بسم الله الرحمن الرحیم

K. N. Toosi University of Technology

Faculty of Materials Science and Engineering

Selection of Engineering Materials

Ninth Session
(Ashby's Material Selection Charts- 1)

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Introduction

Ashby's charts are among the diagrams that are used in the design and selection of materials for mechanical, electrical, thermal, etc. applications., These charts were designed by Michael Ashby of Cambridge University. An Ashby chart, is a scatter plot which displays two or more properties of many materials or classes of materials. These plots are useful to compare the ratio between different properties and give comprehensive information about all materials in different groups for a specific characteristic.

Introduction

By examining and studying Ashby's diagrams, it is easier to achieve the desired properties in a specific engineering material, and it will be easier to choose materials according to the desired properties.

Data sheets for materials list their properties, but they do not provide any perspective or comparison. The way to achieve these is to plot material properties charts. They are of two types:

1- Bar Chart

2- Bubble Chart

Introduction

A bar chart is simply a plot of one property for all the materials of the Universe, or a subset of them. In the figure, as an example, there is a bar chart for the modulus (E). The largest is more than 10 million times greater than the smallest. Many other properties have similarly large ranges, so it makes sense to plot them on logarithmic rather than linear scales. The length of each bar shows the range of the property for each material, here segregated by family.

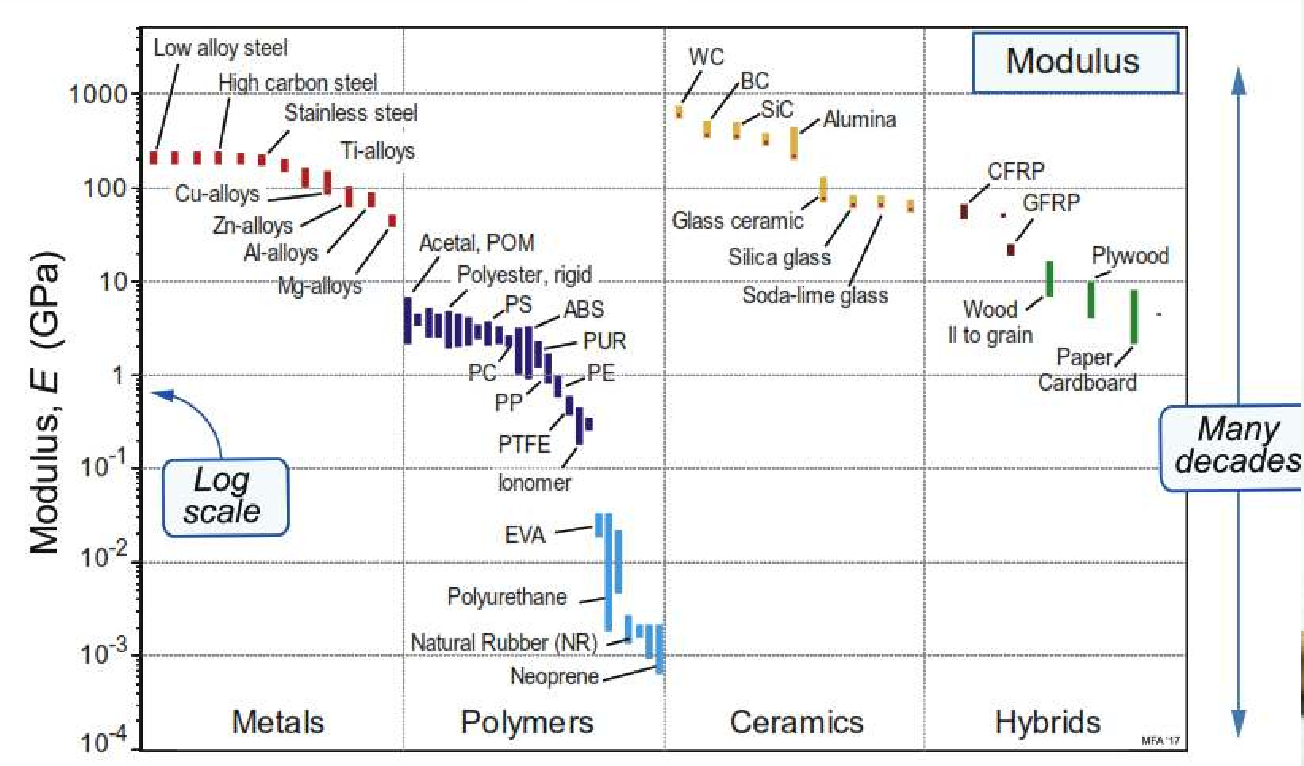
Introduction

The differences between the families now become apparent. Metals and ceramics have high moduli. Those of polymers are smaller, by a factor of about 50, than those of metals, while those of elastomeric polymers are some 500 times smaller still.

