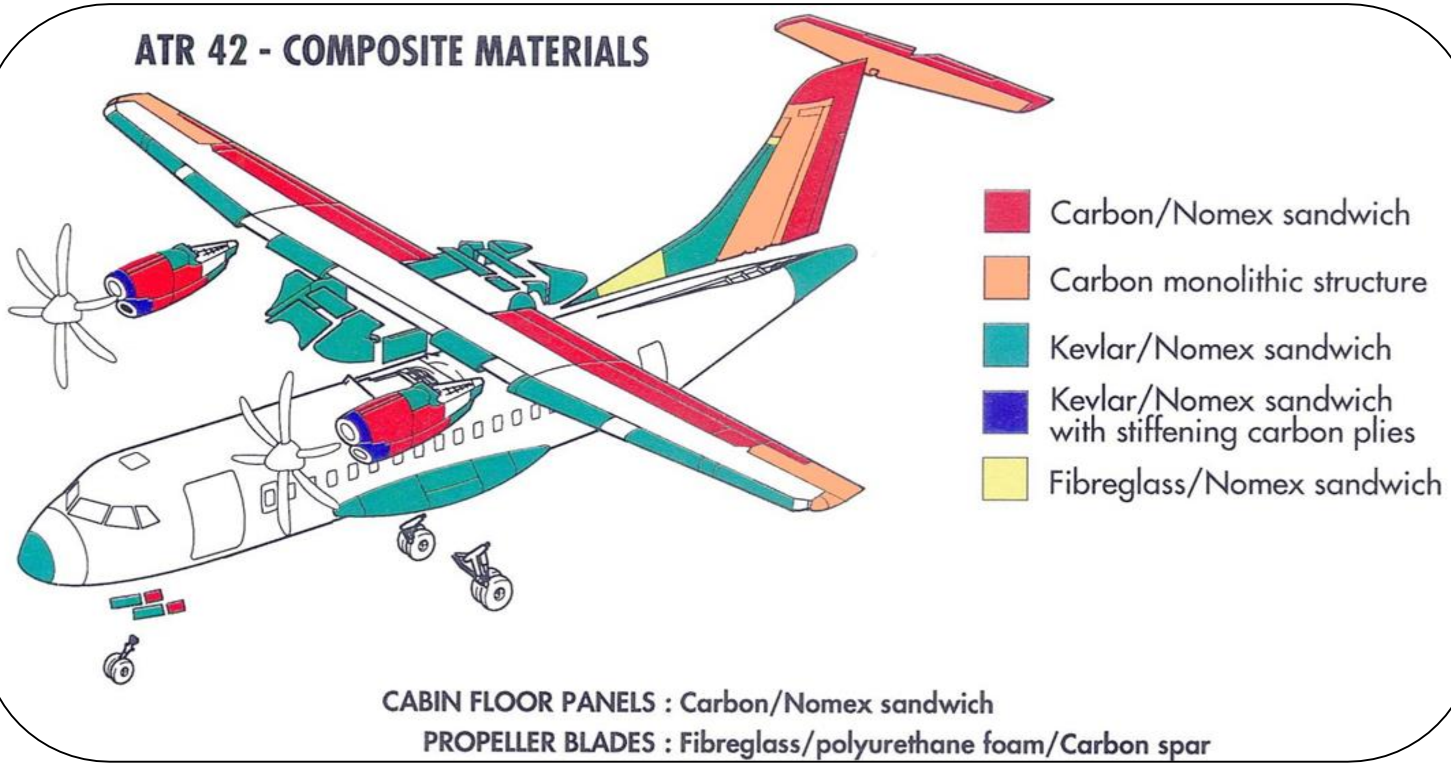


Image courtesy: http://www.compositesworld.com/