Introduction

A Bar Chart of Modulus E

(The Difference in Stiffness of Materials Families)



Introduction

Example Use of Bar Charts

In a cost-cutting exercise, a designer suggests that certain die-cast zinc parts could be replaced by cheaper molded polyethylene (PE) parts with the same shape. Another member of the team expresses concern that the PE replacement might be too flexible. By what factor will the stiffness of the part change if the substitution is made?

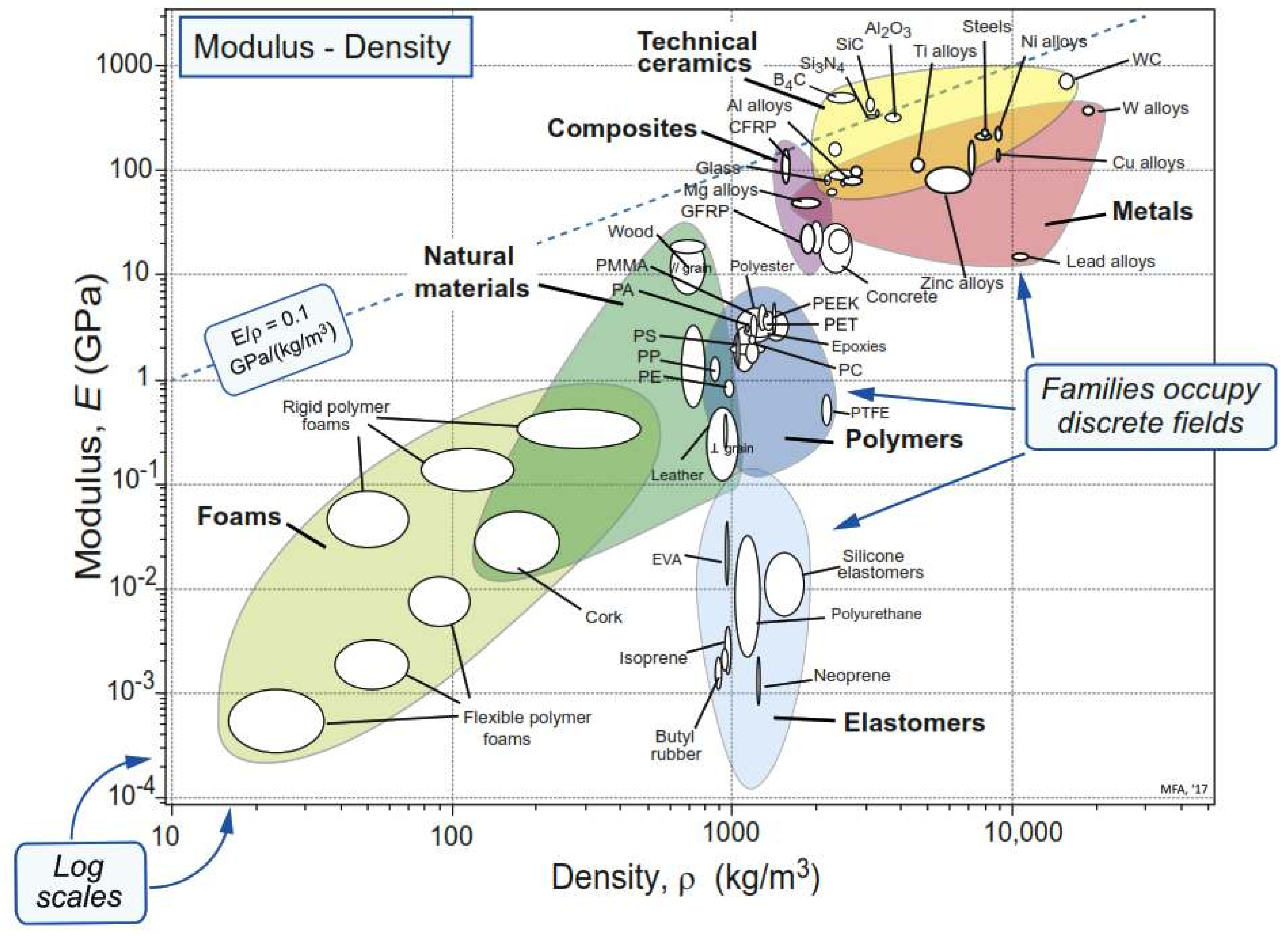
Introduction

Answer: The stiffness of two parts with the same shape, but made of different materials, will differ by the same factor as the moduli of the materials. The bar chart shows that the modulus of PE is less, by a factor of about 100, than that of zinc alloys. The concern is a real one.

Introduction

Bubble Charts: More information is packed into the picture if two properties are plotted to give a bubble chart, as in next Figure, here showing modulus E and density ρ. As before, the scales are logarithmic. Now the families are more distinctly separated: all metals lie in the reddish zone near the top right; all polymers lie in the dark-blue envelope in the centre, elastomers in the lighter blue envelope below, ceramics in the yellow envelope at the top. Each family occupies a distinct, characteristic field. Within these fields, individual materials appear as smaller ellipses.

Introduction



Families occupy discrete fields

Log scales

Introduction

Example Use of Bubble Charts

Steel is stiff (big modulus E) and heavy (big density ρ). Aluminium alloys are less stiff but also less dense. One criterion for lightweight design is a high value of the ratio E/ρ, defining materials that have a high stiffness per unit weight. Does aluminium have a significantly higher value of E/ρ than steel? What about carbon fibers reinforced polymer (CFRP)?

Introduction

Answer: The E/ρ chart can answer the question in seconds. All three materials appear on it. Materials with equal values of E/ρ lie along a line. Materials with high E/ρ towards the top left, those with low values towards the bottom right. If a line with the same slope is drawn through Al alloys on the chart, it passes almost exactly through steels. The two materials have almost the same value of E/ρ, a surprise when you think that aircraft are made of aluminium, not steel. CFRP, by contrast, has a much higher E/ρ than either aluminium or steel.

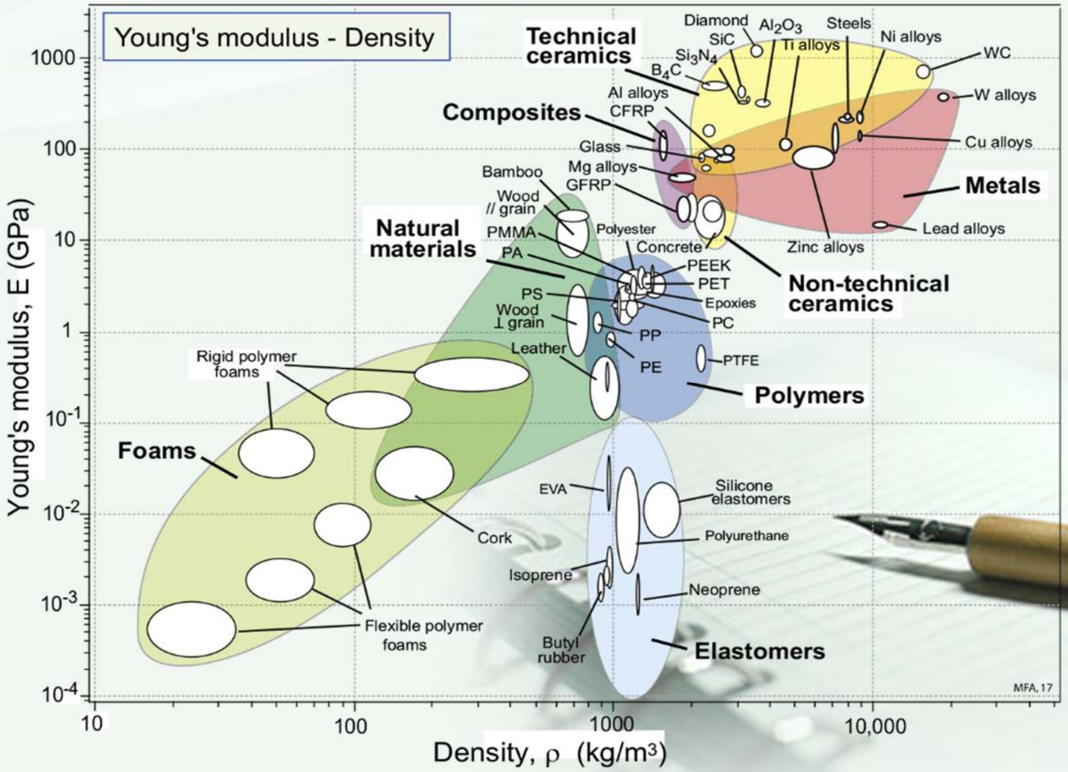
Introduction

Material properties charts are a core tool in materials selection:

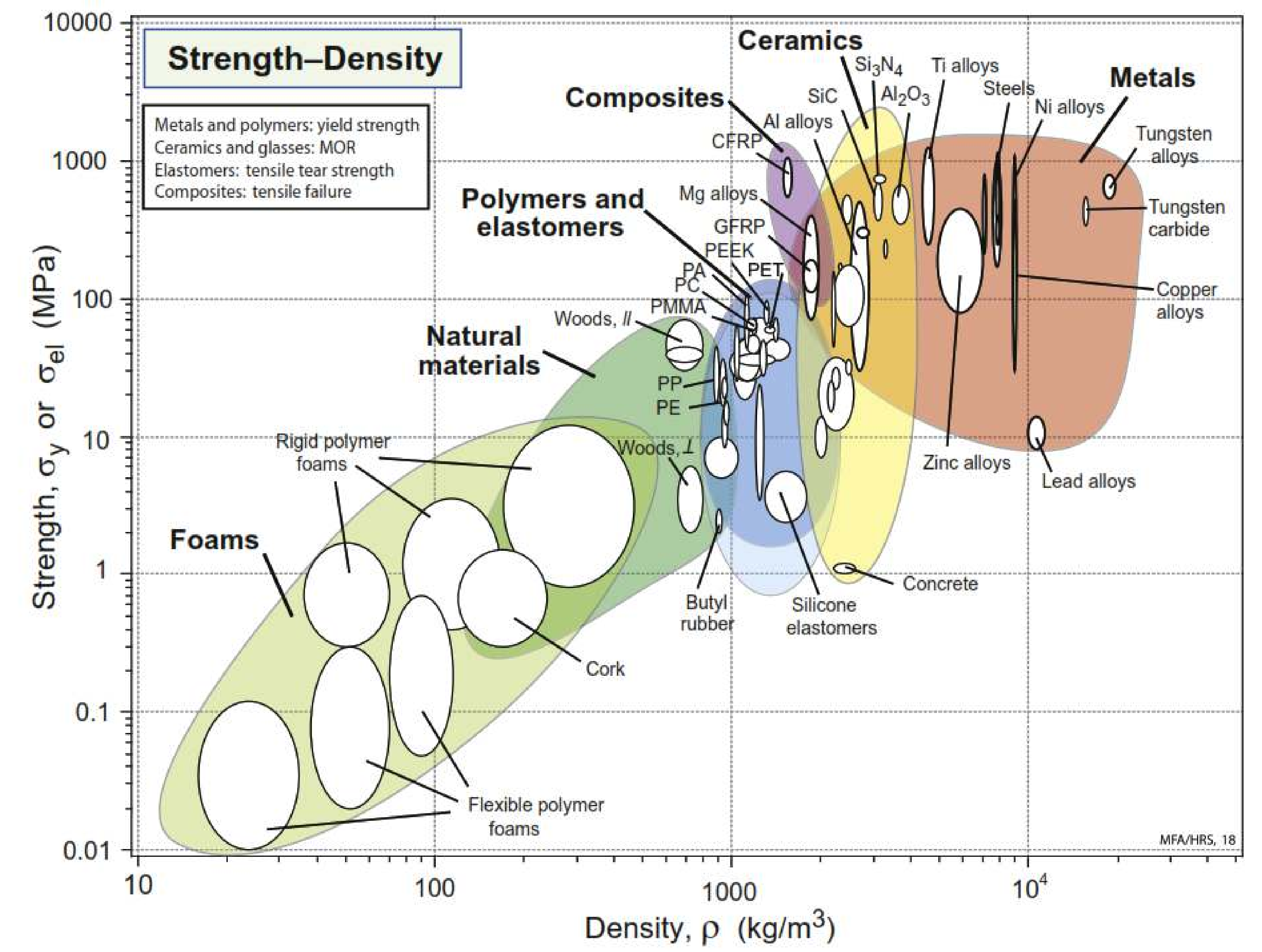
- ✓ They give an overview of the physical, mechanical and functional properties of materials, presenting the information about them in a compact way.
- ✓ They reveal aspects of the physical origins of properties, a help in understanding the underlying science.
- ✓ They become a tool for optimal selection of materials to meet given design requirements, and they help us understand the use of materials in existing products.

The Young's Modulus-Density Chart

Among the Ashby charts, there are Young's modulus charts in terms of density, which are presented based on the classification of engineering materials. This graph is drawn in logarithmic form and studies all engineering materials and gives information about density and Young's modulus.



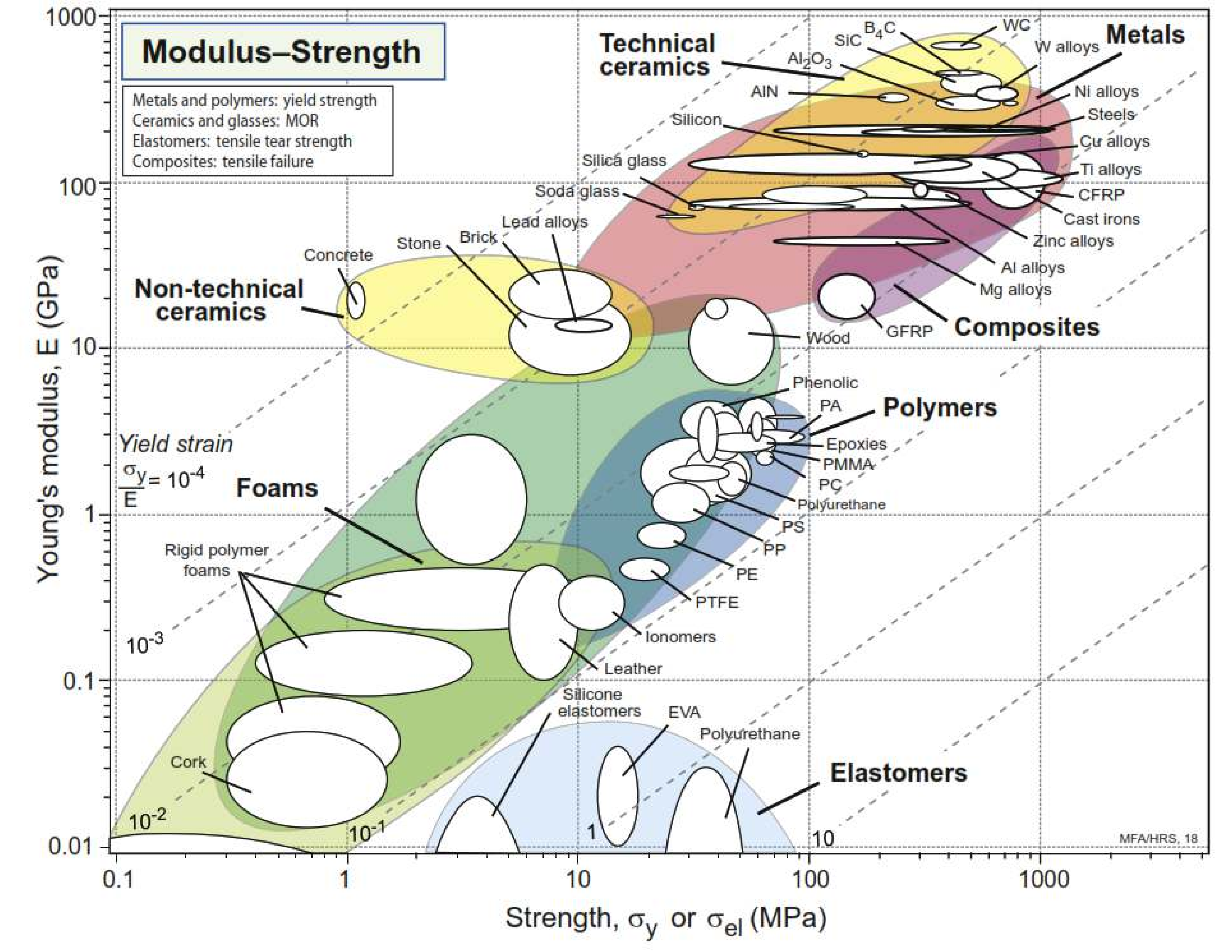
The Strength-Density Chart



The Strength-Density Chart

Figure shows the yield strength σ_y or elastic limit σ_{el} plotted against density ρ. The range of strength for engineering materials, like that of the modulus, spans about 6 decades (from less than 0.01 MPa for foams, used in packaging and energy-absorbing systems, to 10^4 MPa for diamond, exploited in diamond tooling for machining and as the indenter of the Vickers hardness test). Members of each family again cluster together and can be enclosed in envelopes, each of which occupies a characteristic part of the chart.

The Modulus-Strength Chart



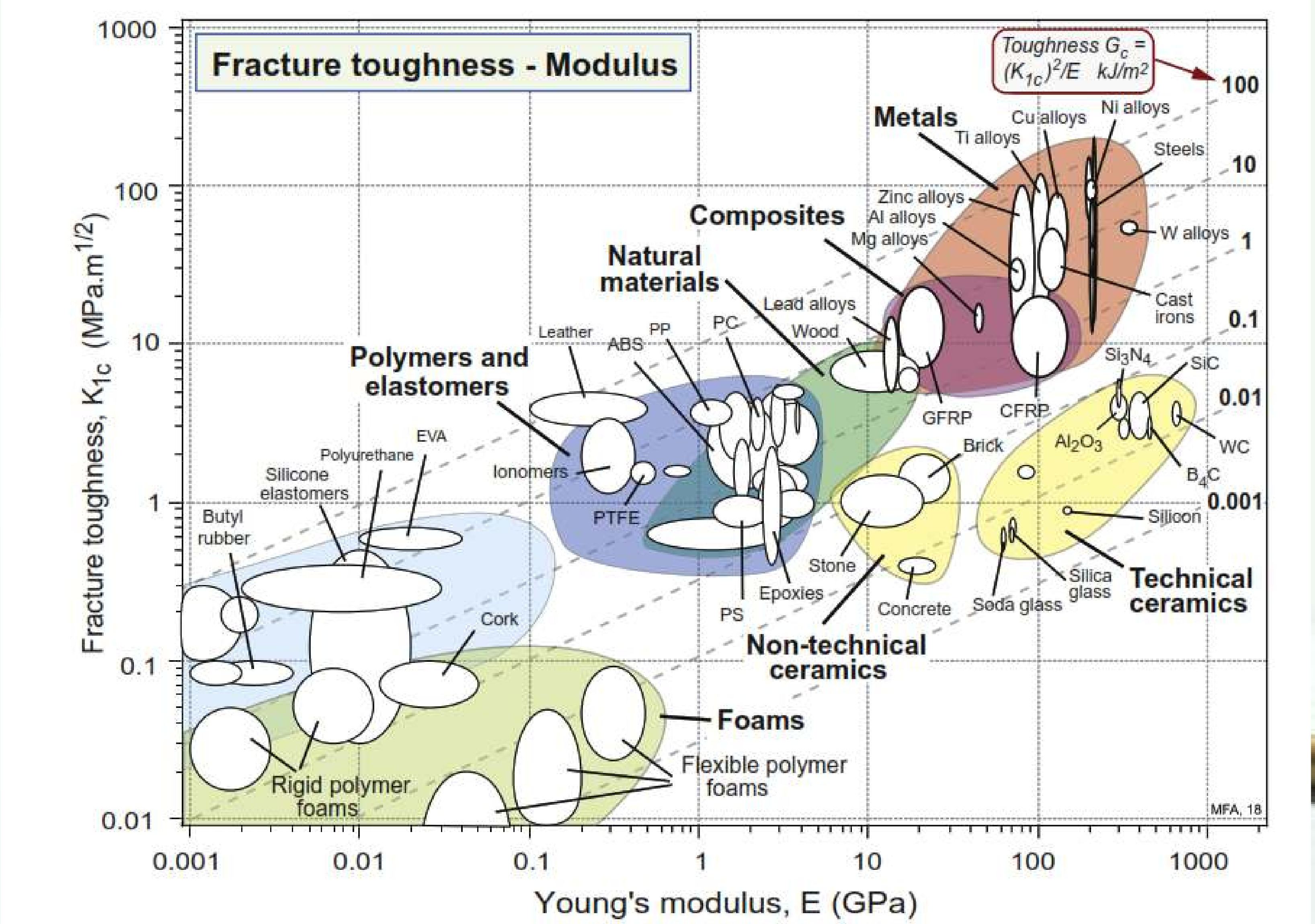
The Modulus-Structure Chart

Among other Ashby charts, the Young’s modulus, E, plotted against yield strength, σ_y or elastic limit, $\sigma_{el,}$ for various engineering materials that are used in the design and selection of materials. This diagram has parallel dashed lines that show the ratios of yield stress to Young's modulus (σ_y/E). Yield strain (σ_y/E), means the strain at which the material leaves the linear elastic state.

The Modulus-Structure Chart

Engineering polymers have large yield strains, between 0.01-0.1. The values for metals are at least a factor of 10 smaller. Composites and woods lie on the 0.01 contour, as good as the best metals. Elastomers, because of their exceptionally low moduli, have values of σ_y /E in the range 1-10, much larger than any other class of material.

The Fracture Toughness-Modulus Chart



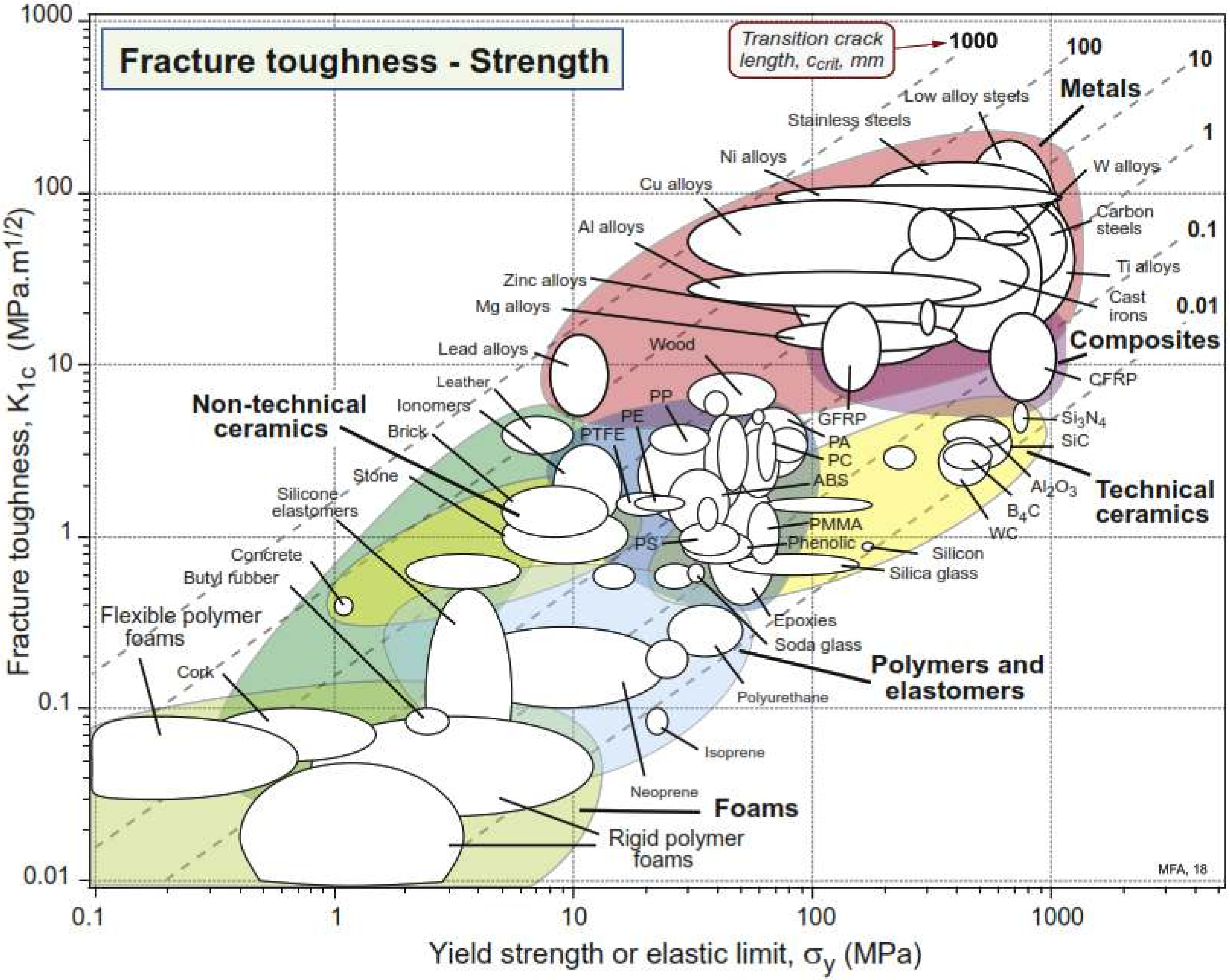
The Fracture Toughness-Modulus Chart

The fracture toughness K_{1c} is plotted against modulus E in next Figure. The range of K_{1c} is large (from less than 0.01 to over 100 MPa.$m^{1/2}$). At the lower end of this range are brittle materials, which, when loaded, remain elastic until they fracture. For these, linear elastic fracture mechanics works well, and the fracture toughness itself is a well-defined property.

The Fracture Toughness-Modulus Chart

At the upper end lie the super-tough materials, all of which show substantial plasticity before they break. For these the values of K_{1c} are approximate but still helpful in providing a ranking of materials. The figure shows one reason for the dominance of metals in engineering. They almost all have values of K_{1c} above 15 $MPa.m^{1/2}$, a value often quoted as a minimum for conventional design.

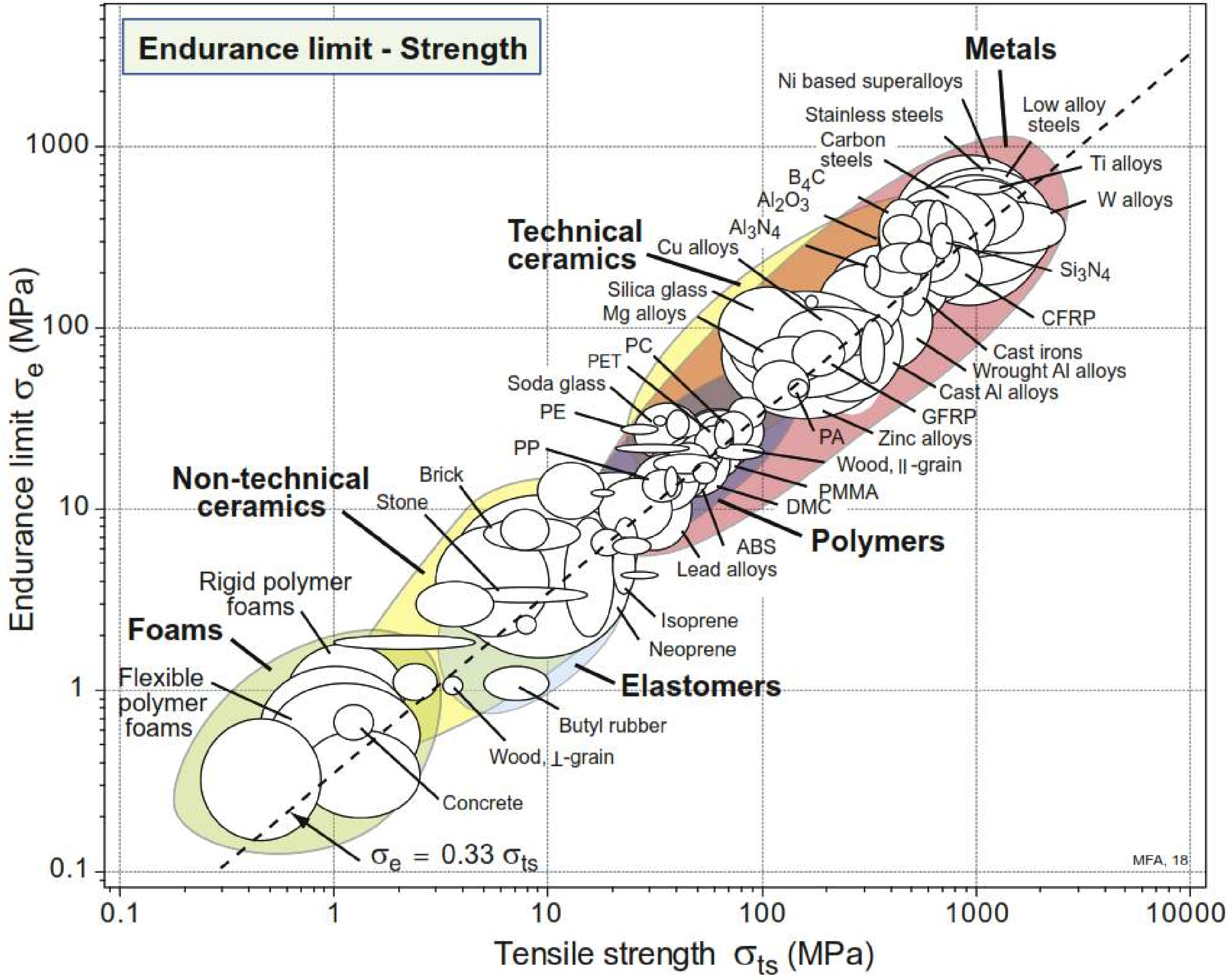
The Fracture Toughness-Yield Strength Chart



The Fracture Toughness-Yield Strength Chart

Strength-limited design relies on the component yielding before it fractures. This involves a comparison between strength and toughness. Figure shows them on a property chart. Metals are both strong and tough. That is why they have become the workhorse materials of mechanical and structural engineering.

The Fatigue Limit-Tensile Strength Chart



The Fatigue Limit-Tensile Strength Chart

Another Ashby diagram is the diagram of fatigue limit (durability limit) in terms of tensile strength. This graph has a dashed line that shows the equation $\sigma_e \approx 0.33\sigma_{ts}$. According to this diagram, foam materials, the lowest fatigue limit and the highest fatigue limit, are related to metal materials such as titanium alloys, tungsten and low alloy steels.

The Fatigue Limite-Tensile Strength Chart

The most important single property characterising fatigue strength is the endurance limit (σ_e) at 10^7 cycles and zero mean stress (an R-value of -1). Not surprisingly, endurance limit and strength are related. The strongest correlation is with the tensile strength σ_{ts}, shown in the chart of Figure. The data for metals and polymers ($\sigma_e \approx 0.33\sigma_{ts}$), and ceramics and glasses ($\sigma_e \approx 0.9\sigma_{ts}$) cluster around the line shown on the chart.